Genetics

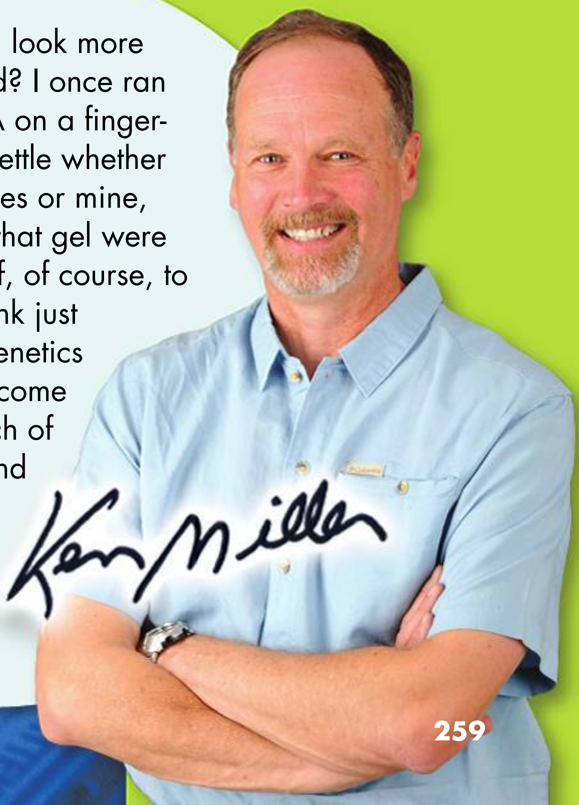
UNIT 4

Chapters

INTRODUCE the **Big ideas**

- **Information and Heredity**
- **Cellular Basis of Life**
- **Science as a Way of Knowing**

“Do you look more like mom or dad? I once ran my daughter’s DNA on a finger-printing gel. It didn’t settle whether she had her mother’s eyes or mine, but half of the bands on that gel were identical to mine, and half, of course, to her mom’s. It made me think just how remarkable human genetics really is. Our genes may come from our parents, but each of us gets a fresh shuffle and a brand-new deal of those genetic cards as we start our lives.”



11 Introduction to Genetics

Big idea

Information and Heredity

Q: How does biological information pass from one generation to another?

Labrador retrievers may be black, brown, or yellow. Each puppy in a litter can have a different color based on the genes it inherits.

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INSIDE:

- 11.1 The Work of Gregor Mendel
- 11.2 Applying Mendel's Principles
- 11.3 Other Patterns of Inheritance
- 11.4 Meiosis

CHAPTER MYSTERY

GREEN PARAKEETS

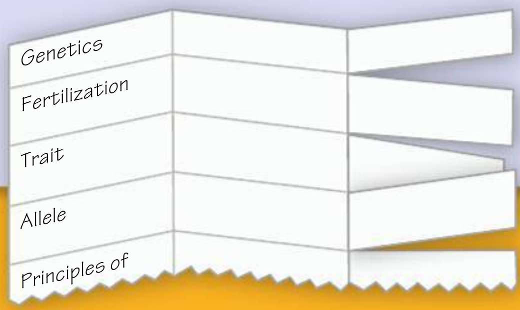
Susan's birthday was coming up. Parakeets make great pets, so Susan's parents wanted to give two birds to her as a birthday present. At the pet store, they chose two healthy green parakeets—one male and one female. They knew that green was Susan's favorite color.

Susan was happy about her birthday present. She fed the birds and kept their cage clean. A few weeks later, Susan found three small eggs in the birds' nest. When the eggs hatched, Susan was amazed. None of the chicks was green! One chick was white, one was blue, and one was yellow. Why weren't any of them green? What had happened to the green color of the birds' parents?

Read for Mystery Clues As you read this chapter, look for clues to help you figure out why the parakeet chicks were colored differently than their parents. Then solve the mystery at the end of the Chapter.

FOUNDATIONS for Learning

Before you read the chapter, write each vocabulary word on the open side of the Undercover Vocabulary Tool. As you read the chapter, fill in the definitions. You can use different color highlighters to show the different categories. At the end of the chapter are two activities that use the tool to help answer the question: How does information in cells pass from one generation to another?



- Untamed Science Video
- Chapter Mystery

11.1 The Work of Gregor Mendel

Key Questions

Where does an organism get its unique characteristics?

How are different forms of a gene passed to offspring?

BUILD Understanding

Two-Column Chart Before you read, draw a line down the center of a piece of paper. On the left side, write the main ideas in this lesson. On the right side, note the details and examples that support each of those ideas.

In Your Workbook Go to your workbook to learn more about making a two-column chart for Lesson 11.1.

The Experiments of Gregor Mendel

Every living thing has a set of characteristics inherited from its parent or parents. The scientific study of this biological inheritance is **genetics.** Genetics is the key to understanding what makes each organism unique.

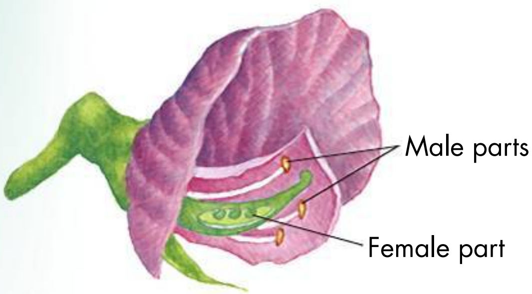
The modern science of genetics was started by a monk named Gregor Mendel. Mendel was in charge of the garden in the monastery where he lived. In this garden, he did work that changed biology forever.

Mendel used ordinary garden peas in his studies. He used peas partly because peas are small and easy to grow. A single pea plant can make hundreds of offspring. Also, pea plants grow quickly and have many traits that are easy to see.

The Role of Fertilization When Mendel started his experiments, he knew that the male part of each flower makes pollen. Pollen contains the plant's male reproductive cells, called sperm. Mendel also knew that the female part of each flower makes reproductive cells called eggs. During sexual reproduction, male and female reproductive cells join in a process known as **fertilization** to make a new cell. In peas, this new cell develops into a tiny embryo wrapped inside a seed.

The male and female reproductive cells of pea plants are in every pea flower. Since pea flowers have both kinds of cells, a pea flower normally pollinates itself. A plant grown from a seed made by self-pollination has just one parent, because both reproductive cells came from the same plant.

Pea Flower



Flowers have male parts and female parts. During fertilization, pollen is transferred from the male parts to the female parts.

True-Breeding Plants Mendel's monastery garden had several stocks of pea plants. These plants were "true-breeding." True-breeding plants are self-pollinating. They make offspring identical to themselves. The traits in each generation are the same. A **trait** is a specific characteristic, such as seed color or plant height, of an individual. A trait may vary from one individual to another. For example, one stock of Mendel's seeds made only tall plants. Another stock made only short ones. One stock made only green seeds. Another stock made only yellow seeds.

Crossbreeding Mendel wanted to learn more about how traits are passed from parent to offspring. So, he used pollen from one stock of plants to fertilize the female parts of flowers from other stocks of plants. This process is called cross pollination and produces a plant that has different parents.

Mendel studied seven different traits of pea plants. Each of the traits had two contrasting forms. Seed color is one example of a trait Mendel studied. The seeds were either green or yellow. Mendel wanted to see what would happen if he made a plant from two parents that had different traits. The offspring of crosses between parents with different traits are called hybrids.

Two Conclusions When a yellow-seed plant was crossed with a green-seed plant, all the offspring produced yellow seeds. It seemed that the green trait had disappeared. The same thing happened with each of the other traits. Mendel drew two conclusions from this.

▶ ***Passing Traits to Offspring*** First, Mendel found that an individual's characteristics are controlled by factors that are passed from parent to offspring. Today, scientists call these factors **genes** (jeenz). Each of the traits Mendel studied was controlled by a single gene that existed in two different forms. Each form of the gene controlled one form of a trait. For example, the gene for plant height came in one form that made tall plants and another form that made short plants. The different forms of the same gene are called **alleles** (uh LEELZ).

▶ ***Dominant and Recessive Alleles*** Mendel's second conclusion explains why some of the traits seemed to disappear in the offspring. This conclusion is called the **principle of dominance.** This principle states that some alleles are dominant and others are recessive (ree SESS iv). An organism with at least one dominant allele for a form of a trait will show that form of the trait. An organism with a recessive allele for a form of a trait will show that form only when the dominant allele for the trait is not there. In Mendel's experiments, the allele for tall plants was dominant, and the allele for short plants was recessive. Similarly, the allele for yellow seeds was dominant over the recessive allele for green seeds.

Key Question Where does an organism get its unique characteristics?
An individual's unique characteristics are determined by factors that are passed from parent to offspring.

BUILD Vocabulary

genetics
the scientific study of heredity

fertilization
the process in sexual reproduction in which male and female reproductive cells join to form a new cell

trait
a specific characteristic of an individual

gene
a factor that is passed from parent to offspring

allele
one of a number of different forms of a gene

principle of dominance
states that some alleles are dominant and others are recessive

WORD ORIGINS
The word *fertilization* is from the Latin word *fertilis,* which means "to be fruitful" or "to make offspring."

This table shows three of the characteristics Mendel studied in his experiments.

Mendel's Seven F_1 Crosses on Pea Plants

	Seed Shape	Seed Color	Seed Coat
P	Round X Wrinkled	Yellow X Green	Gray X White
F_1	Round	Yellow	Gray

BUILD Vocabulary

segregation
the separation of alleles

gametes
sex cells

WORD ORIGINS

Like the word *segment*, the word *segregate* comes from the Latin root word *segmentum*, which means "a piece cut off."

Segregation

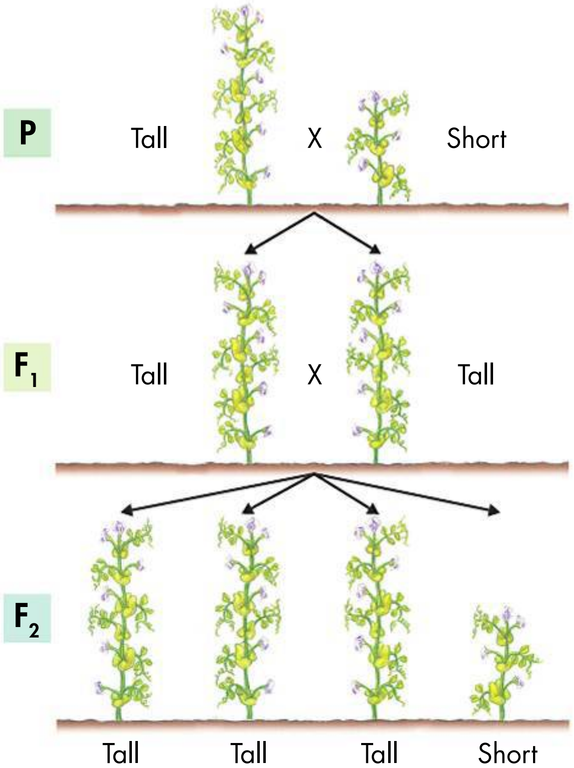
When doing genetic crosses, we call each original pair of plants the P, or parental, generation. Their offspring are called the F_1 generation. Mendel had a question about his F_1 generation of pea plants. Had the recessive alleles simply disappeared, or were they still in the new plants? To find out, he had all seven kinds of F_1 hybrids self-pollinate. The offspring of an F_1 cross are called the F_2 generation. So, Mendel crossed the F_1 generation with itself to make the F_2 offspring.

Recessive Traits Reappear Mendel found that the traits controlled by the recessive alleles reappeared in the second generation. About one fourth of the F_2 plants showed the trait controlled by the recessive allele. Why did the recessive alleles seem to disappear in the F_1 generation and then reappear in the F_2 generation?

Explaining the F_1 Cross Mendel figured out that only the dominant alleles determined the traits of the F_1 generation. However, the trait controlled by the recessive allele did show up in some of the F_2 second generation of plants. So, Mendel realized that the allele for shortness had separated from the allele for tallness. When did this separation, or **segregation,** of alleles happen?

Mendel thought that the alleles for tallness and shortness in the F_1 plants must have segregated from each other during the formation of the gametes. **Gametes** (GAM eetz) are the sperm and egg cells that combine during fertilization.

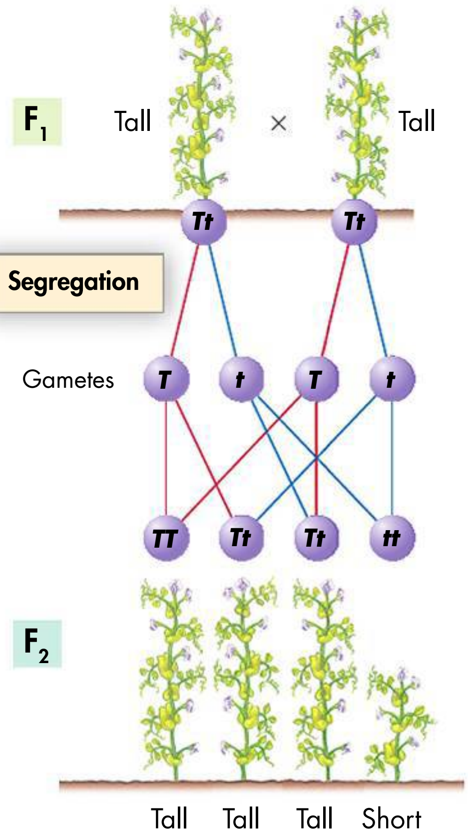
Making Gametes Was Mendel right? Let's assume that the tall F_1 plants inherited two alleles controlling their height. They inherited an allele for tallness from their tall parent and an allele for shortness from their short parent. Because the allele for tallness is dominant, all the F_1 plants are tall. When each parent makes gametes, the alleles for each gene segregate from one another. Therefore, each gamete carries only one allele for each gene. So, each F_1 plant makes two kinds of gametes. Some have the tall allele, and some have the short allele.



Recessive traits reappeared in the second generation when the first generation of plants were allowed to self-pollinate.

Look at the segregation diagram to see how alleles separate during gamete formation and then pair up again in the F_2 generation. A capital letter shows a dominant allele. A lowercase letter shows a recessive allele. Now we can see why the recessive trait for height, *t*, reappeared in Mendel's F_2 generation. Each F_1 plant in Mendel's cross made two kinds of gametes. Some had the allele for tallness, and some had the allele for shortness. Whenever a gamete that carried the *t* allele paired with another gamete that carried the *t* allele to make an F_2 plant, that F_2 plant was short. Every time a gamete carrying the *T* allele paired with another gamete carrying either the *T* or *t* allele, they made a tall plant. In other words, the F_2 generation had new combinations of alleles.

Key Question How are different forms of a gene passed to offspring?
When gametes are made, the alleles for each trait separate from each other. That way each gamete carries only one allele from each gene.



When gametes are made, the two alleles of each gene separate so that each gamete carries only a single copy of each gene. Each F_1 plant makes two types of gametes: those with an allele for tallness and those with an allele for shortness.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence.

1. The inherited factors that determine traits are called ______.
2. ______ is the process of male and female gametes joining.

Critical Thinking

3. **Compare and Contrast** How are dominant and recessive alleles alike and different?
4. **Write to Learn** Answer the first clue of the mystery. Write a paragraph that includes the terms *gene*, *allele*, and *trait*.

MYSTERY CLUE

Parakeets come in four colors: white, green, blue, and yellow. How many alleles might there be for feather color? (Hint: See p. 263.)

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11.2 Applying Mendel's Principles

Key Questions

How can we use probability to predict traits?

How do alleles segregate when more than one gene is involved?

What did Mendel contribute to what we know about genetics?

BUILD Understanding

Previewing Visuals Before you read, look at one of the figures in the lesson. Try to understand the purpose of that figure. As you read, compare your original impression to what you learn about the figure in the text. After you read, revise your statement if it was incorrect. Write a new statement if needed.

In Your Workbook Go to your workbook to learn more about previewing visuals. Complete the preview statement for Lesson 11.2.

Probability and Punnett Squares

We cannot always know exactly how a genetic cross will turn out. However, by carefully studying what happens in a cross, Mendel began to figure out how genetic information is inherited. This information can be used to find the possible outcomes of a genetic cross.

Whenever Mendel performed a cross with pea plants, he carefully identified and counted the offspring. So he had plenty of data to analyze. He noticed trends. For example, whenever he crossed two plants that were hybrids for stem height (*Tt*), about three fourths of the offspring were tall and about one fourth were short.

Mendel figured out that the principles of probability could be used to explain these results of his genetic crosses. **Probability** (prah buh BILL uh tee) is the likelihood that a particular event will happen. For example, think about flipping a coin. There are only two possible outcomes of a coin flip. The coin can land either heads up or tails up. The chance, or probability, of either outcome is the same. So, the probability that a single coin flip will land heads up is 1 chance in 2. This can be described as a probability of 1/2, or 50 percent.

If you flip a coin three times in a row, what is the probability that it will land heads up every time? Each coin flip is a separate event, with a 1/2 probability of the coin landing heads up. So, the probability of flipping three heads in a row is:

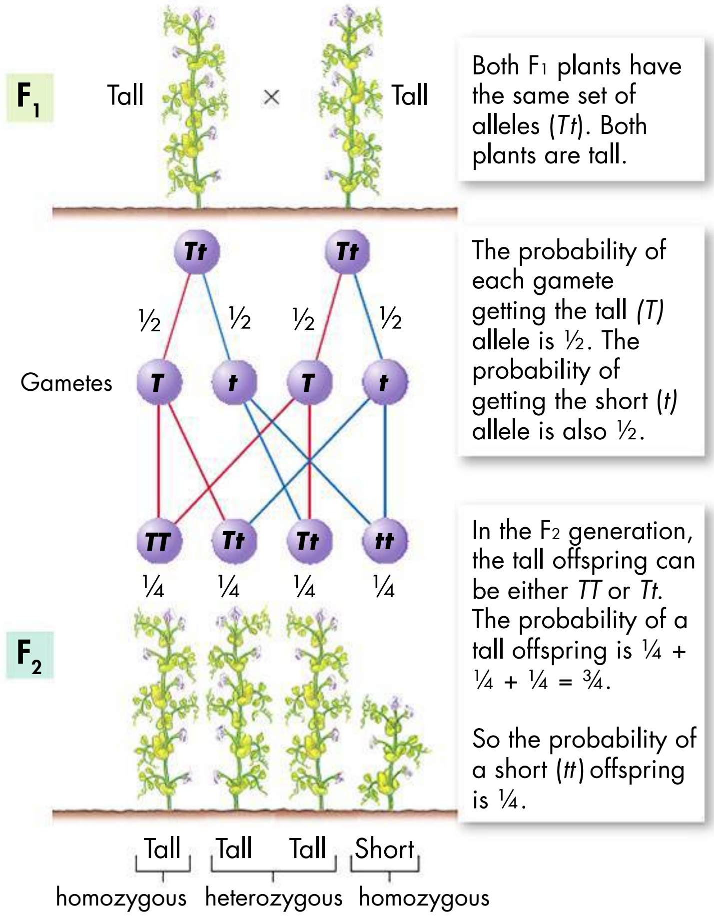
$$1/2 \times 1/2 \times 1/2 = 1/8$$

As you can see, you have 1 chance in 8 of flipping heads three times in a row. Remember: Past coin flips do not affect future coin flips. You may have just flipped 3 heads in a row. Those flips do not change the probability of the next flip. The probability for that flip is still 1/2.

Using Segregation to Predict Outcomes The same type of probability used to predict coin flips can also be used to help understand the outcomes of genetic crosses.

When you flip a coin, the chance that the coin will land heads up is 1/2, or 50 percent.

When alleles segregate to form gametes, there are only two possible outcomes, just like when you flip a coin. Since a pea plant has two alleles for every gene, the probability that a gamete will get either allele is 1/2. If two pea plants that have one of each kind of allele (*Tt*) are crossed, what is the probability that an offspring plant will be short? Remember that to be short, a plant needs two *t* alleles. The chance of a gamete getting either allele is 1/2. Two gametes are in each cross. So, the probability of both gametes creating a *tt* plant is $1/2 \times 1/2 = 1/4$.



Organisms with the same characteristics can have different combinations of alleles. For example, the tall pea plants could be either *TT* or *Tt*. If an organism has two identical alleles of a gene, then the organism is **homozygous** (hoh moh ZY gus). The tall (*TT*) plants are homozygous because they have two identical alleles (*TT*) for a gene. The short plants are also homozygous because they have two identical alleles (*tt*) for a gene. If an organism has two different alleles for the same gene, then the organism is **heterozygous** (het ur oh ZY gus). The parents in this cross are heterozygous because they have two different alleles (*Tt*) for that gene.

Genotype and Phenotype How many different combinations of the alleles *t* and *T* are possible? Three. The options are *Tt*, *TT*, and *tt*. How many different forms of the plant are possible? Two. The options are tall and short. Plants with the combinations *TT* and *Tt* are tall. Plants with the combination *tt* are short. Mendel noticed that all of the tall pea plants had the same **phenotype** (FEE nuh typ), or physical traits. They did not, however, have the same **genotype** (JEE nuh typ), or genetic makeup.

Using Punnett Squares One of the best ways to predict the outcome of a genetic cross is by drawing a simple diagram known as a Punnett square. Making a Punnett square is easy. You begin with a square. Then write all of the alleles that could be in the gametes from one parent along the top of the square. Then, write all possible alleles in the gametes from the other parent along the left side. Next, write every possible combination of alleles into the boxes inside the square. The next page shows instructions for making a Punnett square.

Key Question How can we use probability to predict traits? **Punnett squares use probability to predict combinations of alleles in a genetic cross.**

BUILD Vocabulary

probability
the likelihood that a particular event will occur

homozygous
having two identical alleles for a particular gene

heterozygous
having two different alleles for a particular gene

phenotype
the physical characteristics of an organism

genotype
the genetic makeup of an organism

PREFIXES
The prefix *hetero-* means "different." The two alleles in a heterozygous organism are different from one another.

BUILD Connections

HOW TO MAKE A PUNNETT SQUARE

One-Factor Cross		Two-Factor Cross

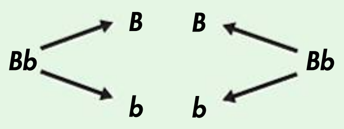
1 Start With the Parents

One-Factor Cross: ***Bb* and *Bb***

Two-Factor Cross: ***TtGg* and *TtGg***

2 Figure Out the Gametes

One-Factor Cross: Figure out what alleles could be found in the gametes of both rabbits.



Two-Factor Cross: Figure out which alleles could be found in gametes of both parent plants.

3 Line Them Up

One-Factor Cross: Draw a table with 4 squares.

	B	b
B		
b		

Two-Factor Cross: In this case, each parent can make 4 different types of gametes. Draw a table with 16 squares so you can show all the possible combinations of alleles.

	TG	tG	Tg	tg
TG				
tG				
Tg				
tg				

4 Write Out the New Genotypes

One-Factor Cross: Fill in the table by combining the gametes' genotypes.

	B	b
B		Bb
b	bB	

	B	b
B	BB	Bb
b	bB	bb

Two-Factor Cross: Fill in the table by combining the gametes' genotypes.

	TG	tG	Tg	tg
TG				
tG			TtGg	
Tg				
tg		ttGg		

	TG	tG	Tg	tg
TG	TTGG	TtGG	TTGg	TtGg
tG	TtGG	ttGG	TtGg	ttGg
Tg	TTGg	TtGg	TTgg	Ttgg
tg	TtGg	ttGg	Ttgg	ttgg

5 Figure Out the Results

One-Factor Cross: Figure out the genotype and phenotype of each offspring.

	B	b
B	BB	Bb
b	bB	bb

Two-Factor Cross: Figure out the genotype and phenotype of each offspring.

	TG	tG	Tg	tg
TG	TTGG	TtGG	TTGg	TtGg
tG	TtGG	ttGG	TtGg	ttGg
Tg	TTGg	TtGg	TTgg	Ttgg
tg	TtGg	ttGg	Ttgg	ttgg

Independent Assortment

Mendel wondered if alleles for one trait affected the alleles for another trait. For example, does the gene that determines the shape of a seed have anything to do with the gene for seed color? To find out, Mendel set up a cross that enabled him to study two different genes at the same time.

Getting the Seeds To get the seeds he needed, Mendel crossed true-breeding plants that made only round yellow peas with plants that produced only wrinkled green peas. The round yellow peas had the genotype *RRYY*. The wrinkled green peas had the genotype *rryy*. All of the F_1 offspring from this cross had round yellow peas with the genotype *RrYy*. This result showed that the alleles for yellow and round peas are dominant.

Showing Independent Assortment In the second part of this experiment, Mendel crossed two of these new *RrYy* plants from the F_1 generation to make the F_2 generation offspring. Remember that each plant was formed by the fusion of a gamete carrying the dominant *RY* alleles with another gamete carrying the recessive *ry* alleles. In Mendel's experiment, the F_2 plants made 556 seeds. Mendel sorted the seeds by trait. He noticed that 315 of the seeds were round and yellow, just like one parent. He saw that 32 seeds were wrinkled and green, just like the other parent. However, he also saw that 209 seeds had other combinations of phenotypes. Those included round and yellow peas and wrinkled and green peas. Those peas had to have allele combinations that were not found in either parent. This outcome showed that the alleles for seed shape segregated independently of those for seed color. Or to put it another way, genes that segregate independently do not influence each other's inheritance.

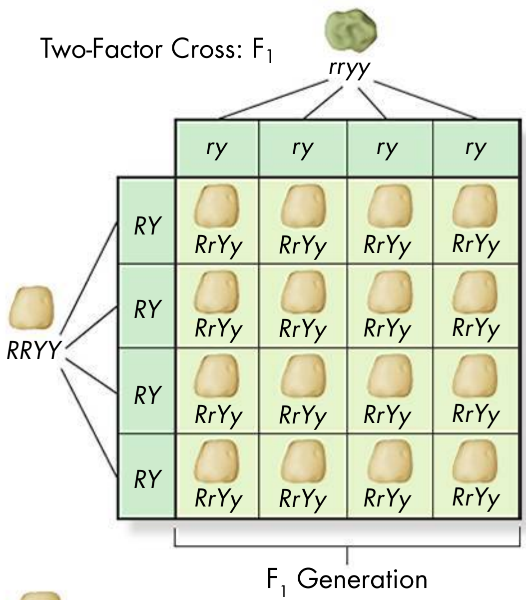
Mendel had discovered the principle of independent assortment. The principle of **independent assortment** states that genes for different traits can segregate independently when gametes are made. Independent assortment helps explain the many genetic variations we see in all living things.

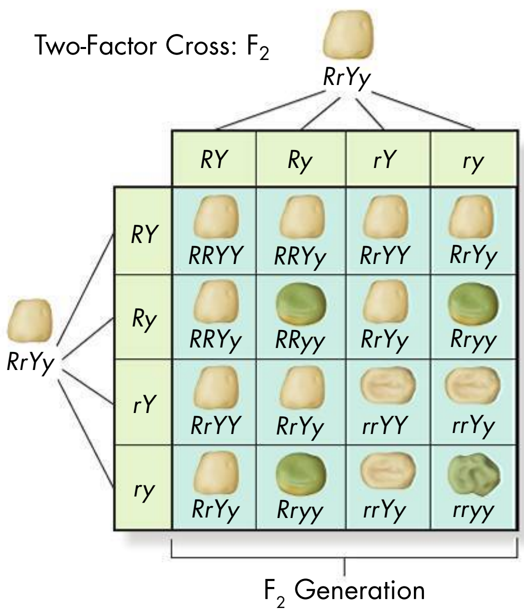
Key Question How do alleles segregate when more than one gene is involved?
Genes for different traits segregate independently.

BUILD Vocabulary

independent assortment
one of Mendel's principles that states that genes for different traits can segregate independently during the formation of gametes

ACADEMIC WORDS
The term *assort* means "to sort out." When alleles undergo independent assortment, they sort out, or separate from each other. Genes for one trait act separately from genes for another trait.





Common fruit flies are good organisms to use to study heredity. These fruit flies are on a lemon.

A Summary of Mendel's Principles

Today, Mendel's principles are the foundation of the modern science of genetics. These principles are below.

- Biological characteristics are inherited through units called genes. Genes are passed from parents to offspring.
- Sometimes there are two or more forms (alleles) of a gene for a single trait. Some forms of a gene may be dominant and others may be recessive.
- In most sexually reproducing organisms, each adult has two copies of each gene. Organisms get one copy from each parent. These alleles segregate from each other when gametes are made.
- Alleles for different genes usually segregate independently of each other.

Pea plants are not the only organisms used to study genetics. At the beginning of the 1900s, the American geneticist Thomas Hunt Morgan began to test Mendel's theories using fruit flies. The fruit fly is a good subject for genetic studies because it quickly produces hundreds of offspring. Using the fruit fly, Morgan and others tested all of Mendel's principles. The principles worked as well in fruit flies as they did in peas.

Key Question What did Mendel contribute to what we know about genetics? **Mendel's principles of heredity form the basis of modern genetics.**

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the text to complete each sentence correctly.

1. ______ is the likelihood that something will happen.

2. If a pea plant has the ______ *Tt*, the plant will be tall.

3. If a rabbit has the alleles *BB* for the gene for fur color, the rabbit is ______ for that trait.

4. The principle of ______ states that the way one allele segregated did not affect the segregation of other alleles.

Critical Thinking

5. Infer Two pea plants with smooth seed pods are crossed. Some of the offspring have wrinkled seed pods. What can you infer about the genotypes of both parents?

6. Review What did Mendel conclude determines biological inheritance?

7. Write to Learn Make a Punnett square showing a cross between two pea plants. One plant is tall *Tt*, and the other is tall *TT*.

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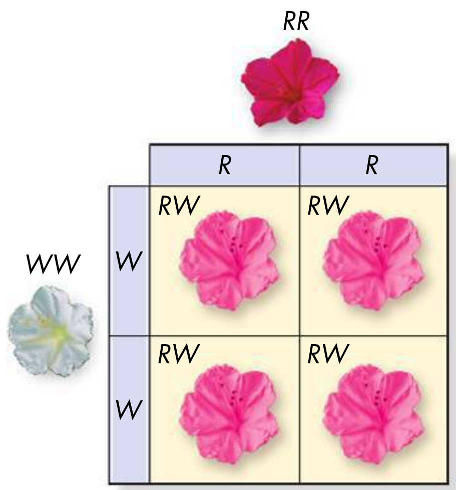
11.3 Other Patterns of Inheritance

Beyond Dominant and Recessive Alleles

We now know that heredity is a bit more complicated than Mendel thought. For example, most genes have more than two alleles. Also, many traits are controlled by more than one gene. Geneticists need to understand these other patterns of inheritance. That way, they can predict how complex traits will be inherited.

Codominance Sometimes neither allele is dominant over the other. If alleles have **codominance,** the phenotypes made by both alleles show up at the same time. For example, in certain kinds of chickens, the allele for black feathers is codominant with the allele for white feathers. Heterozygous chickens are speckled with black and white feathers. Because of codominant alleles, the black and white colors both appear. Many human genes also show codominance.

Incomplete Dominance The cross between two four o'clock plants shows a common exception to Mendel's principles. Some alleles are neither dominant or recessive. Cases where one allele is not completely dominant are called **incomplete dominance.** In incomplete dominance, the heterozygous phenotype lies somewhere between the two homozygous phenotypes. Four o'clock plants are an example of this. A cross between red-flowered (*RR*) and white-flowered (*WW*) plants results in offspring with pink flowers (*RW*).



Incomplete Dominance In four o'clock plants, the alleles for red and white flowers show incomplete dominance. Heterozygous (*RW*) plants have pink flowers.

Key Questions

What are some exceptions to Mendel's principles?

Does the environment have a role in how genes determine traits?

BUILD Understanding

Finding Main Ideas Before you read the lesson, create a list of all the lesson's green and blue headings in order. Leave space under each heading for notes. As you read, write the main idea of each paragraph under the heading above it.

In Your Workbook Your workbook has a table for recording main ideas and details.

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BUILD Vocabulary

codominance
a situation in which the phenotypes produced by both alleles are completely expressed

incomplete dominance
a situation in which one allele is not completely dominant over another allele

multiple alleles
a gene that has more than two alleles

polygenic traits
a trait controlled by two or more genes

PREFIXES

The prefix *co-* means *jointly* or *together*. Books written by coauthors are written by two people who share credit equally. Codominant alleles contribute equally to the phenotype of a trait.

Multiple Alleles So far, our examples have described genes for which there are only two alleles. In nature, such genes are not common. Many genes exist in several different forms. A gene with more than two alleles is said to have **multiple alleles.** An individual, of course, usually has only two copies of each gene. Within a population, however, there are many different alleles. Two individuals having two different alleles each could together have four different alleles for the same gene.

One of the best examples of multiple alleles is coat color in rabbits. A rabbit's coat color is controlled by one gene that has four possible alleles. The four known alleles display a pattern of simple dominance that can produce four coat colors. Many other genes have multiple alleles, including the human genes for blood type.

Polygenic Traits Many traits are controlled by several genes at work at the same time. Traits controlled by two or more genes are said to be **polygenic traits** (pahl ih JEN ik traytz). Polygenic means "many genes." For example, at least three genes are involved in making the reddish-brown pigment in the eyes of fruit flies. Different combinations of alleles for these three genes produce very different eye colors. Polygenic traits often show a wide range of phenotypes. The wide range of skin color in humans comes about partly because more than four different genes are likely to control this trait.

Be sure that you don't confuse polygenic traits with traits determined by one gene with multiple alleles. In multiple alleles, many different alleles exist for a gene in a population. However, an individual organism only has a single pair of these alleles. In polygenic traits, each individual organism has many different gene pairs that all work together on one trait.

Key Question What are some exceptions to Mendel's principles?
Traits can be controlled by incomplete dominant alleles. They can be controlled by codominant alleles, or by genes with more than two possible alleles. Traits can also be controlled by several genes.

Genes and the Environment

The characteristics of any organism are not only controlled by the genes that organism inherits. Genes provide a plan for development. What happens to that plan also depends heavily on the environment. In other words, the phenotype of an organism is only partly determined by its genotype. This is true no matter what the organism is—plant, fruit fly, or human being.

Consider the western white butterfly, *Pontia occidentalis*. It is found throughout western North America. People had noted for years that western whites hatching in the summer had different color patterns on their wings than those hatching in the spring. Scientific studies showed the reason. Butterflies hatching in the shorter days of springtime had greater levels of pigment in their wings. More pigment makes the markings of the springtime butterflies appear darker. In other words, the environment in which the butterflies develop affects how genes make pigments for the wings.

Key Question Does the environment have a role in how genes determine traits? **Environmental conditions can change gene expression and influence genetically controlled traits.**


Summer Buckeye Butterfly


Autumn Buckeye Butterfly

Temperature and Wing Color Buckeye butterflies also have different coloring depending on when they hatch. Summer butterflies are lighter than autumn butterflies.

CHECK Understanding

Use the highlighted words from the text to complete each sentence correctly.

1. When neither allele is dominant over the other, and both phenotypes are fully expressed, the alleles are said to be ___________.

2. In ___________, both alleles of a gene are expressed and the phenotype is a blend of the phenotypes of both alleles.

3. In ___________, several genes control the phenotype.

Critical Thinking

4. **Review** Describe two inheritance patterns besides simple dominance.

5. **Apply** How could you test to see if soil temperature was responsible for a variation in flower color?

6. **Write to Learn** Answer the third clue by writing a paragraph about how polygenic traits are different from the kinds of traits Mendel observed.

MYSTERY CLUE

Green feathers don't actually have green pigments. Rather, they contain a mixture of blue and yellow pigments. Could feather color be controlled by more than one gene? (**Hint:** See p. 272.)

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INQUIRY into Scientific Thinking

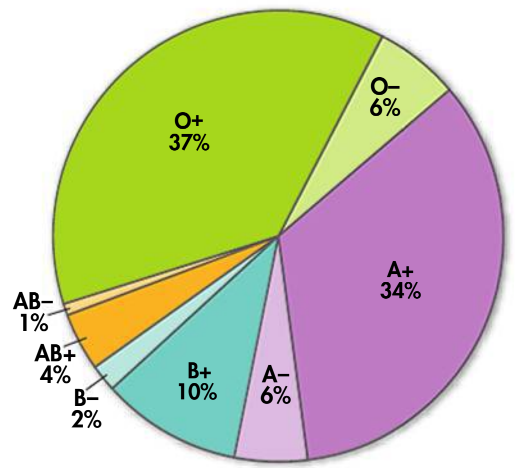
Human Blood Types

Red blood cells have protein markers on them. These antigens can cause a reaction if a person receives the wrong blood type during a blood transfusion. Human blood type A carries an A antigen, type B has a B antigen, and type AB has both antigens. Type O carries neither antigen. The gene for these antigens has three alleles: A, B, and O. A and B are dominant over O. When A and B appear together, they are codominant.

For a transfusion to succeed, it must not put a new antigen into the body of the person getting the blood. So, a person with type A blood may get type O. However, a person with type O may not get type A blood.

Another gene controls a second type of antigen, known as Rh factor. Rh^+ individuals carry this protein. People with Rh^- do not carry it. The pie graph of the U.S. population shows the percentage of each blood type.

Blood Groups in the U.S. Population



Analyze and Conclude

1. Interpret Graphs Which blood type makes up the greatest percentage of the U.S. population?

2. Calculate What percentage of the U.S. population has Rh^+ blood?

3. Predict Alleles are either dominant or recessive. The allele for type O is recessive to the alleles for types A and B. The allele for Rh^+ is dominant over the allele for Rh^-.

- Could a person with O^+ blood have two parents with O^- blood? Explain.
- Could a person with O^+ blood have a daughter with AB^+ blood? Explain your answers.

4. Infer A person with type A, B, or AB blood may receive a transfusion of type O. However, a person with type O may not get types A or AB blood. A person with Rh^+ blood can get Rh^- blood, but a person with Rh^- blood cannot get Rh^+ blood.

Use the graph to answer the questions that follow.

- Which blood type can be donated to the largest percentage of individuals? Explain your answer.
- Which type can be donated to the smallest percentage of people? Explain your answer.

11.4 Meiosis

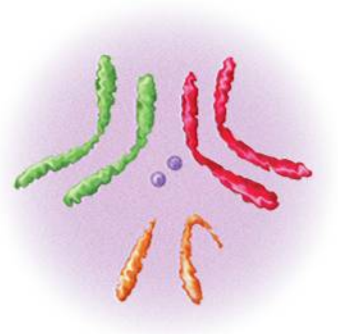
Chromosome Number

What happens in cells to make sure they pass on the correct number of genes? To understand how the number of genes is controlled, we need to learn what happens to chromosomes when gametes are made. Chromosomes are strands of DNA and protein inside the cell nucleus, and they are the carriers of genes. Genes are located in specific places on chromosomes.

Diploid Cells Think about the fruit flies that Morgan used. A body cell in an adult fruit fly has eight chromosomes. Four of the chromosomes come from its male parent, and four come from its female parent. These two sets of chromosomes are **homologous** (hoh MAHL uh gus), because each of the four chromosomes from the male parent has a similar chromosome from the female parent. A cell that has both sets of homologous chromosomes is said to be **diploid,** meaning "two sets." The diploid cells of most adult organisms have two complete sets of chromosomes and so two complete sets of genes. The diploid number of chromosomes can be shown using the symbol 2N. So, for fruit flies, the diploid number is 8, which can be written as 2N = 8.

Key Question How many sets of genes are found in most adult organisms?
The diploid cells of most adult organisms contain two complete sets of inherited chromosomes and so two complete sets of genes.

Haploid Cells Some cells have only a single set of genes on a single set of chromosomes. These cells are **haploid,** meaning "one set." The gametes of sexually reproducing organisms, such as fruit flies and peas, are haploid. For fruit fly gametes, the haploid number is 4. This amount can be written as N = 4.



Fruit Fly Chromosomes These chromosomes are from a fruit fly. Each of the fruit fly's body cells is diploid, containing eight chromosomes.

Key Questions

How many sets of genes are found in most adult organisms?

What happens during each phase of meiosis?

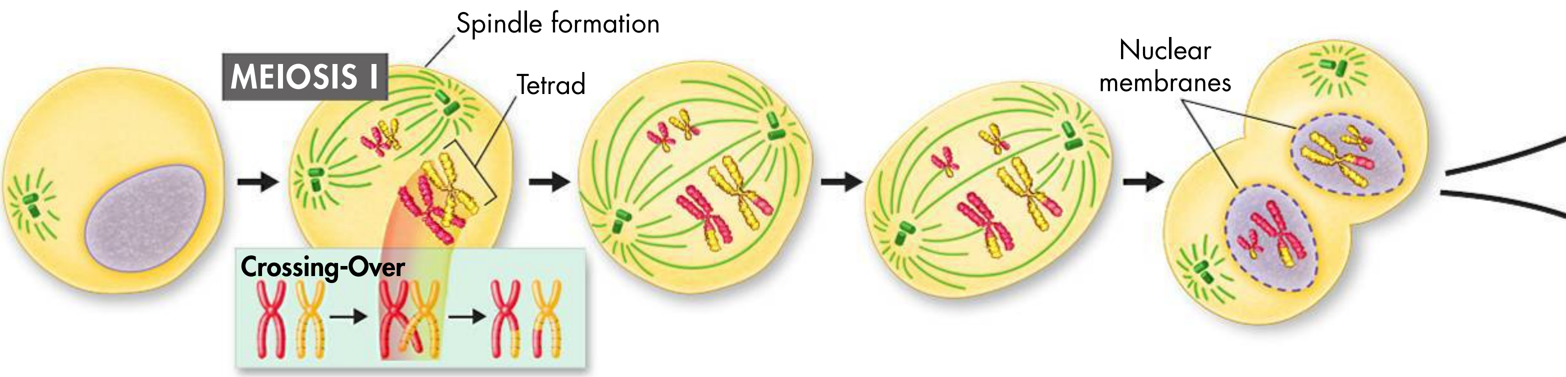
How is meiosis different from mitosis?

How can two alleles from different genes be inherited together?

BUILD Understanding

Compare/Contrast Table Before you read, make a compare/contrast table to show the differences between mitosis and meiosis. As you read, complete the table.

In Your Workbook Refer to your workbook for suggestions about how to use a compare/contrast table.



Interphase
Cells undergo a round of DNA replication, forming duplicate chromosomes.

Prophase I
Each chromosome pairs with its corresponding homologous chromosome to form a tetrad.

Metaphase I
Spindle fibers attach to the chromosomes.

Anaphase I
The fibers pull the homologous chromosomes to opposite ends of the cell.

Telophase I and Cytokinesis
Nuclear membranes form. The cell separates into two cells.

MEIOSIS
During meiosis, the number of chromosomes per cell is cut in half through the separation of the homologous chromosomes. The result of meiosis is 4 haploid cells that are genetically different from one another and from the original cell.

Phases of Meiosis

How are haploid cells made? Haploid cell are made by meiosis. **Meiosis** (my OH sis) is a process in which the number of chromosomes per cell is cut in half through the separation of homologous chromosomes in a diploid cell. Meiosis involves two rounds of cell division, called meiosis I and meiosis II. Let's see how meiosis takes place in a cell that has a diploid number of 4 (2N = 4).

Meiosis I Just before meiosis I, each chromosome is copied, or replicated. As in mitosis, each replicated chromosome is made of two identical chromatids joined at the center.

▶ ***Prophase I*** In prophase of meiosis I, each copied chromosome matches up with its homologous chromosome. This pairing makes a structure called a tetrad, which has four chromatids. After the homologous chromosomes make tetrads, they undergo a process called **crossing-over.** First, the chromatids of the homologous chromosomes cross over one another. Crossing-over produces new combinations of alleles on each chromatid.

▶ ***Metaphase I and Anaphase I*** A spindle forms and attaches to each chromosome in the tetrad. The homologous chromosomes separate in anaphase I.

▶ ***Telophase I and Cytokinesis*** A nuclear membrane forms around each cluster of chromosomes in telophase I. During cytokinesis, the cell splits and two new haploid cells are made. The set of alleles in each cell is different from the set in the other cell.

Key Question What happens during each phase of meiosis I?
During prophase I, each copied chromosome matches up with its homologous chromosome. Crossing-over increases the allele combinations on chromatids.

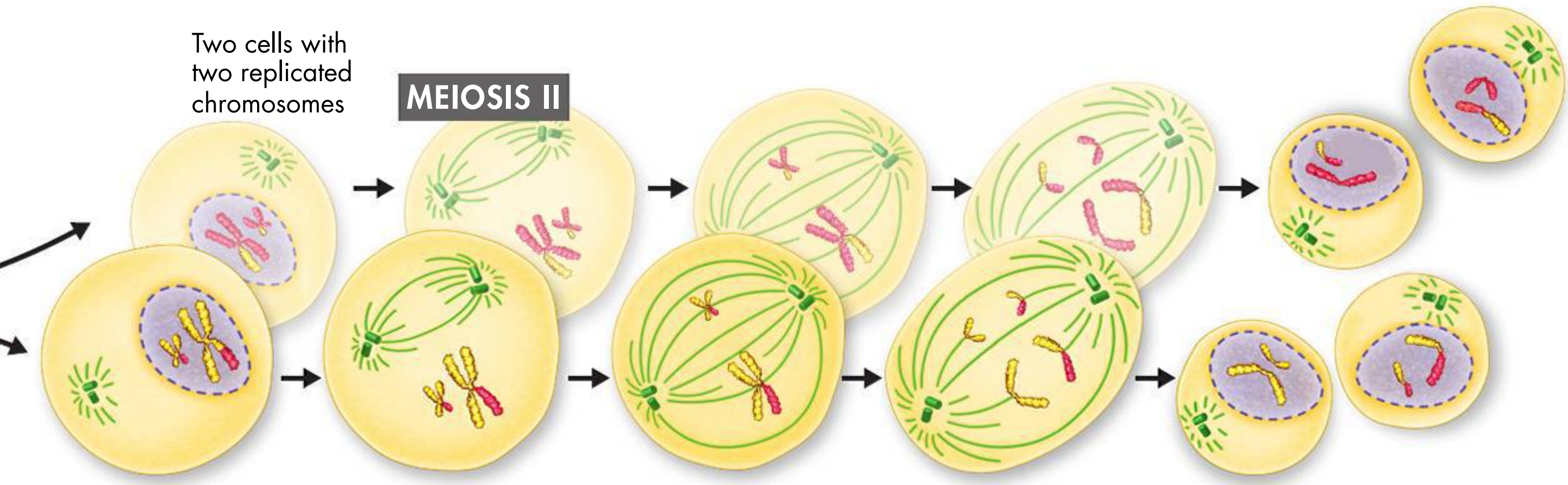
BUILD Vocabulary

homologous
the term used to refer to chromosomes in which one set comes from the male parent and one set comes from the female parent

diploid
the term used to refer to a cell that contains two sets of homologous chromosomes

haploid
the term used to refer to a cell that contains only a single set of genes

WORD ORIGINS
The word *diploid* comes from the Greek root *di-*, which means "double" or "twice."



Prophase II
Meiosis I results in two haploid (N) daughter cells, each with half the number of chromosomes as the original cell.

Metaphase II
The chromosomes line up in a similar way to the metaphase stage of mitosis.

Anaphase II
The sister chromatids separate and move toward opposite ends of the cell.

Telophase II and Cytokinesis
Meiosis II results in four haploid daughter cells.

In metaphase I, the spindle fibers form. In anaphase I, the chromosomes separate. Then, in telophase, a nuclear membrane forms around the chromosomes. During cytokinesis, the cell splits, and two new cells are made.

Meiosis II The two cells get ready to divide once more. The chromosomes do not replicate before this division.

▶ ***Prophase II*** As the cells enter prophase II, their chromosomes become visible. Each prophase chromosome consists of two identical sister chromatids.

▶ ***Metaphase II, Anaphase II, Telophase II, and Cytokinesis*** During metaphase II, the chromosomes line up in the middle of the cell. As the cell enters anaphase II, the paired chromatids separate. When anaphase II is complete, the separated chromosomes cluster at opposite ends of the cell. In telophase II, the nuclear membrane forms around each cluster of chromosomes. In the example shown here, each of the four daughter cells produced in meiosis II receives two chromosomes. The four daughter cells now contain the haploid number (N)—two chromosomes each.

Key Question What happens during each phase of meiosis II? **As the cells enter prophase II, their chromosomes become visible. During metaphase II, the chromosomes line up in the middle of the cell. In the second anaphase, the chromatids separate. In the second telophase and cytokinesis, four new haploid cells are formed.**

Gametes to Zygotes The haploid cells made by meiosis II are gametes, which are important to heredity. Gametes, such as eggs and sperm, join in fertilization to form a **zygote** (ZY goht), which has new combinations of alleles. The zygote undergoes cell division by mitosis and grows into an organism.

BUILD Vocabulary

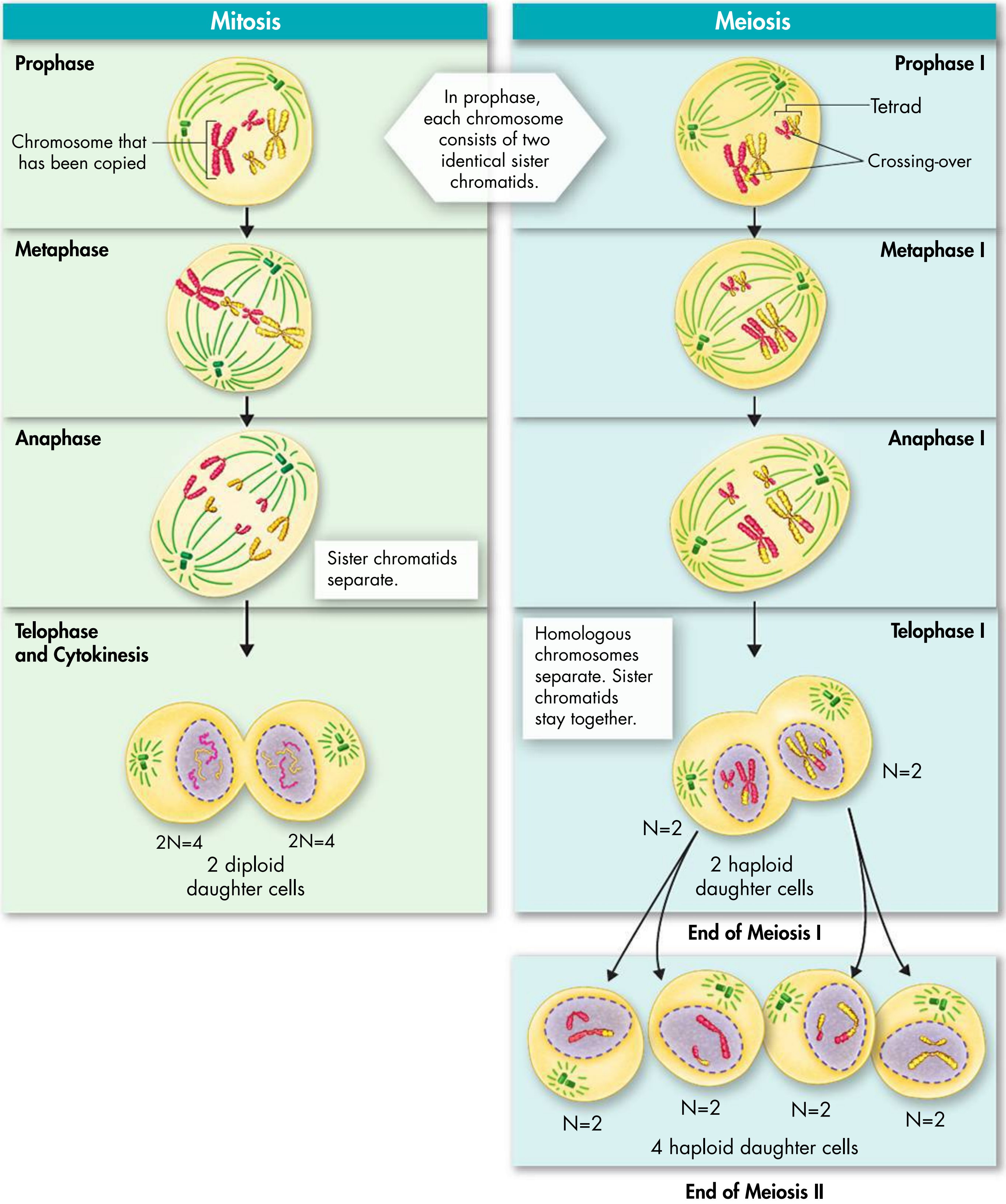
meiosis
the process in which the number of chromosomes per cell is cut in half through the separation of homologous chromosomes in a diploid cell

crossing-over
the process in which homologous chromosomes exchange portions of their chromatids during meiosis

zygote
a fertilized egg

WORD ORIGINS

The word *meiosis* comes from a Greek word that means "to lessen or reduce." Because of meiosis, gametes have a reduced number of chromosomes.


Mitosis
Prophase
Chromosome that has been copied
Metaphase
Anaphase
Sister chromatids separate.
Telophase and Cytokinesis
2N=4
2N=4
2 diploid daughter cells
In prophase, each chromosome consists of two identical sister chromatids.
Meiosis
Prophase I
Tetrad
Crossing-over
Metaphase I
Anaphase I
Telophase I
Homologous chromosomes separate. Sister chromatids stay together.
N=2
N=2
2 haploid daughter cells
End of Meiosis I
N=2
N=2
N=2
N=2
4 haploid daughter cells
End of Meiosis II

Comparing Meiosis and Mitosis

Even though mitosis and meiosis both involve chromosomes and cell division, they are very different. Mitosis can be a form of asexual reproduction. Meiosis is an early step in sexual reproduction. Review the table to compare the two processes.

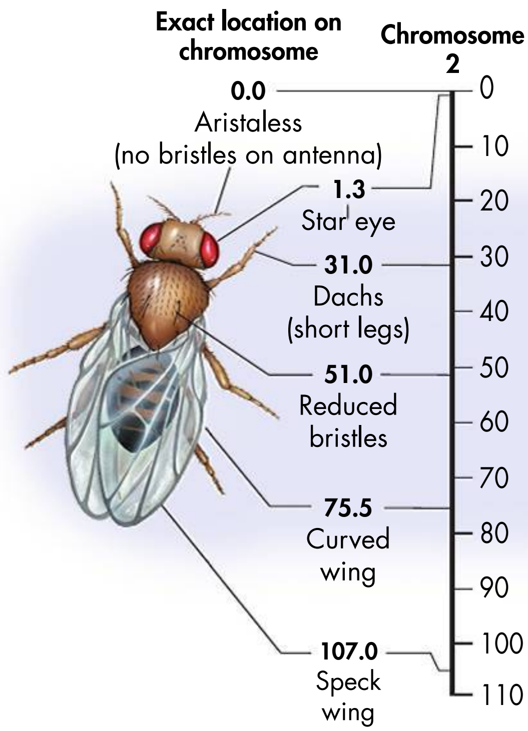
Key Question How is meiosis different from mitosis? **Mitosis can be a form of asexual reproduction. It does not change the number of chromosomes. It makes two identical diploid cells. Meiosis is a step in sexual reproduction. It cuts the chromosome number in half. It makes four genetically different haploid cells.**

Gene Linkage and Gene Maps

Genes that are located on the same chromosome are usually inherited together because they are linked. Thomas Hunt Morgan's research on fruit flies helped show that some genes are linked. Morgan used a fly with reddish-orange eyes and miniature wings in a series of test crosses. His results showed that the genes for those two traits were almost always inherited together.

Linked genes are not always inherited together. If crossing-over happens during meiosis, then linked genes can be separated. The farther apart genes are on a chromosome, the more likely crossing-over will separate them. This trend means that the rate of crossing-over can be used to locate and even to map genes on a chromosome.

Key Question How can two alleles from different genes be inherited together? **Alleles of different genes tend to be inherited together when those genes are on the same chromosome.**



Chromosomes are made of many genes linked together. Gene maps show how far apart these genes are from each other.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the text to complete each sentence correctly.

1. A cell that contains two sets of homologous chromosomes is ______.

2. A ______ is formed when an egg is fertilized by sperm.

Critical Thinking

3. Summarize What happens in meiosis I and II?

4. Write to Learn Answer the mystery clue.

MYSTERY CLUE

Traits can be controlled by more than one gene. White is the least common color found in parakeets. What does this fact suggest about the genotypes of both green parents? (Hint: See p. 271.)

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Pre-Lab: Modeling Meiosis

Problem How does meiosis increase genetic variation?

Materials pop-it beads, magnetic centromeres, large sheet of paper, colored pencils, scissors

Lab Manual Chapter 11 Lab

Skills Use Models, Sequence, Draw Conclusions

Connect to the Big idea Inherited traits are passed from parents to offspring in the form of genes. Offspring produced by sexual reproduction receive one set of genes from each parent when the reproductive cells, or gametes, combine. Meiosis is the process by which gametes are produced. During meiosis, new combinations of genes form when genes cross over from one homologous chromosome to the other. Also, the sorting of chromatids among gametes is random. Both crossing-over and sorting lead to greater diversity in the genes of a population.

In this lab, you will model the steps of meiosis and track what happens to alleles as they move from diploid cells to haploid gametes.

Background Questions

a. **Review** What are alleles?

b. **Sequence** What happens during prophase I of meiosis? What happens during metaphase I? What happens during anaphase I?

c. **Compare and Contrast** In what ways does meiosis differ from mitosis?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Control Variables** Why must you use the same number of beads when you construct the second chromosome in Step 1?

2. **Infer** Why is the longer chromosome pair used to model crossing-over?

3. **Calculate** A diploid cell has two pairs of homologous chromosomes. How many different combinations of chromosomes could there be in the gametes? MATH

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Visit Chapter 11 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Travel back in time with the Untamed Science explorers as they prove Mendel was no pea brain!

Art in Motion View a short animation that brings the process of meiosis to life.

Art Review Review your understanding of multiple alleles, incomplete dominance, and other exceptions to Mendel's principles.

InterActive Art Build your understanding of Punnett squares with this animation.

Data Analysis Investigate the connection between crossing-over and gene location.

Tutor Tube Hear suggestions from the tutor for help remembering what happens to chromosomes during meiosis.

11 CHAPTER Summary

11.1 The Work of Gregor Mendel

- An individual's unique characteristics are determined by factors that are passed from parent to offspring.
- When gametes are made, the alleles for each trait separate from each other. That way each gamete carries only one allele from each gene.

genetics (p. 262)
fertilization (p. 262)
trait (p. 262)
gene (p. 263)
allele (p. 263)
principle of dominance (p. 263)
segregation (p. 264)
gamete (p. 264)

11.2 Applying Mendel's Principles

- Punnett squares use probability to predict combinations of alleles in a genetic cross.
- Genes for different traits segregate independently.
- Mendel's principles of heredity form the basis of modern genetics.

probability (p. 266)
homozygous (p. 267)
heterozygous (p. 267)
phenotype (p. 267)
genotype (p. 267)
independent assortment (p. 269)

11.3 Other Patterns of Inheritance

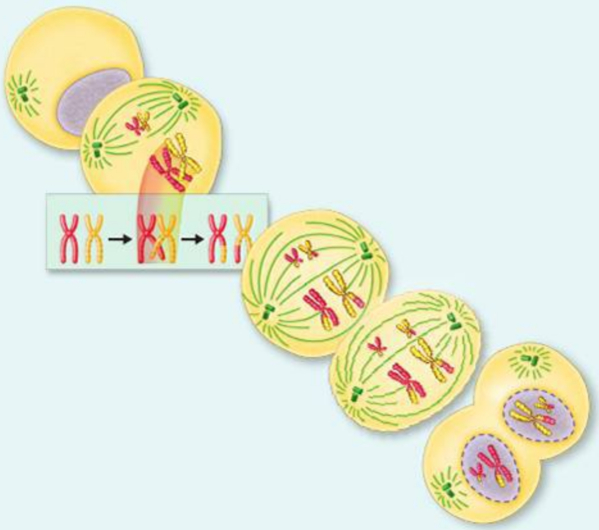
- Traits can be controlled by incomplete dominant alleles, codominant alleles, more than two possible alleles, and several genes.
- Environmental conditions can affect gene expression and influence genetically determined traits.

codominance (p. 271)
incomplete dominance (p. 271)
multiple alleles (p. 272)
polygenic trait (p. 272)

11.4 Meiosis

- The diploid cells of most adult organisms contain two complete sets of inherited chromosomes and so two complete sets of genes.
- Meiosis is a process of cell division that results in gametes that have half the number of chromosomes that other body cells have. In prophase I, copied chromosomes pair with their matching homologous chromosomes. At metaphase I, paired chromosomes line up across the center of the cell. In anaphase I, chromosome pairs move toward opposite ends of the cell. In telophase I, a nuclear membrane forms around each cluster of chromosomes. Cytokinesis then forms two new cells. As the cells enter prophase II, their chromosomes become visible. The final four phases of meiosis II result in four haploid daughter cells.
- Meiosis results in four genetically different haploid cells. Mitosis results in two genetically identical diploid cells.
- Alleles of different genes tend to be inherited together when those genes are on the same chromosome.

homologous (p. 275)
diploid (p. 275)
haploid (p. 275)
meiosis (p. 276)
crossing-over (p. 276)
zygote (p. 277)



11 CHECK Understanding

Assess the Big idea: Information and Heredity

Write an answer to the question below.

Q: How does biological information pass from one generation to another?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each numbered question should be one or two paragraphs long. To help you begin, read the **Hints** below each of the questions.

1. **What did Mendel discover about biological characteristics?**

   Hint Mendel crossed pea plants and studied offspring.

   Hint Mendel learned that the traits of the parents affected the traits of the offspring.

2. **How can two siblings have the same parents and have different information on their chromosomes?**

   Hint Every multicellular organism has two alleles for every gene. Some populations have more than two alleles for each gene.

   Hint Genes for different traits can sort independently when gametes are made.

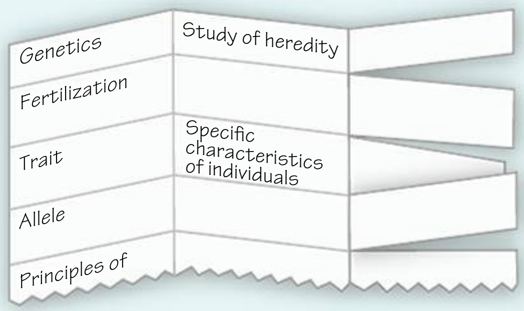
3. **What are the main differences between meiosis and mitosis?**

   Hint The purpose of meiosis is to make gametes.

   Hint The purpose of mitosis is to make daughter cells that are identical to the parent cell.

Foundations for Learning Wrap-Up

Use the undercover vocabulary tool you made as you read the chapter to help you review the material on heredity and meiosis.



Activity 1 Form groups of three. Have one person read a definition from the terms on the undercover vocabulary tool. Have the other two students try to identify the terms associated with the definitions. Take turns reading the definitions.

Activity 2 Use scissors to carefully cut the definitions and terms from your undercover vocabulary tool. When all the terms and definitions are on separate pieces of paper, mix them up. Try to match the terms and the definitions.

11.1 The Work of Gregor Mendel

Understand Key Concepts

1. Different forms of a gene are called
a. hybrids. **c.** alleles.
b. dominant factors. **d.** recessive factors.

Test-Taking Tip

Use Time Wisely Before you start your test, look at the kinds of questions being asked. Usually, multiple-choice questions take less time to answer than critical-thinking questions. Be sure not to spend so much time on multiple-choice questions that you won't have time to answer the essay questions.

Think Critically

2. **Infer** Suppose Mendel crossed two pea plants and got both tall and short offspring. What could have been the genotypes of the two original plants? What genotype could *not* have been present?

11.2 Applying Mendel's Principles

Understand Key Concepts

3. Organisms that have two identical alleles for a particular trait are said to be
a. hybrid. **c.** homozygous.
b. heterozygous. **d.** dominant.

4. A Punnett square is used to determine the
a. probable outcome of a cross.
b. actual outcome of a cross.
c. result of incomplete dominance.
d. result of meiosis.

5. The physical characteristics of an organism are called its
a. genetics. **c.** phenotype.
b. heredity. **d.** genotype.

6. List the four basic principles of genetics that Mendel discovered in his experiments. Briefly describe each of these principles.

Think Critically

7. **Apply Concepts** In guinea pigs, the allele for a rough coat (R) is dominant over the allele for a smooth coat (r). A heterozygous guinea pig (Rr) and a homozygous recessive guinea pig (rr) have a total of nine offspring. Is it possible for all the offspring to have smooth coats? Explain your answer.

11.3 Other Patterns of Inheritance

Understand Key Concepts

8. A situation in which a gene has more than two alleles is known as
a. complete dominance.
b. codominance.
c. polygenic dominance.
d. multiple alleles.

9. Are an organism's characteristics determined only by its genes? Explain your answer.

Think Critically

10. **Interpret Visuals** Genes that control hair or feather color in some animals are expressed differently in the winter than in the summer. How might such a difference be beneficial to the ptarmigan shown here?

11 CHECK Understanding

11.4 Meiosis

11. Unlike mitosis, meiosis in male mammals results in the formation of

a. one haploid gamete.

b. three diploid gametes.

c. four diploid gametes.

d. four haploid gametes.

Think Critically

12. Compare and Contrast Make a table that compares and contrasts meiosis and mitosis.

Connecting Concepts

Use Science Graphics

In pea plants, the coat, or covering, of the seed is either smooth or wrinkled. Suppose a researcher has two plants—one that makes smooth seeds and another that makes wrinkled seeds. The researcher crosses the wrinkled-seed plants and the smooth-seed plants, obtaining the following data. Use the data to answer questions 13 and 14.

13. Infer Mendel knew that the allele for smooth (R) seeds was dominant over the allele for wrinkled (r) seeds. If this cross was $Rr \times rr$, what numbers would fill the middle column?

Results of Seed Experiment

Phenotype	Number of Plants in the F_1 Generation	
	Expected	Observed
Smooth seeds		60
Wrinkled seeds		72

14. Analyze Data Are the observed numbers consistent with the hypothesis that the cross is $Rr \times rr$? Explain your answer.

solve the CHAPTER MYSTERY

GREEN PARAKEETS

After talking to the owner of the pet store, Susan realized she had a rare gift. White parakeets are very uncommon. The pet shop owner told Susan that two genes control feather color. A dominant Y allele results in a yellow pigment. The dominant B allele controls melanin production.

- If the genotype contains a capital Y (either YY or Yy) and a capital B, the offspring will be green.
- If the genotype contains a capital Y (either YY or Yy) and two lowercase b's, the offspring will be yellow.
- If the genotype contains two lowercase y's, and a capital B, the offspring will be blue.
- If the genotype contains two lowercase y's and two lowercase b's, the offspring will be white. The Punnett square below shows the possible genotypes for the cross that produced Susan's baby parakeets. Copy this Punnett square onto a piece of paper. Use it to answer the questions that follow.

	?	?	?	?
?	BBYY	BBYy	BbYY	BbYy
?	BBYy	BByy	BbYy	Bbyy
?	BbYY	BbYy	bbYY	bbYy
?	BbYy	Bbyy	bbYy	bbyy

1. Use Models Write "blue" in the squares that represent a blue parakeet. Write "yellow" in the squares that represent a yellow parakeet. Write "green" in the squares that represent a green parakeet.

2. Use Models Write "white" in the square that represents a white parakeet.

3. Apply Concepts What are the genotypes of the parents in this cross?

Standardized Test Prep

Multiple Choice

1. What happens to the chromosome number during meiosis?
   A It doubles.
   B It stays the same.
   C It halves.
   D It becomes diploid.

2. Which ratio did Mendel find in his F_2 generation?
   A 3 : 1
   B 1 : 3 : 1
   C 1 : 2
   D 3 : 4

3. During which phase of meiosis is the chromosome number reduced?
   A anaphase I
   B metaphase I
   C telophase I
   D telophase II

4. Two pink-flowering plants are crossed. The offspring flower as follows: 25% red, 25% white, and 50% pink. What pattern of inheritance does flower color in these flowers follow?
   A dominance
   B multiple alleles
   C incomplete dominance
   D polygenic traits

5. The physical characteristics of an organism are its
   A heredity.
   B genotype.
   C genetics.
   D phenotype.

6. Alleles for the same trait are separated from each other during the process of
   A cytokinesis.
   B meiosis I.
   C meiosis II.
   D metaphase II.

7. Which of the following is NOT one of Gregor Mendel's principles?
   A The alleles for different genes usually segregate independently.
   B Some forms of a gene may be dominant.
   C The inheritance of characteristics is determined by factors (genes).
   D Crossing-over occurs during meiosis.

Questions 8–10

The Punnett square below shows a cross between two pea plants each with round seeds.

	?	?
R	*RR*	*Rr*
R	*RR*	*Rr*

8. The unknown genotype is
   A Rr.
   B rR.
   C rr.
   D RR.

9. Which statement is true about the cross in the Punnett square?
   A Both parents are heterozygous for the trait.
   B Both parents are homozygous for the trait.
   C One parent is heterozygous and the other is homozygous for the trait.
   D The trait is controlled by codominant alleles.

10. What percentage of the offspring of this cross will produce round seeds?
    A 0%
    B 25%
    C 50%
    D 100%

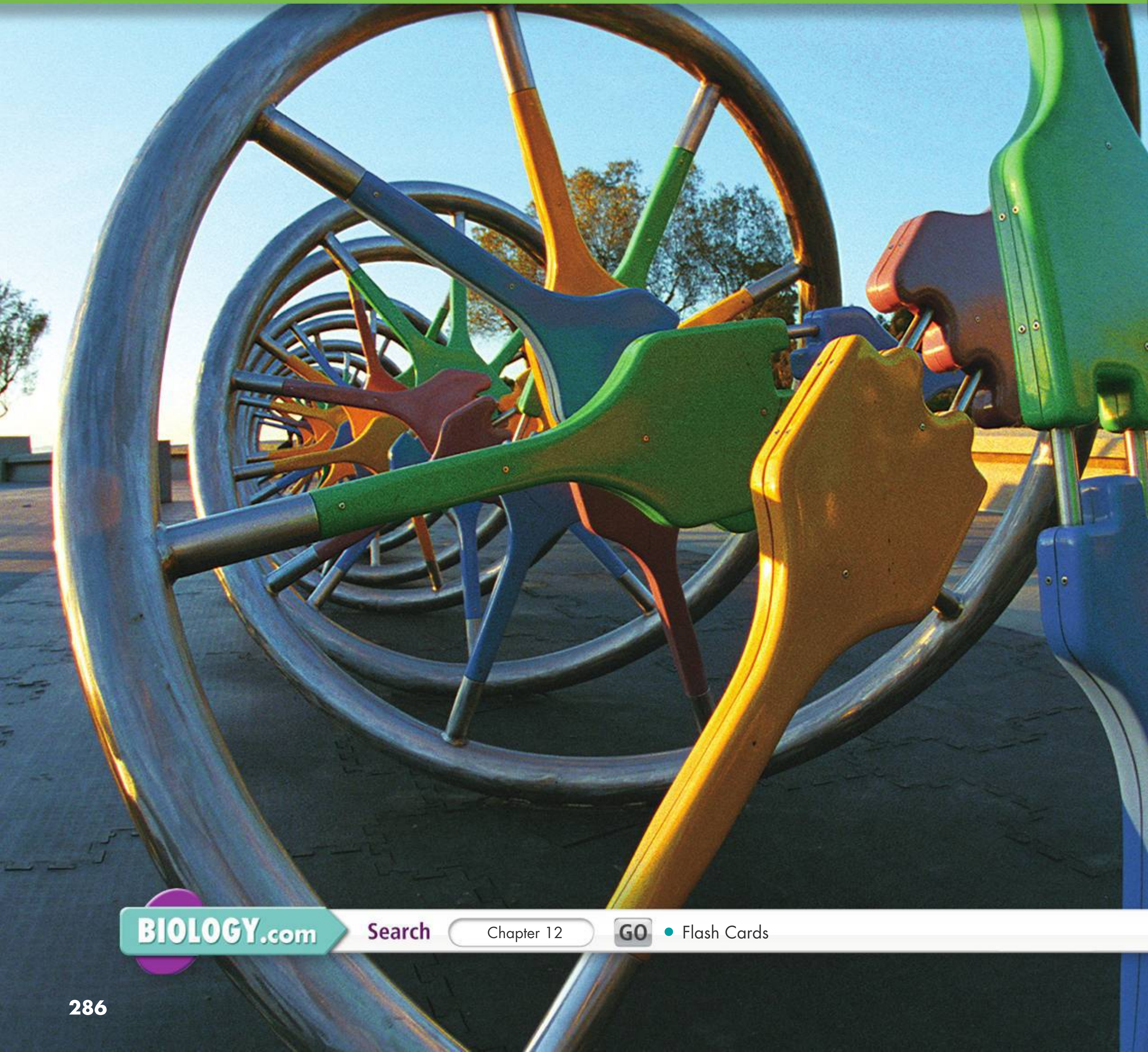
If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	11.4	11.1	11.4	11.3	11.4	11.4	11.2	11.2	11.2	11.2

12 DNA

Big ideas
Information and Heredity, Cellular Basis of Life

Q: What is the structure of DNA, and how does it function in genetic inheritance?



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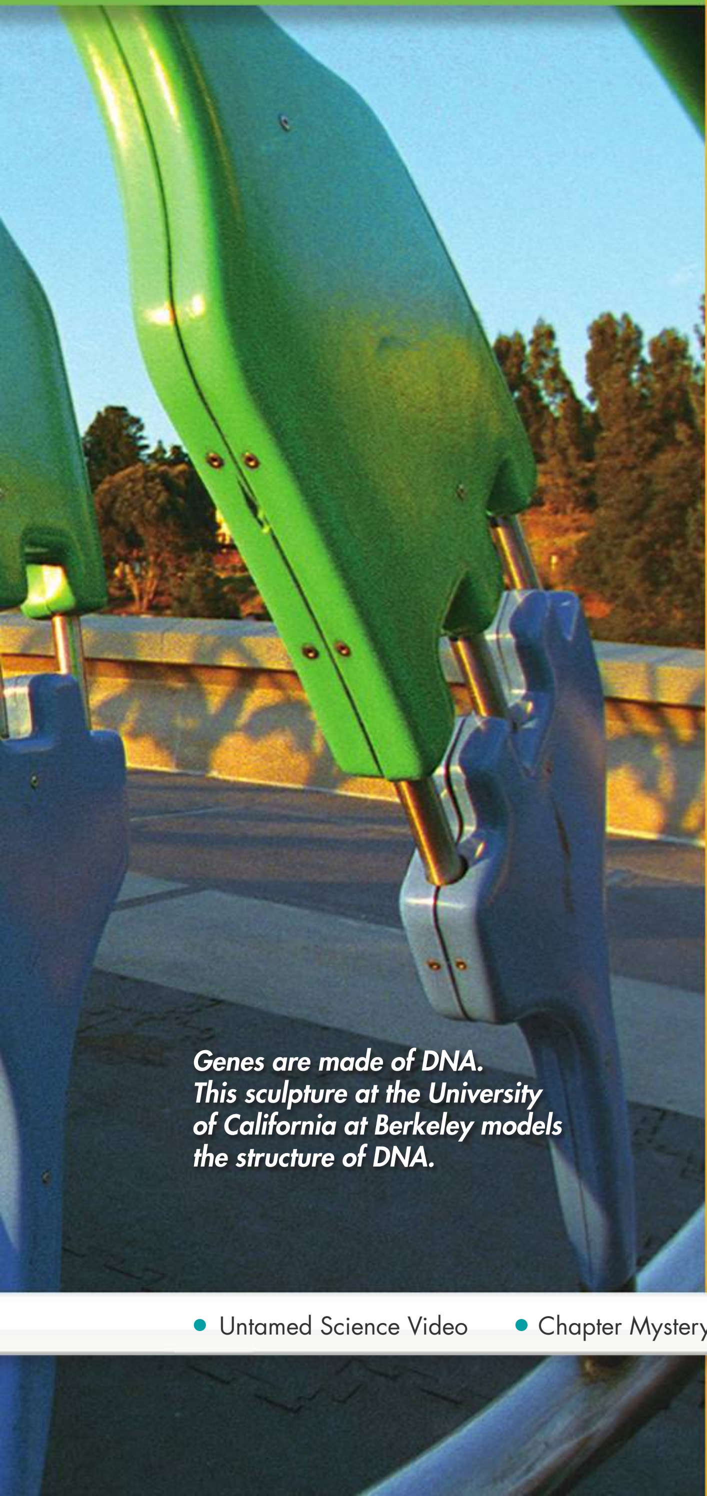
INSIDE:

- 12.1 Identifying the Substance of Genes
- 12.2 The Structure of DNA
- 12.3 DNA Replication



Genes are made of DNA. This sculpture at the University of California at Berkeley models the structure of DNA.

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

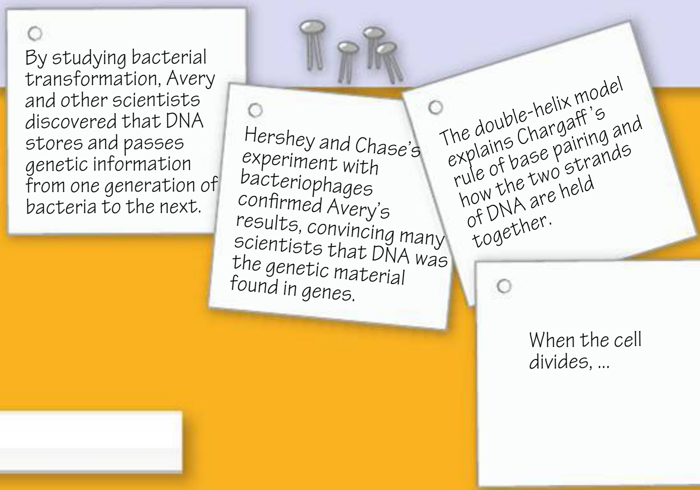
UV LIGHT

"Put on your sunscreen!" You can hear people say this at beaches on a sunny day. Why do people say it? Sunlight can harm the skin. The most dangerous part of sunlight is the part we can't see: the ultraviolet (UV) rays of the electromagnetic spectrum. Overexposure to UV light harms skin cells. It can also cause a deadly form of skin cancer that kills nearly 10,000 Americans each year. Why is UV light so dangerous? How can these particular wavelengths of light harm our cells to the point of causing cell death and cancer?

Read for Mystery Clues As you read this chapter, look for clues to help you solve the question of why UV light is so harmful to skin cells. Then, solve the mystery.

FOUNDATIONS for Learning

The main ideas from the chapter can be found as the answers to the Key Questions. They are the building blocks of the Big Idea. Before you read the chapter, go through and use the answers to the Key Questions to make Connected Ideas cards. Write only one idea per card. Use several cards to cover all the ideas in long answers. As you read through the chapter, make additional cards that describe important discoveries and the steps of processes you learn. At the end of the chapter are two activities that use the cards to help answer the question: What is the structure of DNA, and how does it function in genetic inheritance?



12.1 Identifying the Substance of Genes

Key Questions

- *What clues did bacterial transformation give about the gene?*
- *What role did bacterial viruses play in identifying genetic material?*
- *What is the role of DNA in heredity?*

BUILD Understanding

Flowchart As you read this section, make a flowchart that shows how scientists came to understand the molecule known as DNA.

In Your Workbook Go to your workbook to learn more about making a flowchart. Complete the flowchart for Lesson 12.1.

BUILD Vocabulary

transformation
a process in which one strain of bacteria is changed by a gene or genes from another strain of bacteria

bacteriophage
a kind of virus that infects bacteria

SUFFIXES

The suffix -*phage* comes from the Greek word *phagien*, which means "to eat." Bacteriophages do not actually eat bacteria, but they can harm or kill them.

Bacterial Transformation

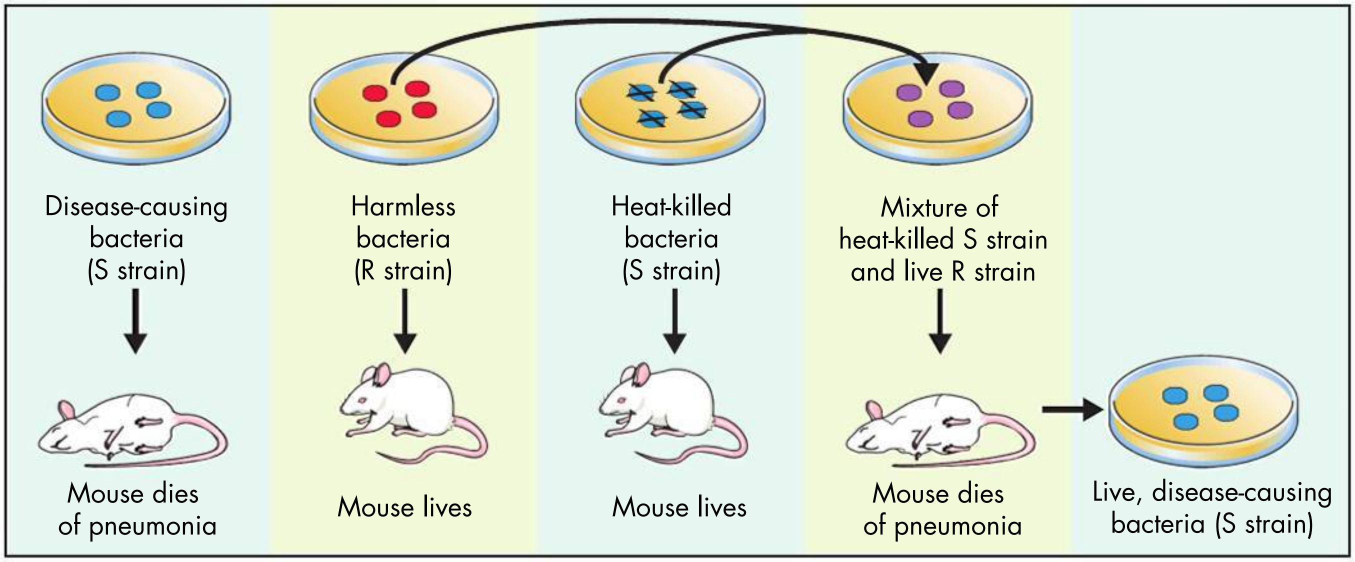
How do genes work? You need to know what genes are made of to answer that question. The first scientist to help figure this out was Frederick Griffith. He found two similar types (or strains) of bacteria in mice. One of the strains (S strain) caused pneumonia. Pneumonia is a deadly lung disease. The other strain (R strain) was harmless. Griffith wondered why the S strain was deadly but the R strain was harmless.

Griffith's Experiments When Griffith injected mice with disease-causing bacteria, the mice developed pneumonia and died. When he injected mice with harmless bacteria, the mice stayed healthy. Griffith thought the S strain might make a toxin that made mice sick. So, he heated some of the S cells to kill them. Then he injected the heat-killed S cells into mice. The mice survived. This suggested that the pneumonia was not caused by a toxin.

Next Griffith mixed heat-killed S cells with R cells. He injected the mixture into mice. Griffith was surprised because the mice got sick with pneumonia. He found live disease-causing bacteria in some of the dead mice. How did this happen if he had injected dead S cells?

Transformation The heat-killed bacteria had made the harmless bacteria deadly. Griffith wondered if a particular molecule from the deadly strain had changed the harmless R cells into S cells. He called this process **transformation.** If he was right, this molecule was passed along to the transformed bacteria. Identifying the molecule could be the key to understanding heredity.

The Molecular Cause of Transformation What molecule causes transformation? In 1944, a team led by Oswald Avery tried to find out. They thought knowing this molecule would allow them to know what made up genes. Avery and his team took a mixture of molecules out of heat-killed bacteria. They treated this mixture to destroy proteins, lipids, carbohydrates, and RNA, one at a time. Every time, transformation still occurred. But then they tried one more experiment in which they destroyed the DNA. This time, transformation did not happen. They concluded that DNA was the transforming molecule.



Griffith's Experiments Griffith injected mice with four different samples of bacteria. Disease-causing bacteria that had been heat-killed did not kill the mice. Harmless bacteria did not kill the mice. But when the two strains were mixed together, the mice died. Griffith concluded that genetic information could be passed from one bacterial strain to another.

Key Question What clues did bacterial transformation give about the gene? **Avery and other scientists discovered that DNA stores and passes genetic information from one generation of bacteria to the next.**

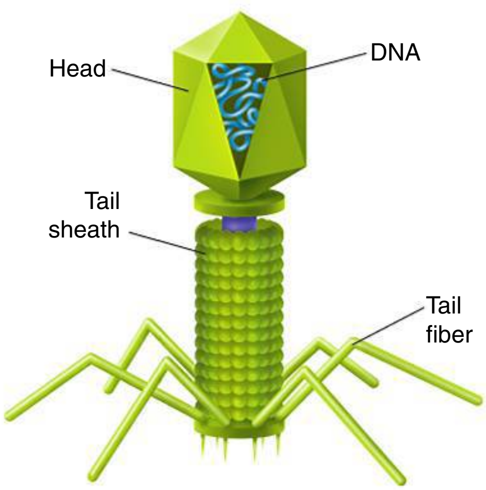
Bacterial Viruses

Other scientists tried to confirm Avery's discovery. In 1952, Alfred Hershey and Martha Chase used viruses to study DNA. Viruses are tiny, nonliving particles that can infect living cells.

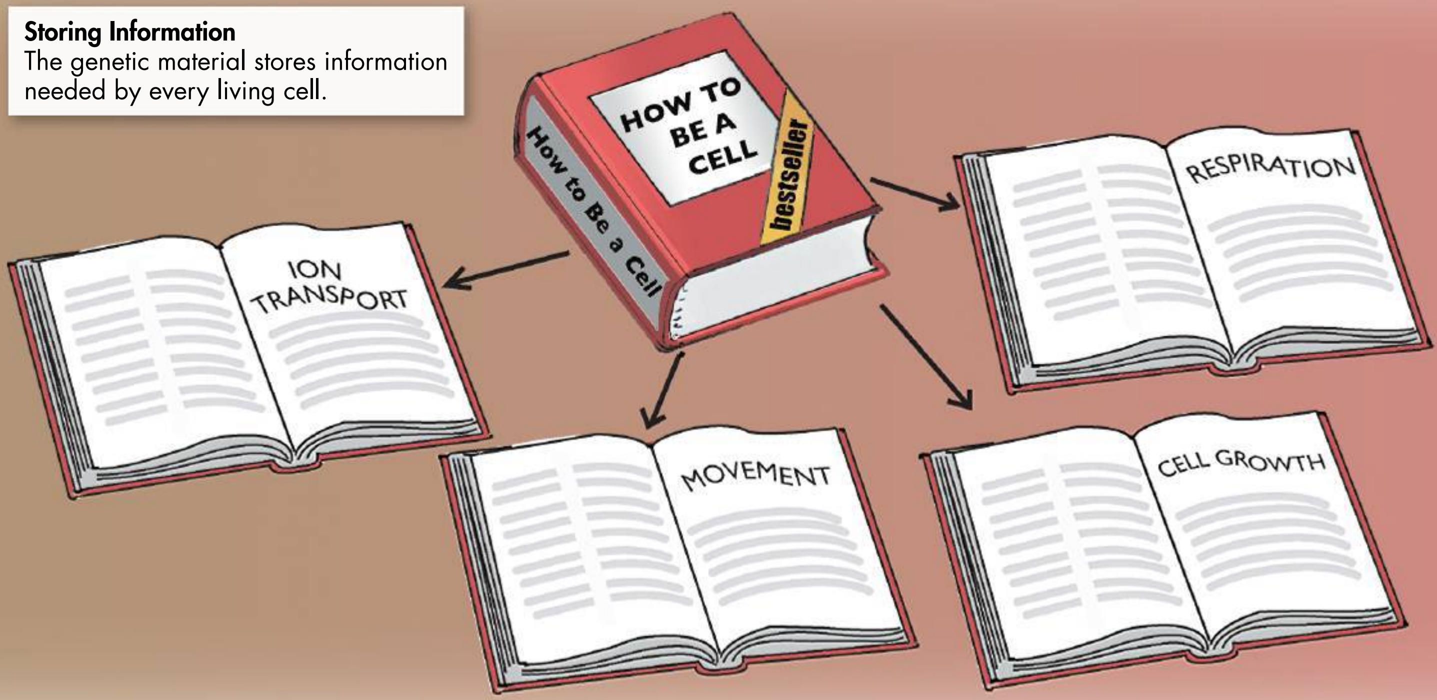
Bacteriophage A **bacteriophage** is a kind of virus that infects bacterial cells. A bacteriophage sticks to the surface of the cell and injects its genetic information into it. The viral genes make many new bacteriophages, which destroy the bacterium. When the cell splits open, hundreds of new viruses burst out.

The Hershey-Chase Experiment Hershey and Chase used a bacteriophage that had a DNA core and a protein coat. They wanted to find out which part of the virus—the protein coat or the DNA core—entered bacterial cells. They made different parts of these viruses radioactive using two different tags. They used radioactive ^{35}S to tag the protein coats. They used radioactive ^{32}P to tag the DNA. Then, they infected bacterial cells with the viruses. After infection, Hershey and Chase separated the bacteria from the viruses. What they found was that the bacteria had received ^{32}P from the DNA but not ^{35}S from the coat. This finding confirmed that DNA is the molecule of heredity.

T4 Bacteriophage



Key Question What role did bacterial viruses play in identifying genetic material?
Hershey and Chase's experiment with bacteriophages confirmed Avery's results, convincing many scientists that DNA was the genetic material found in genes.



BUILD Connections

THE MAIN FUNCTIONS OF DNA

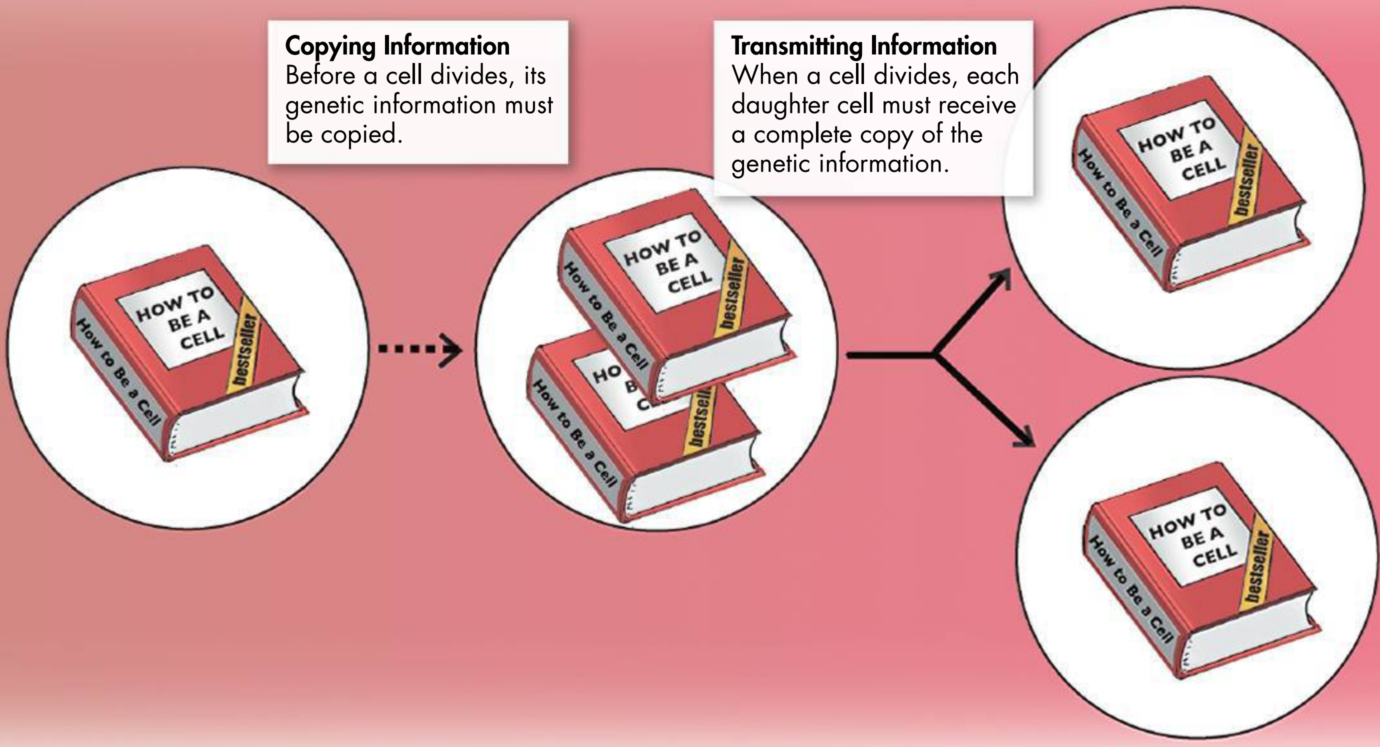
Like DNA, the book in this diagram contains coded instructions for a cell to carry out important biological processes. The book, like DNA, can also be copied and passed along to the next generation. These three tasks—storing, copying, and passing on information—are also the three main functions of DNA.

The Role of DNA

After scientists learned that genes were made of DNA, they had another question. How could DNA do all the things that genes were known to do? The DNA that makes up genes must be capable of storing, copying, and passing on the genetic information in a cell. These three functions are similar to the way you might share an important book.

Storing Information The main job of DNA is to store information. The genes that make a flower purple must carry the information needed to make purple pigment. Genes for blood type and eye color must have the information needed for their jobs, as well. Other genes have to do even more. Genes control patterns of development. The instructions that cause a single cell to develop into an oak tree, a goldfish, or a dog must be written into the DNA of each of these organisms.

Copying Information A cell must make a complete copy of every one of its genes before the cell divides. After the experiments of Avery, Hershey, and Chase, scientists wanted to know how DNA is copied. The answer to this puzzle had to wait until the scientists could figure out the structure of DNA. Within a few weeks of learning DNA's structure, scientists suggested a way DNA could be copied. You will learn about this mechanism later in the chapter.



Transmitting Information Mendel's work showed that genes are passed down from parents to offspring. Therefore, DNA molecules must be carefully sorted and passed along when cells divide. Such careful sorting is especially important when reproductive cells are made in meiosis. Remember, the chromosomes of eukaryotic cells contain genes made of DNA. The loss of any DNA during meiosis might mean a loss of valuable genetic information that offspring might need to survive.

Key Question What is the role of DNA in heredity?
The DNA that makes up genes must be capable of storing, copying, and passing on the genetic information in a cell.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A _______ is a virus that infects bacteria.

2. _______ is a process that changes the nature of cells.

Critical Thinking

3. Review Define *transformation.*

4. Review Briefly describe how Avery and his group determined which molecule was most important for transformation.

5. Review What are the three key roles of DNA?

6. Quick Write Create a time line that shows the sequence of the scientific discoveries in this lesson.

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12.2 The Structure of DNA

Key Questions

What are the chemical parts of DNA?

What clues helped scientists solve the structure of DNA?

What does the double-helix model tell us about DNA?

BUILD Understanding

T-Chart Make a T-chart with all the green and blue headings in the left column. As you read, find the key ideas for each heading. Write down a few key words from each main idea in the right column.

In Your Workbook Go to your workbook to learn more about T-charts. Finish the chart for Lesson 12.2.

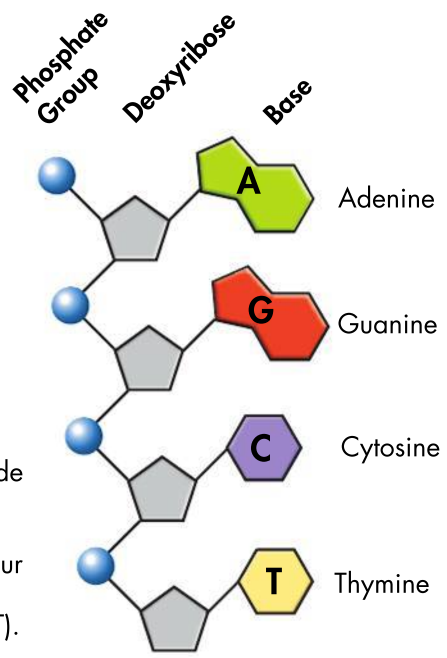
The Components of DNA

Deoxyribonucleic acid, or DNA, can be copied and passed from one generation to the next. It also specifies how proteins are made. These features make DNA a very special molecule. DNA also has a special structure. Understanding the structure of DNA is the key to understanding how genes work.

DNA is a nucleic acid made up of nucleotides joined into long strands or chains by covalent bonds. Let's look at each of these parts more closely.

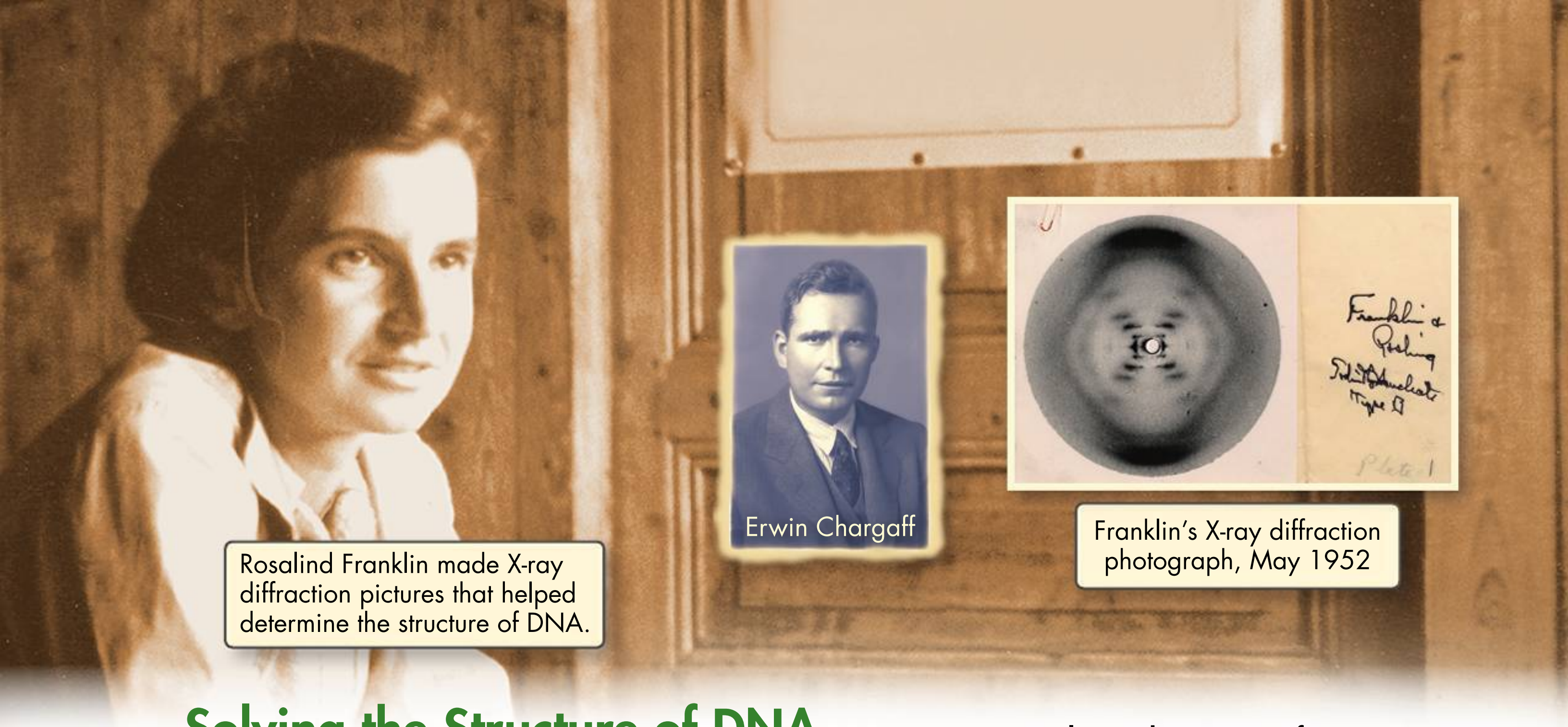
Nucleic Acids and Nucleotides Nucleic acids are long molecules found in cell nuclei. Like other big molecules, nucleic acids are made up of smaller subunits, or parts. These parts are linked together to form long chains. Nucleotides are the building blocks of nucleic acids. These nucleotides are made up of three basic parts: a 5-carbon sugar called deoxyribose, a phosphate group, and a nitrogenous base.

Nitrogenous Bases and Covalent Bonds Nitrogenous bases are bases that have nitrogen in them. DNA has four kinds of nitrogenous bases: adenine (AD uh neen) guanine (GWAH neen), cytosine (SY tuh zeen), and thymine (THY meen). Biologists often refer to the nucleotides in DNA by the first letters of their base names: A, G, C, and T. The nucleotides in a strand of DNA are joined by covalent bonds formed between the sugar of one nucleotide and the phosphate group of the next. The nitrogenous bases stick out sideways from the nucleotide chain. The nucleotides can be joined together in any order. So, any order of bases is possible. The structure of DNA makes it very good at absorbing ultraviolet (UV) light. This property is one way that scientists can measure the amount of DNA in a solution.



DNA Nucleotides DNA is made up of nucleotides. Each nucleotide has a deoxyribose molecule, a phosphate group, and a nitrogen-containing base. The four bases are adenine (A), guanine (G), cytosine (C), and thymine (T).

Key Question What are the chemical parts of DNA?
DNA is a nucleic acid made up of nucleotides joined into long strands or chains by covalent bonds.



Rosalind Franklin made X-ray diffraction pictures that helped determine the structure of DNA.

Erwin Chargaff

Franklin's X-ray diffraction photograph, May 1952

Solving the Structure of DNA

Knowing that DNA is made from long chains of nucleotides was only the beginning of understanding the structure of this molecule. The next step was to figure out how those chains are arranged.

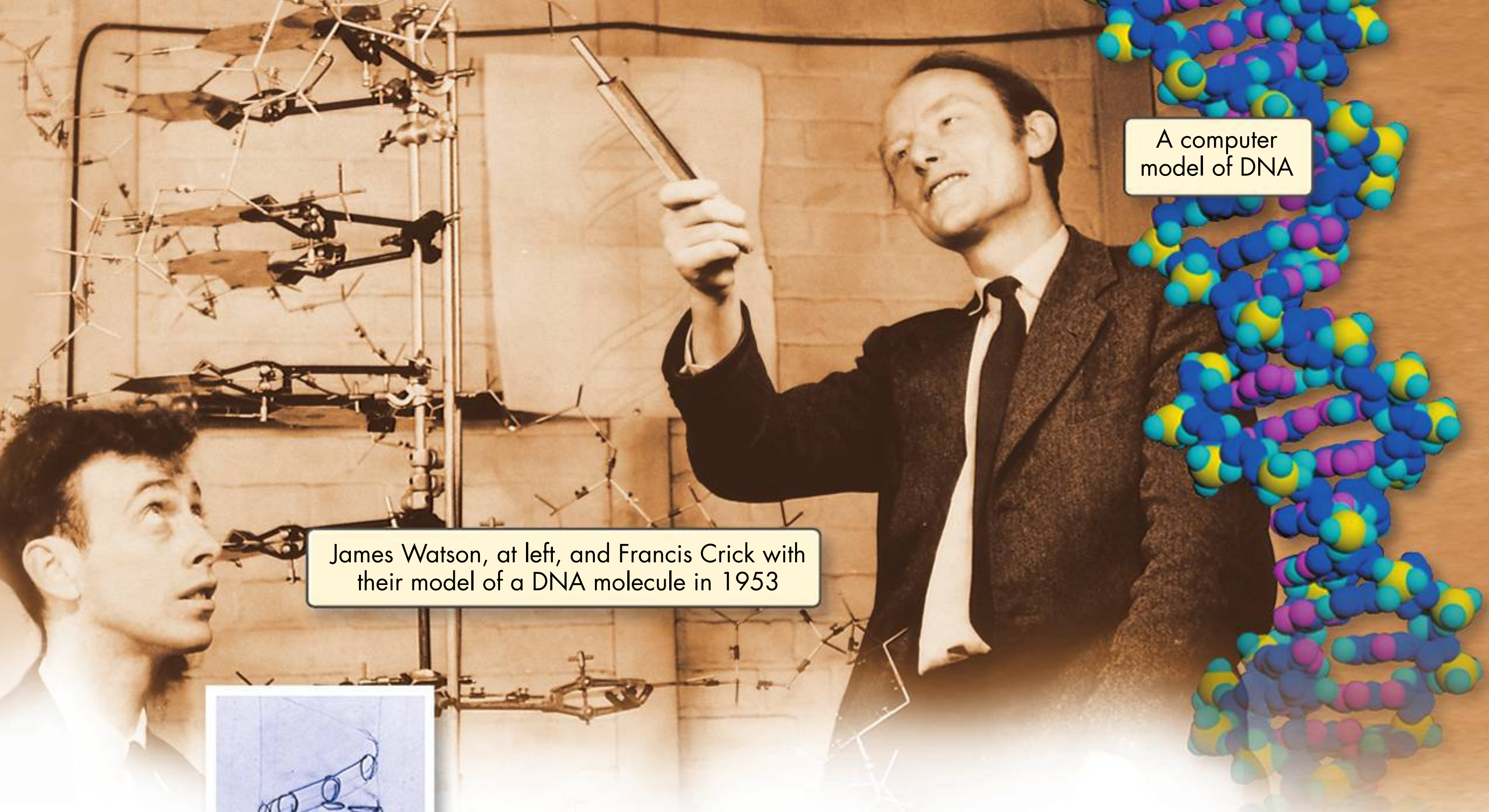
Chargaff's Rule Erwin Chargaff had discovered years earlier that the percentages of adenine [A] and thymine [T] bases are almost equal in any sample of DNA. The same thing is true for guanine [G] and cytosine [C]. The observation that [A] = [T] and [G] = [C] became known as "Chargaff's rule." DNA samples from organisms as different as bacteria and humans obeyed this rule. However, no one knew why they did.

Franklin's X-Rays In the early 1950s, Rosalind Franklin began to study DNA. She used a technique called X-ray diffraction to get information about the structure of the DNA molecule. Her X-ray pictures showed that the strands in DNA are twisted around each other. This shape is known as a helix. She also showed that DNA is made of two strands. Other clues suggested that the nitrogenous bases are near the center of the DNA molecule.

The Work of Watson and Crick Meanwhile, James Watson and Francis Crick were also trying to understand the structure of DNA. They tried to build models of DNA out of cardboard and wire. Nothing worked. The pieces did not fit. Then, in 1953, Watson saw a copy of Franklin's X-ray picture. Immediately, he realized that it was the missing piece of the puzzle. Watson rushed back to tell Crick about the picture, and a few weeks later they had solved the structure of DNA.

Key Question What clues helped scientists solve the structure of DNA? **The clues in Franklin's X-ray pattern allowed Watson and Crick to build a model that explained the specific structure and properties of DNA.**

Clues to the Structure of DNA Erwin Chargaff and Rosalind Franklin both helped solve the puzzle of the structure of DNA.



A computer model of DNA

James Watson, at left, and Francis Crick with their model of a DNA molecule in 1953

Crick's original sketch of DNA

A Double Helix Watson and Crick determined that DNA has the structure of a double helix.

The Double-Helix Model

DNA is a double helix. A double helix looks like a twisted ladder. In the double-helix model of DNA, the two strands twist around each other like spiral staircases. Watson and Crick realized that the double helix explained Franklin's X-ray pattern. The shape also explains many of the most important properties of DNA. The double-helix model explains the reasons behind Chargaff's rule. It also explains how the two strands of DNA are held together. This model can even tell us how DNA carries genetic information.

Antiparallel Strands One of the surprising discoveries of the double-helix model is that the two strands of DNA run in opposite directions. As biochemists say, these strands are "antiparallel." Because of this arrangement, the nitrogenous bases on both strands meet at the center of the molecule. The structure also allows each strand of the double helix to carry a sequence of nucleotides. These bases are arranged almost like letters in a four-letter alphabet.

Hydrogen Bonding At first, Watson and Crick could not explain what forces held the two strands of DNA's double helix together. Then, they discovered that hydrogen bonds could form between certain nitrogenous bases. Hydrogen bonds are fairly weak forces. These bonds have just enough force to hold the two strands of DNA together.

Why would a molecule as important as DNA be held together by weak bonds? Well, if the two strands of the helix were held together by strong bonds, it might not be possible to pull them apart. As we will see, DNA's strands have to be able to separate easily to function.

Base Pairing Watson and Crick's DNA model showed that hydrogen bonds could hold the bases together along the center of the molecule. However, these bonds would form only between certain base pairs. Adenine paired with thymine, and guanine paired with cytosine. This nearly perfect fit between A–T and G–C nucleotides is known as **base pairing.**

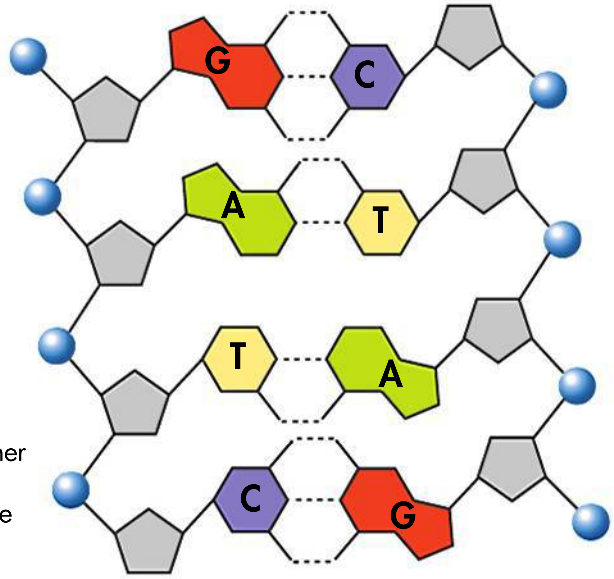
Once they discovered the fit between bases, Watson and Crick realized that base pairing explained Chargaff's rule. It gave a reason why [A] = [T] and [G] = [C]. For every adenine in a double-stranded DNA molecule, there has to be one thymine. For each guanine, there is one cytosine. Their model explained Chargaff's observations. It also accounted for Rosalind Franklin's findings. At last, Watson and Crick were confident that they had come to the right conclusion.

Key Question What does the double-helix model tell us about DNA?
The double-helix model explains Chargaff's rule of base pairing and how the two strands of DNA are held together.

BUILD Vocabulary

base pairing
the principle that bonds in DNA can form only between adenine and thymine and between guanine and cytosine

WORD ORIGINS
The word *base* is from the Greek word *basis*, meaning "foundation" or "step."



Base Pairing The two strands of DNA are held together by hydrogen bonds. The bonds here are represented by the dashes between the nitrogenous bases adenine and thymine, and between guanine and cytosine.

CHECK Understanding

Apply Vocabulary

1. The principle of _______ states that bonds in DNA can form only between adenine and thymine and between guanine and cytosine.

Critical Thinking

2. Review List the chemical components of DNA.

3. Relate Cause and Effect Why are hydrogen bonds so important to the structure of DNA?

4. Review Describe the discoveries that led to the modeling of DNA.

5. Review Describe Watson and Crick's model of the DNA molecule.

6. Write to Learn Answer the first mystery clue.

MYSTERY CLUE

The energy from UV light can excite electrons in a substance. The excited electrons can cause chemical changes. What chemical changes might occur in the nitrogenous bases of DNA? (**Hint:** See p. 294.)

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12.3 DNA Replication

Key Questions

What role does DNA polymerase play in copying DNA?

How does DNA replication differ in prokaryotic cells and eukaryotic cells?

BUILD Understanding

Preview Visuals Before you read, study the DNA Replication figure on the next page. Make a list of questions about the figure. As you read, write down the answers to your questions.

In Your Workbook Go to your workbook to learn more about previewing visuals.

BUILD Vocabulary

replication
the process of copying DNA prior to cell division

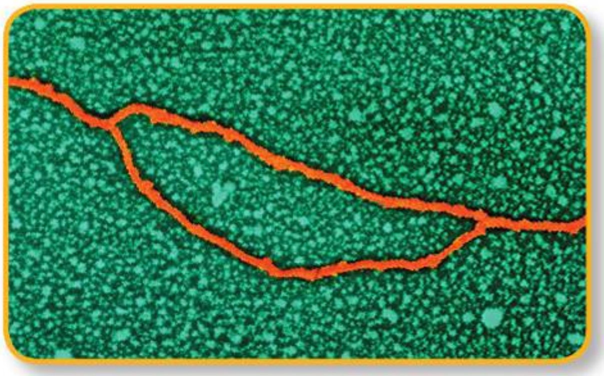
USE SUFFIXES
The suffix *-tion* means "process of." A replica is a copy. So, replication is the process of making a copy.

Copying the Code

When Watson and Crick discovered the structure of DNA, they immediately recognized something important. Each strand of the double helix has all the information needed to make the other strand. Because each strand can be used to make the other strand, the strands are said to be complementary.

The Replication Process Before a cell divides, it makes a copy of its DNA in a process called **replication.** Replication makes sure that each daughter cell has the same complete set of DNA molecules. During replication, the DNA molecule first separates into two strands. Then, the process makes two new strands following the rules of base pairing. Each strand of the double helix of DNA is a template, or model, for making the new strand.

The two strands of the double helix separate, the same way two sides of a zipper come apart. This separation makes two replication forks. As each new strand forms, new bases are added following the rules of base pairing. Adenine (A) is always paired with thymine (T). Guanine (G) is always paired to cytosine (C). For example, a strand that has the base sequence TACGTT makes a strand with the base sequence ATGCAA. The end result is two DNA molecules. Each is identical to the other and to the original DNA molecule.



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Replication Forks The DNA molecule comes apart the way the two sides of a zipper come apart. The result is two areas called replication forks, where the DNA molecule can be copied. This micrograph shows a pair of replication forks in human DNA.

The Role of Enzymes DNA replication is carried out by special proteins called enzymes. These enzymes pull apart a molecule of DNA. They break the hydrogen bonds between base pairs. Then, they unwind the two strands. Each strand then serves as a template for making a new strand. The main enzyme involved in DNA replication is called **DNA polymerase** (PAHL ih mur ayz). DNA polymerase is an enzyme that joins individual nucleotides to make a new strand of DNA. DNA polymerase produces the sugar-phosphate bonds that join nucleotides together to form the new strands. DNA polymerase also checks each new DNA strand, so that each molecule is a close copy of the original.

Key Question What role does DNA polymerase play in copying DNA?
DNA polymerase is an enzyme that joins individual nucleotides to produce a new strand of DNA.

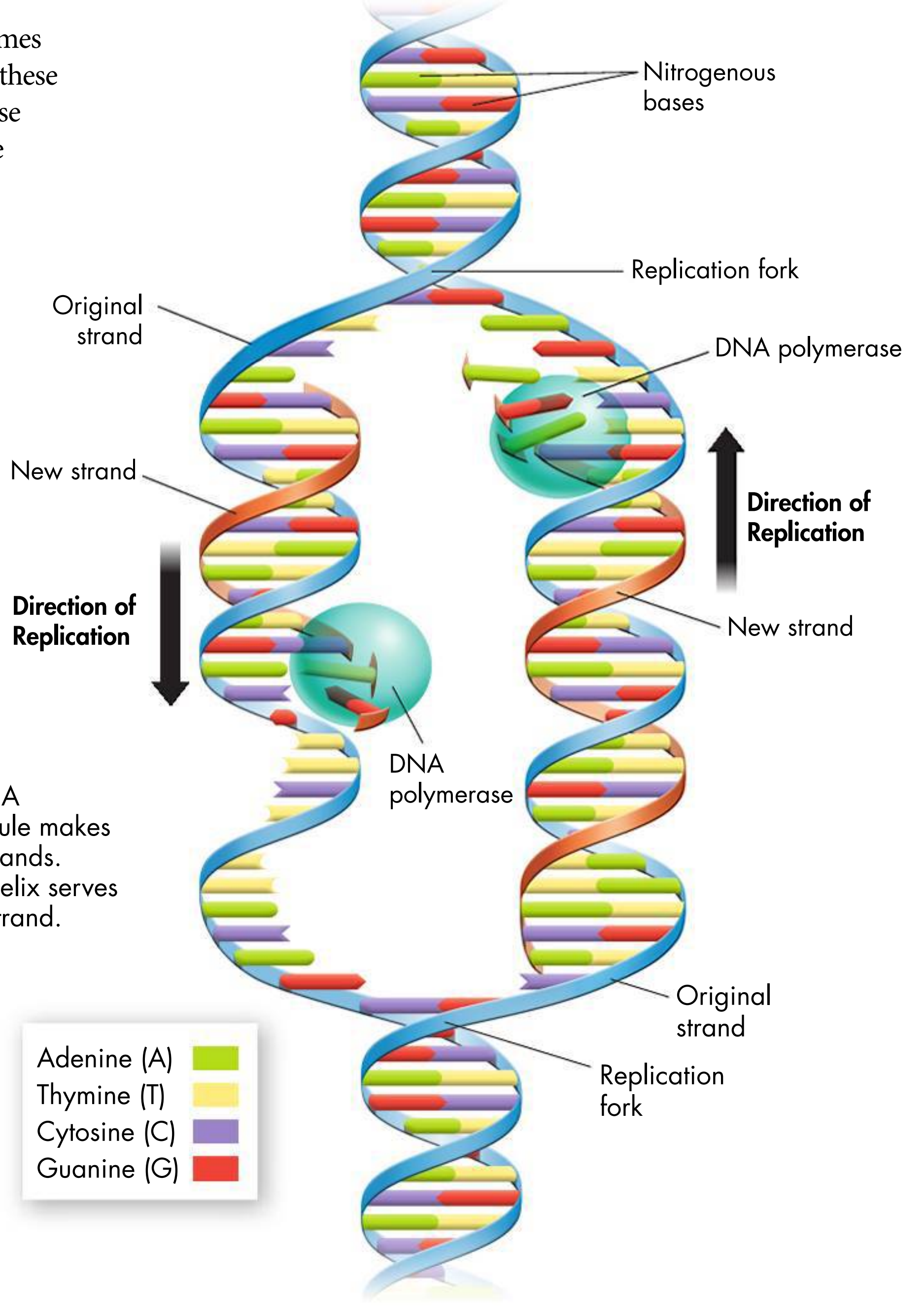
Telomeres The tips of chromosomes are known as **telomeres.** DNA in these regions is hard to replicate. Cells use a special enzyme called telomerase to fix this problem. Telomerase makes it less likely that genes will be damaged or lost during replication of rapidly dividing cells. Telomerase is often switched off in normal adult cells. But, in cancer cells, telomerase may be switched on. This may be one of the reasons why cancer cells are able to grow and divide rapidly.

BUILD Vocabulary

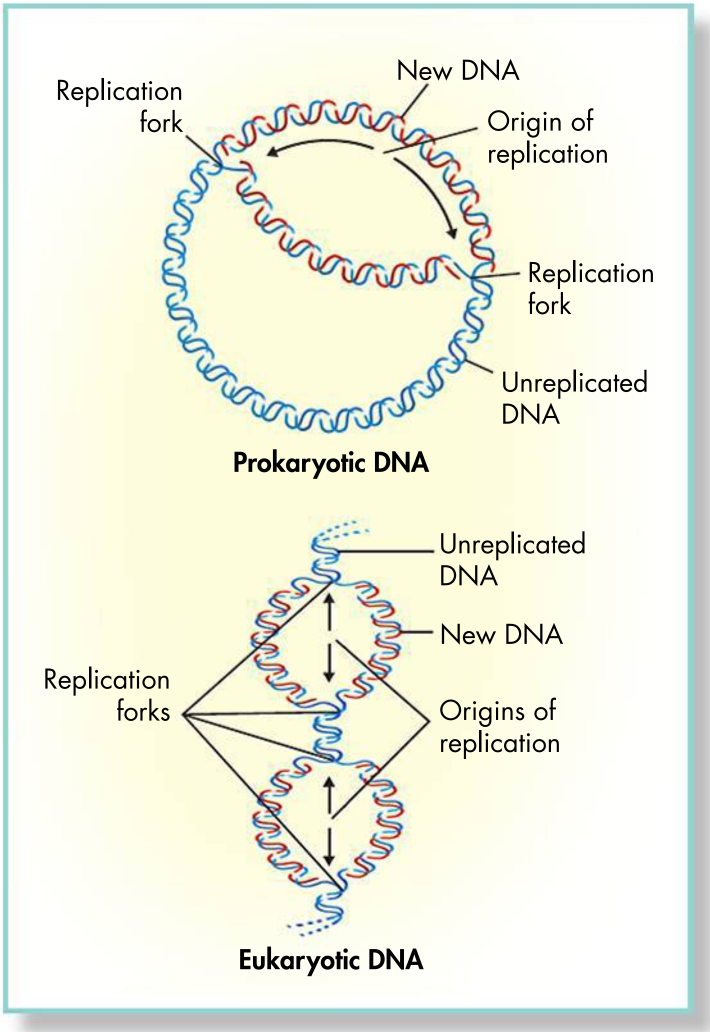
DNA polymerase
the principal enzyme involved in DNA replication

telomere
repetitive DNA at the end of a eukaryotic chromosome

PREFIXES
The prefix *telo-* means "end." The root *-mere* means "part." The telomere is the end part of the chromosome.



DNA Replication During DNA replication, the DNA molecule makes two new complementary strands. Each strand of the double helix serves as a template for the new strand.



Differences in DNA Replication Replication in most prokaryotic cells (top) begins at one point and goes in two directions until the entire DNA ring is copied. In eukaryotic cells (bottom), replication happens at many starting points on chromosomes. Replication ends when all the chromosomes are copied.

Replication in Living Cells

Where is DNA found inside a cell? The cells of most prokaryotes have a single, ring-shaped DNA molecule in the body of the cell. This ring contains almost all of the cell's genetic information. Eukaryotic cells have much more DNA. Their DNA is found in chromosomes in the nucleus.

Prokaryotic DNA Replication In most prokaryotes, DNA replication starts when special proteins bind to one starting point on the chromosome. Replication usually goes in two directions until the whole chromosome is copied. Often, the two chromosomes made by replication are attached to different points inside the cell membrane. They are separated when the cell splits to make two new cells.

Eukaryotic DNA Replication Eukaryotic chromosomes are bigger than those of prokaryotes. In eukaryotic cells, replication may begin at many places on the DNA. Replication moves in both directions. Proteins check to make sure the copies are accurate. However, mistakes happen, and then the order of the bases in DNA changes. When the base order changes, the information on a gene may change. Sometimes this can have serious consequences.

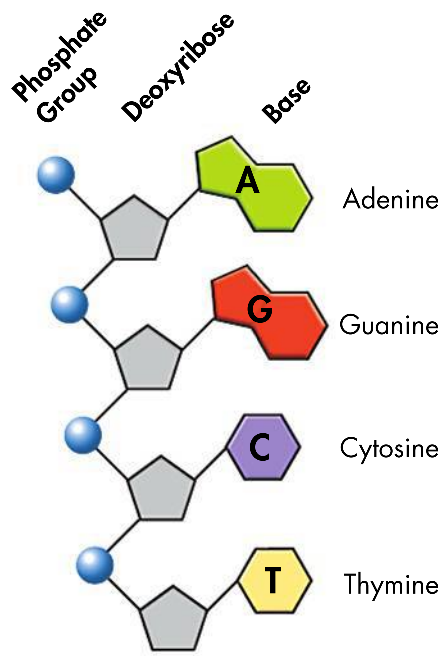
As you learned in Chapter 10, the chromosomes stay together until anaphase of mitosis. Then, the chromosomes separate, and each new cell has a complete set of genes coded in DNA.

Key Question How does DNA replication differ in prokaryotic cells and eukaryotic cells?
In most prokaryotic cells, replication starts from a single point, and it continues in two directions until the whole chromosome is copied. In eukaryotic cells, replication may begin in hundreds of places on the DNA molecule. Replication then occurs in both directions until each chromosome is completely copied.

INQUIRY into Scientific Thinking

Modeling DNA Replication

1. Cut out small squares of blue and gray paper to represent phosphate and sugar molecules.
2. Cut out small strips of purple, green, red, and yellow paper to represent the four nitrogenous bases.
3. Build a set of five nucleotides using your paper strips and tape.
4. Using your nucleotides, tape together a single strand of DNA. For example you could make a pattern of bases that reads, “ATTGC.”
5. Exchange your paper strand with a partner’s strand.
6. Model DNA replication by creating a strand that is complementary to your partner’s original strand.



Analyze and Conclude

1. Use Models When you taped the nucleotides together, what enzyme were you modeling?

2. Analyze How does your model follow Chargaff’s rule?

3. Evaluate How does your model differ from real DNA?

In Your Workbook Get more help for this activity in your workbook.

CHECK Understanding

Apply Vocabulary

Use the highlighted word from the lesson to complete the sentence correctly.

1. _______ are the tips of chromosomes.

2. _______ is the primary enzyme used in DNA replication.

Critical Thinking

3. Review How is DNA replicated?

4. Apply Concepts What is the role of DNA polymerase in DNA replication?

5. Compare and Contrast How is replication in eukaryotic cells different from replication in prokaryotic cells?

6. Write to Learn Answer the mystery clue.

MYSTERY CLUE

UV light can cause chemical changes in bases. How might these chemical changes in bases affect the process of DNA replication? (Hint: See p. 297.)

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Skills Lab

GUIDED INQUIRY

Pre-Lab: Extracting DNA

Problem What properties of DNA can you observe when you extract DNA from cells?

Materials self-sealing plastic freezer bag, ripe strawberry, detergent solution, 25-mL graduated cylinder, cheesecloth, funnel, test tube, test tube rack, chilled ethanol, stirring rod

Lab Manual Chapter 12 Lab

Skills Focus Predict, Observe, Draw Conclusions

Connect to the Big idea Not surprisingly, the molecules that store genetic information are long molecules. If the DNA from a human cell were unfolded, the double helix structure would be about one meter long. Yet, most of a cell's DNA can be folded and tightly packed inside the cell's tiny nucleus. How can scientists remove DNA from the nucleus so that it can be studied and analyzed? In this lab, you will learn that extracting DNA from living tissue is not as difficult as you might think.

Background Questions

a. **Review** Describe the structure of a DNA molecule.

b. **Review** What type of bond holds the strands of DNA together?

c. **Apply Concepts** How does the strength of those bonds affect how DNA functions?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Apply Concepts** Why do strawberry cells need DNA?
2. **Form a Hypothesis** If you observe a cell nucleus under a compound microscope, you will not see a molecule of DNA. Why will you be able to see the DNA you extract?
3. **Predict** Use what you know about DNA to predict some of the physical properties of DNA.
4. **Design an Experiment** How could you determine what percentage of a strawberry's mass is DNA?

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Visit Chapter 12 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video The Untamed Science CSI crew unravels the secrets of DNA left at the scene of a crime.

Art in Motion View an animation that re-creates the Hershey-Chase experiments.

Art Review Review your understanding of both prokaryotic and eukaryotic DNA replication.

InterActive Art Drag-and-drop base pairs to build your own strand of DNA while you practice the process of DNA replication.

Tutor Tube Tune into the tutor to find out hints for remembering which bases pair together.

Visual Analogy Compare transcription and translation with the process of publishing a book.

12 CHAPTER Summary

12.1 Identifying the Substance of Genes

- By studying bacterial transformation, Avery and other scientists discovered that DNA stores and passes genetic information from one generation of bacteria to the next.
- Hershey and Chase's experiment with bacteriophages confirmed Avery's results, convincing many scientists that DNA was the genetic material found in genes.
- The DNA that makes up genes must be capable of storing, copying, and transmitting the genetic information in a cell.

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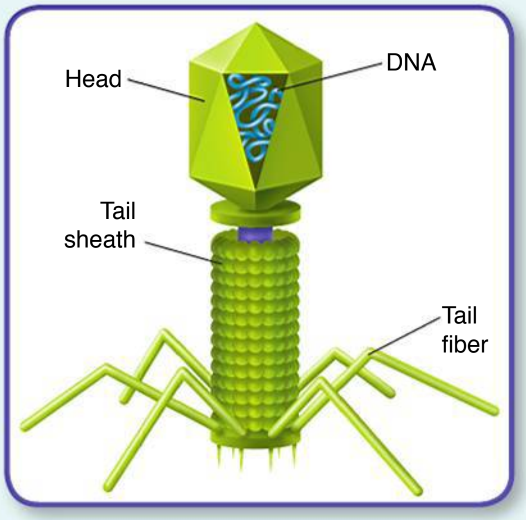
transformation (p. 288)
bacteriophage (p. 289)



12.2 The Structure of DNA

- DNA is a nucleic acid made up of nucleotides joined into long strands or chains by covalent bonds.
- The clues in Franklin's X-ray pattern allowed Watson and Crick to build a model that explained the specific structure and properties of DNA.
- The double-helix model explains the reasons behind Chargaff 's rule and how the two strands of DNA are held together.

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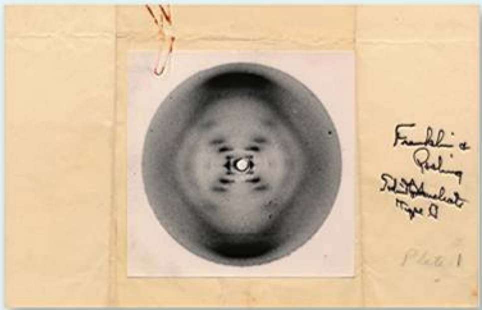
base pairing (p. 295)



12.3 DNA Replication

- DNA polymerase is an enzyme that joins individual nucleotides to produce a new strand of DNA.
- In most prokaryotic cells, replication starts from a single point, and it continues in two directions until the entire chromosome is copied.
- In eukaryotic cells, replication may begin in hundreds of places on the DNA molecule. Replication then moves in both directions until each chromosome is completely copied.

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replication (p. 296)
DNA polymerase (p. 297)
telomere (p. 297)

12 CHECK Understanding

Assess the Big idea — Information and Heredity, Cellular Basis of Life

Write an answer to the question below.

Q: What is the structure of DNA, and how does it function in genetic inheritance?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs. To help you begin, read the **Hints** below the questions.

1. **How did Hershey and Chase confirm that genetic material was a nucleic acid?**

   Hint Bacteriophages are viruses that infect bacteria.

   Hint Viruses have a protein coat around a nucleic acid core.

2. **How did Chargaff's rule help Watson and Crick determine the structure of DNA?**

   Hint Adenine always pairs with thymine, and cytosine always pairs with guanine.

3. **If a change happens in the genetic code in the gamete of a eukaryotic parent, will offspring have that change, too?**

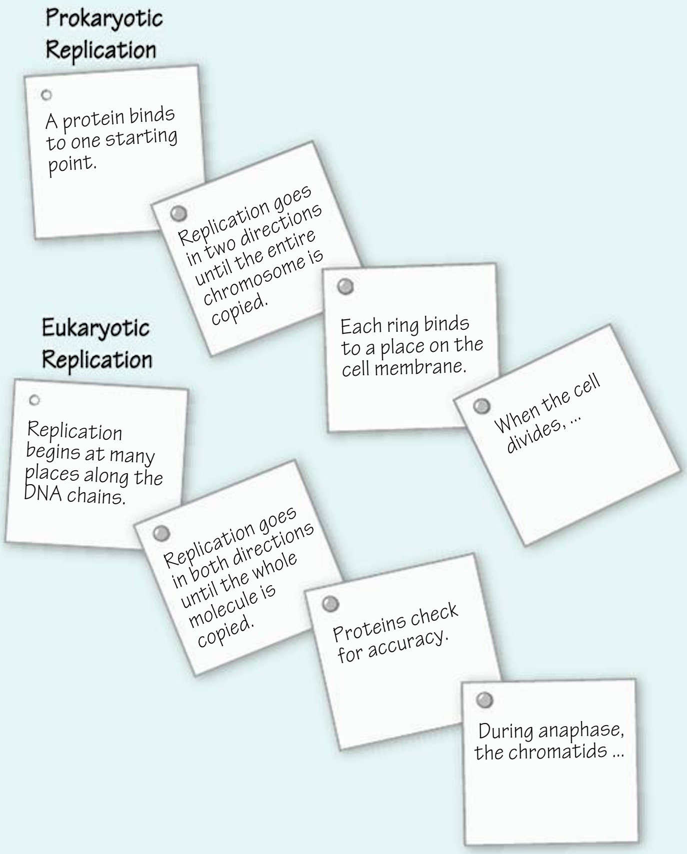
   Hint Changes in the genetic code can sometimes be copied when the DNA is copied.

Foundations for Learning Wrap-Up

Use the Connected Ideas cards you made as you read the chapter to help you organize your thoughts about DNA structure and replication.

Activity 1 Combine your cards with the cards of a partner. Using as many cards you can, make a time line of the history of the discoveries that led to understanding the structure of DNA.

Activity 2 With a partner, make cards to complete the two chains of connected ideas shown below. One chain shows the process of DNA replication in eukaryotes. The other chain shows the process of DNA replication in prokaryotes.



12.1 Identifying the Substance of Genes

Understand Key Concepts

1. The process by which one strain of bacterium is apparently changed into another strain is called
   a. transcription.
   b. transformation.
   c. duplication.
   d. replication.

> ### Test-Taking Tip
> **Use Root Words** As you read the answers, look for root words to help you choose the correct answer. The root words for the answers in question 1 are *transcrip*, *transform*, *duplica*, and *replica*. Remember that *transform* means "to change." Now read the question again. The question asks which process changed one strain of bacterium. You know that transformation means change, so **b** is the correct answer.

2. Bacteriophages are
   a. a form of bacteria.
   b. enzymes.
   c. coils of DNA.
   d. viruses.
3. Before DNA could be shown to be the genetic material in cells, scientists had to show that it could
   a. tolerate high temperatures.
   b. carry and make copies of information.
   c. be modified in response to environmental conditions.
   d. be broken down into small subunits.
4. Briefly describe the conclusion that could be drawn from the experiments of Frederick Griffith.

Think Critically

5. **Evaluate** Avery and his team identified DNA as the molecule that caused transformation. How did they control variables in their experiment to make sure that only DNA caused the change?

12.2 The Structure of DNA

Understand Key Concepts

6. A nucleotide does NOT contain a
   a. 5-carbon sugar.
   b. protein.
   c. nitrogen base.
   d. phosphate group.
7. According to Chargaff's rule of base pairing, which of the following is true about DNA?
   a. A = T, and C = G
   b. A = C, and T = G
   c. A = G, and T = C
   d. A = T = C = G
8. The bonds that hold the two strands of DNA together come from
   a. the attraction of phosphate groups for each other.
   b. strong bonds between nitrogenous bases and the sugar-phosphate backbone.
   c. hydrogen bonds between nitrogenous bases.
   d. carbon-to-carbon bonds in the sugar portion of the nucleotides.
9. Describe the parts and structure of a DNA nucleotide.

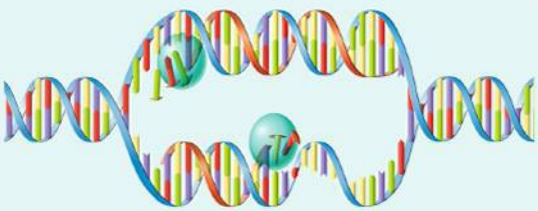
Think Critically

10. **Infer** Adenine and guanine are longer than thymine and cytosine. What would happen to the parallel strands if adenine were paired with guanine?

12.3 DNA Replication

Understand Key Concepts

11. The diagram below shows the process of DNA
    a. replication.
    b. digestion.
    c. transformation.
    d. transpiration.



12 CHECK Understanding

12. What is meant by the term *base pairing*?

13. Explain the process of replication. When a DNA molecule is replicated, how do the new molecules compare to the original molecule?

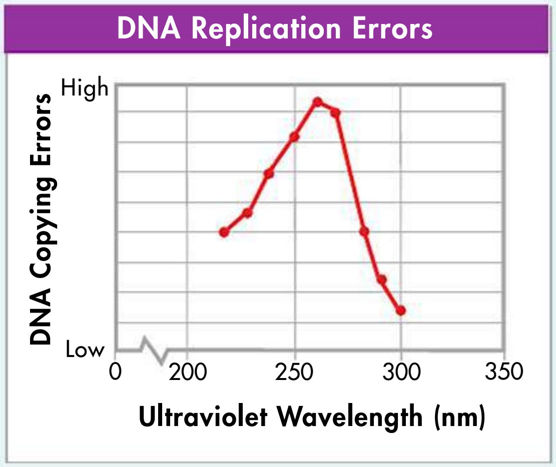
Think Critically

14. **Use Analogies** How is photocopying a page similar to DNA replication? Think of the original materials, the copying process, and the final products. Explain how the two processes are alike. Identify major differences.

Connecting Concepts

Use Science Graphics

A scientist studied the effect of exposing DNA to various wavelengths of ultraviolet light. The scientist determined the number of copying errors made after exposure to ultraviolet rays. The graph shows the results. Use the graph to answer questions 15 and 16.



15. **Interpret Graphs** The most damaging effects of ultraviolet light on DNA replication occur closest to which wavelength?
    a. 200
    b. 250
    c. 300
    d. 350

16. **Infer** What conclusion would you draw from the graph about the effect of ultraviolet light on living organisms?

solve the CHAPTER MYSTERY

UV LIGHT

Nucleotides are small parts that are linked together to make the larger DNA molecule. The three parts of each nucleotide include a nitrogenous base—adenine, cytosine, guanine, or thymine (A, C, G, or T). The energy of ultraviolet light can cause chemical changes between the nitrogenous bases in DNA.

1. **Predict** Think about the structure of DNA. What sorts of problems could too much UV light cause in the DNA molecule? How might these changes affect the way DNA works?

2. **Relate Cause and Effect** Analyze the effects that UV light might have on skin cells. Why is UV light so dangerous? Why is the skin particularly vulnerable to it?

UntamedScience™ **Never Stop Exploring Your World.** Finding the connection between UV light and DNA is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. During replication, which sequence of nucleotides would bond with the DNA sequence TATGA?
A TATGA
B ATACT
C CACTA
D AGTAT

2. The scientist(s) responsible for the discovery of bacterial transformation is (are)
A Watson and Crick.
B Avery.
C Griffith.
D Franklin.

3. Which of the following does NOT describe the structure of DNA?
A double helix
B long chain of nucleotides
C contains adenine-guanine pairs
D sugar-phosphate backbone

4. What did Hershey and Chase's work show?
A Genes are probably made of DNA.
B Genes are probably made of protein.
C Viruses contain DNA but not protein.
D Bacteria contain DNA but not protein.

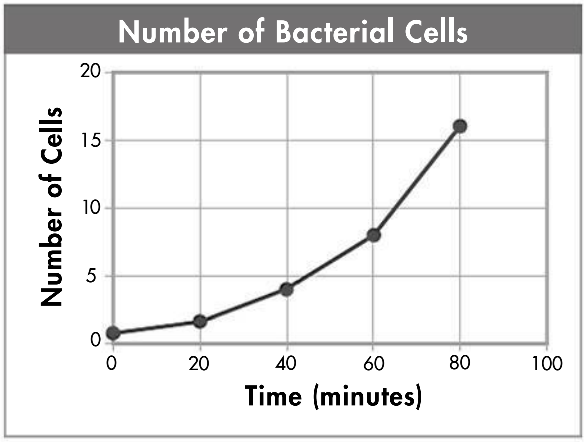
5. The two "backbones" of the DNA molecule consist of
A adenines and sugars.
B phosphates and sugars.
C adenines and thymines.
D thymines and sugars.

6. When prokaryotic cells copy their DNA, replication begins at
A one point on the DNA molecule.
B two points on opposite ends of the DNA molecule.
C dozens to hundreds of points along the molecule.
D opposite ends of the molecule.

7. Compared to eukaryotic cells, prokaryotic cells contain
A much more DNA.
B much less DNA.
C twice as much DNA.
D the same amount of DNA.

Questions 8 and 9

Under ideal conditions, a single bacterial cell can reproduce every 20 minutes. The graph shows how the total number of cells under ideal conditions can change over time.



8. How many cells are present after 80 minutes?
A 1
B 2
C 16
D 32

9. If the DNA of this bacterium is 4 million base pairs in length, how many total molecules of A, T, C, and G are required for replication to be successful?
A 2 million
B 4 million
C 8 million
D 32 million

Open-Ended Response

10. Describe how eukaryotic cells are able to keep such large amounts of DNA in the small volume of the cell nucleus. (**Hint** Review the structure of a chromosome in Chapter 10.)

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	12.3	12.1	12.2	12.1	12.2	12.3	12.3	12.3	12.3	12.3

13 RNA and Protein Synthesis

Big idea: Information and Heredity

Q: How does information flow from DNA to RNA to direct the synthesis of proteins?

BIOLOGY.com Search Chapter 13 GO • Flash Cards

INSIDE:

- 13.1 RNA
- 13.2 Ribosomes and Protein Synthesis
- 13.3 Mutations
- 13.4 Gene Regulation and Expression

CHAPTER MYSTERY

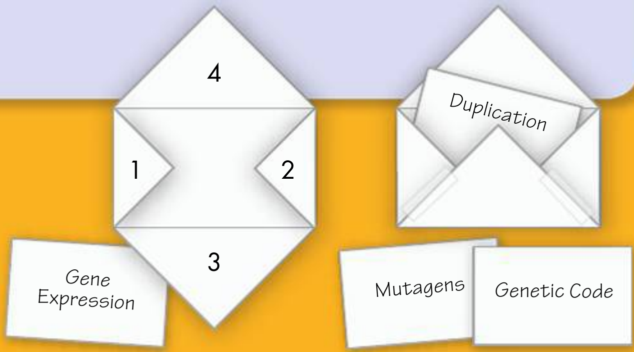
MOUSE-EYED FLY

It was not a science fiction movie. The animal in the lab was real. It had two forward-looking eyes. It also had eyes on its knees and eyes on its hind legs. It even had eyes in the back of its head! Yet, as strange as it looked, this animal was not a monster. It was simply a fruit fly with eyes in very strange places. These eyes looked like the fly's normal compound eyes. However, a mouse gene transplanted into the fly's DNA had made them. How could a mouse gene make extra eyes in a fly?

Read for Mystery Clues This gene normally controls the growth of eyes in mice. As you read, look for clues to explain how it could cause a fly to grow eyes in unusual places. Then, solve the mystery.

FOUNDATIONS for Learning

Create an Important Facts Envelope by drawing and cutting out the shape below. Fold the flaps in order, taping flap 3 to flaps 1 and 2. As you read the chapter, record important facts on slips of paper and put them in the envelope. Facts can include key terms and drawings of processes. The facts and terms can be organized into themes, such as "Mutations." At the end of the chapter are two activities that use the facts to help answer the question: How does information flow from DNA to RNA to direct the synthesis of proteins?



These two Bengal tigers both have abnormal coloring due to genetic mutations. Typical Bengal tigers have dark orange fur with black stripes.

- Untamed Science Video
- Chapter Mystery

13.1 RNA

Key Questions

How does RNA differ from DNA?

How does the cell make RNA?

BUILD Understanding

Preview Visuals Before you read, preview the Transcribing DNA Into RNA figure on the last page of this lesson. Write a prediction of how you think a cell makes RNA. Then, as you read, take notes on how a cell makes RNA. After you read, compare your notes to your prediction.

In Your Workbook Go to your workbook and complete the prediction chart in Lesson 13.1.

The Role of RNA

We know that DNA is the genetic material. We also know that its sequence of nucleotides carries our genetic code. But DNA cannot put genes into action by itself. Ribonucleic acid, or **RNA,** is also needed. RNA, like DNA, is a nucleic acid made of a long chain of nucleotides.

Genes are made of instructions coded into DNA that tell cells how to build proteins. The first step in decoding these instructions is to copy part of the base sequence from DNA into RNA. RNA then uses these instructions to direct the making of proteins. Proteins help to determine an organism's characteristics.

Comparing DNA and RNA There are three important differences between RNA and DNA:
- The sugar in RNA is ribose, not deoxyribose.
- RNA is usually single-stranded, not double-stranded.
- RNA has uracil in place of thymine.

These chemical differences make it easy for enzymes in the cell to tell DNA and RNA apart. You can compare the different roles played by DNA and RNA molecules in the making of proteins to the two types of plans builders use. A master plan has all the information needed to make a building. That plan is valuable. So, builders use only copies of the plan, called blueprints, on the building site. The cell's "master plan" is its DNA, which it uses to prepare RNA "blueprints" for protein synthesis.

BUILD Connections

MASTER PLANS AND BLUEPRINTS

The roles of DNA and RNA molecules are like the two types of plans used by builders. DNA is like the master plan used by builders. RNA is like a cheap, disposable copy of that plan.

In Your Workbook Explore how DNA and RNA act like a cell's master plans and blueprints in Lesson 13.1.

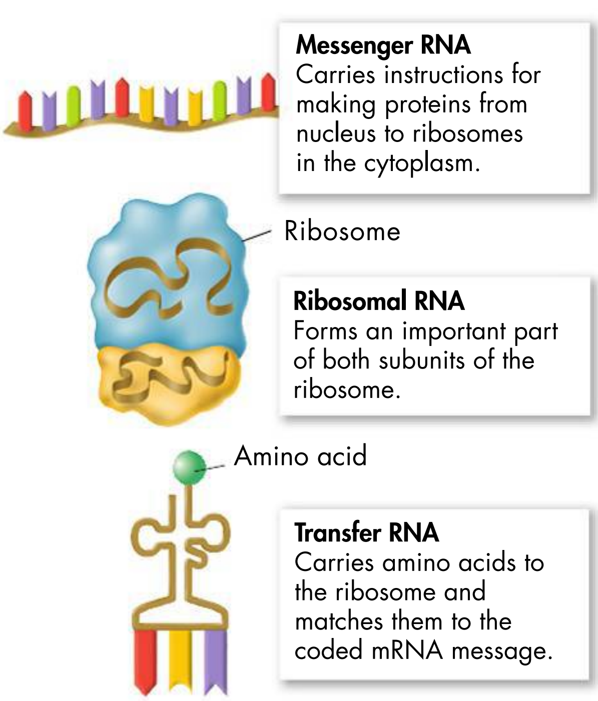
Key Question How does RNA differ from DNA?
There are three main differences between RNA and DNA. The sugar in RNA is ribose instead of deoxyribose. RNA is usually single-stranded and not double-stranded. RNA contains uracil in place of thymine.

Functions of RNA Think of an RNA molecule as a disposable copy of a piece of DNA. It is a working copy of a single gene. RNA has many jobs. But most RNA molecules just make proteins. This process is called protein synthesis. RNA controls how amino acids are made into proteins. There are three main kinds of RNA: messenger RNA, ribosomal RNA, and transfer RNA.

▶ ***Messenger RNA*** Most genes have instructions for assembling amino acids into proteins. **Messenger RNA** (mRNA) molecules carry copies of this information to ribosomes within the cell.

▶ ***Ribosomal RNA*** Proteins are put together on ribosomes. Ribosomes are small organelles made of two parts, or subunits. These subunits have several **ribosomal RNA** (rRNA) molecules and up to 80 different proteins.

▶ ***Transfer RNA*** A third kind of RNA molecule carries amino acids to the ribosome. This kind of RNA molecule is known as **transfer RNA** (tRNA).



Types of RNA The three main types of RNA are messenger RNA, ribosomal RNA, and transfer RNA.

RNA Synthesis

To understand how genes work, we need to learn how cells make RNA using the information found in DNA.

Transcription Most of the work of making RNA takes place during **transcription.** In transcription, RNA molecules are produced that are complementary to the DNA sequences in genes. The order of the RNA bases complements the base sequences of the DNA. In eukaryotes, RNA is made in the cell's nucleus. Then it moves to the cytoplasm to help make proteins.

Transcription requires an enzyme known as *RNA polymerase.* This enzyme is like DNA polymerase and binds to DNA during transcription. It pulls the DNA strands apart. One strand is used as a pattern to make a complementary strand of RNA. Hundreds or even thousands of RNA copies can be made from a single gene.

Key Question How does the cell make RNA?
In transcription, segments of DNA act as templates, or patterns, to make complementary RNA molecules.

BUILD Vocabulary

ribonucleic acid (RNA)
a single-stranded nucleic acid that contains the sugar ribose

messenger RNA
a type of RNA that carries copies of instructions for the assembly of amino acids into proteins from DNA to the rest of the cell

ribosomal RNA
a type of RNA that combines with proteins to form ribosomes

transfer RNA
a type of RNA that carries each amino acid to a ribosome during protein synthesis

transcription
the synthesis of an RNA molecule from a DNA template, or pattern

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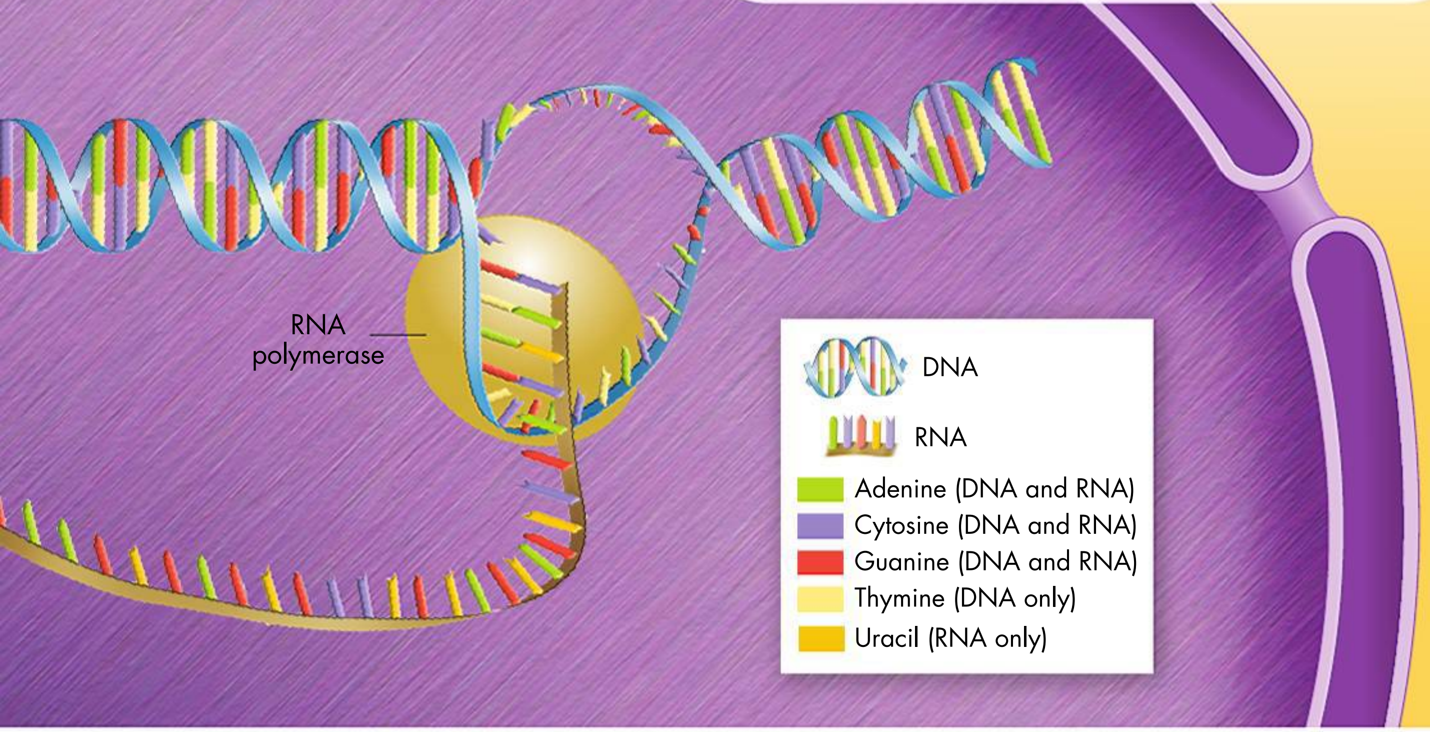
Transcribing DNA Into RNA
During transcription, the enzyme RNA polymerase uses one strand of DNA as a template to put together nucleotides to make a strand of RNA.

Promoters How does RNA polymerase know where to start and stop making a strand of RNA? The enzyme binds only to promoters, regions of DNA that have specific base sequences. Promoters are signals in the DNA that show RNA polymerase exactly where to begin making RNA. Other signals in DNA cause transcription to stop when a new RNA molecule is finished.

RNA Editing Many RNA molecules are edited before they are ready to be used. Bits and pieces called introns are cut out and discarded from these RNAs. The remaining pieces, called exons, are then spliced back together.



CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. ________ carries amino acids.

2. ________ combines with up to 80 proteins to form an important organelle in the cytoplasm.

3. The information from DNA is transcribed into ________ and then carried out of the nucleus.

Critical Thinking

4. Explain Describe three main differences between RNA and DNA.

5. Predict What do you think would happen if introns were not removed from RNA?

6. Quick Write Using the terms *RNA polymerase* and *transcription*, describe how RNA gets made.

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13.2 Ribosomes and Protein Synthesis

The Genetic Code

The DNA bases in genes are like a code. You have to know the code to understand what the bases mean.

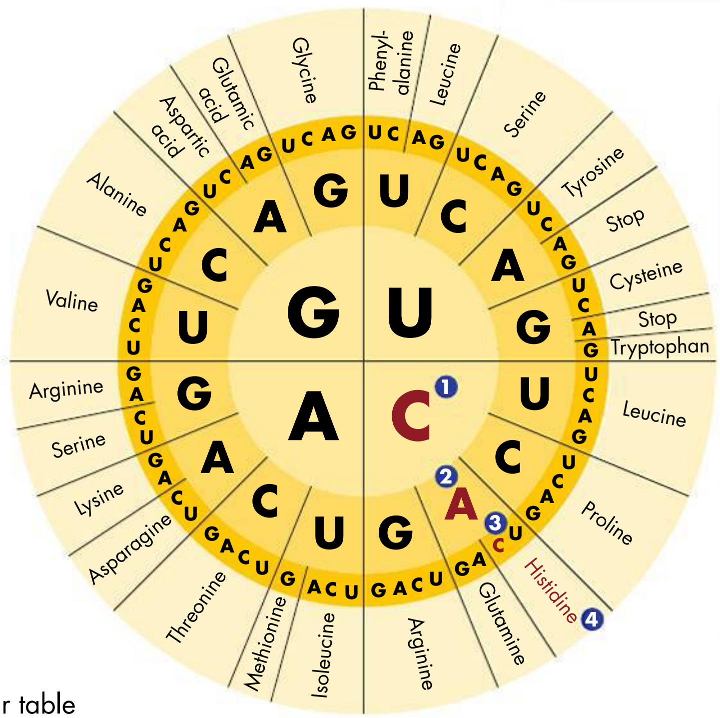
Remember that the first step in decoding genetic messages is using transcription to make RNA from a sequence of DNA bases. This RNA holds a code for making proteins. Proteins are made of long chains of amino acids called **polypeptides.** Up to 20 different amino acids are found in polypeptides.

The shape and function of a protein are determined by its amino acids and their sequence. How is the order of RNA bases related to the sequence of amino acids? RNA contains four different bases: adenine (A), cytosine (C), guanine (G), and uracil (U). These bases are like the letters of a language. We call this language the **genetic code.** Each word in the genetic code is three "letters," or three bases. Each three-base set is called a **codon.** A codon specifies one amino acid.

How to Read Codons There are four different bases in RNA. These four bases mean there are 64 possible three-base codons in the genetic code. Most amino acids can be specified by more than one codon. For example, six different codons—UUA, UUG, CUU, CUC, CUA, and CUG—specify the amino acid leucine.

Start and Stop Codons

Special codons tell the cell where to start and stop translating RNA. The codon AUG acts as the "start" codon for protein synthesis. After the start codon, mRNA is read three bases at a time.



Reading Codons The circular table shows the animo acid that corresponds to each of the 64 codons.

1 To decode the codon CAC, find the first letter in the set of bases at the center of the circle.

2 Find the second letter of the codon A, in the "C" quarter of the next ring.

3 Find the third letter, C, in the next ring, in the "C-A" grouping.

4 Read the name of the amino acid in that sector—in this case histidine.

Key Questions

What is the genetic code, and how is it read?

What role does the ribosome play in assembling proteins?

What is the "central dogma" of molecular biology?

BUILD Understanding

Two-Column Chart In the left column of a two-column chart, write the section headings. In the right column, list the main ideas.

In Your Workbook Go to your workbook and complete the chart for Lesson 13.2.

BUILD Vocabulary

polypeptide
a long chain of amino acids that makes proteins

genetic code
a collection of codons of mRNA, each of which directs the incorporation of a particular amino acid into a protein during protein synthesis

codon
a group of three nucleotide bases in mRNA that specify a particular amino acid to be incorporated into a protein

ROOT WORDS

The word *codon* was created by adding the suffix *-on* to the word *code*. The suffix *-on* means "chemical compound," so a codon is a chemical code.

Translation continues until one of three different "stop" codons is reached. Then, translation stops and the polypeptide is complete.

Key Question What is the genetic code, and how is it read? **The genetic code is a code for making proteins. The genetic code is read three "letters" at a time. Each "word" is three bases long and corresponds to a single amino acid.**

Translation

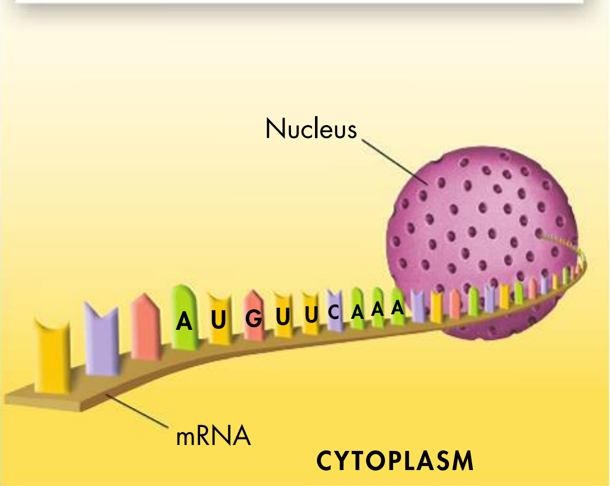
The sequence of nucleotide bases in each mRNA strand is a set of instructions. The instructions give the order in which amino acids should be joined to make a polypeptide. Once a polypeptide is made, it folds into its final shape or joins with other polypeptides. Once it folds or joins with other polypeptides, it becomes a working protein.

To put together a complex toy, you need instructions. Once you read them, you can put the parts together. In the cell, the ribosome reads the instructions and puts together proteins. Ribosomes use the sequence of codons in mRNA to assemble amino acids into polypeptide chains. The decoding of an mRNA message into a protein is a process called **translation.**

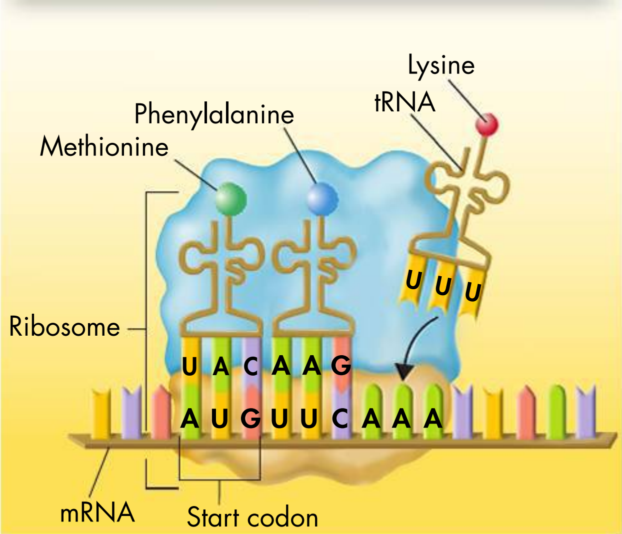
Steps in Translation Transcription produces the mRNA molecules that are used in protein synthesis, or translation. In eukaroytes, transcription occurs in the cell's nucleus. After transcription, mRNA leaves the nucleus, and translation takes place in the cytoplasm. The figure below shows this process.

Translation The cell uses information from messenger RNA to make proteins during translation.

Messenger RNA
Messenger RNA is transcribed in the nucleus and then enters the cytoplasm.



A Transfer RNA
Translation begins at AUG, the start codon. Each tRNA has an anticodon. The anticodon has bases that are complementary to the bases of an mRNA codon. The ribosome allows the start codon to attract and bind to its anticodon, a tRNA carrying the amino acid methionine. The ribosome also binds the next codon and its anticodon.



A ***Transfer RNA*** Translation begins when a ribosome attaches to an mRNA molecule in the cytoplasm. As each codon passes through the ribosome, tRNAs bring the correct amino acids into the ribosome. One at a time, the ribosome then attaches these amino acids to the growing polypeptide chain.

Each tRNA molecule carries just one kind of amino acid. Each tRNA molecule also has three unpaired bases. This set of bases is called the **anticodon.** Each tRNA anticodon is complementary to one mRNA codon.

The anticodon of the tRNA molecule for methionine is UAC. It will pair with the methionine codon, AUG. The ribosome has a second binding site for a tRNA molecule for the next codon. Notice that the second codon in the figure is UUC. A tRNA molecule with an AAG anticodon will bind to this codon. This tRNA molecule brings the amino acid phenylalanine into the ribosome.

B ***Joining Amino Acids*** Next, the ribosome helps make a peptide bond between the first and second amino acids. At the same time, the bond holding the first tRNA molecule to its amino acid is broken. That tRNA moves into an exit site, from which it leaves the ribosome. The ribosome moves to the next codon. Another tRNA then carries in the amino acid specified by that codon.

BUILD Vocabulary

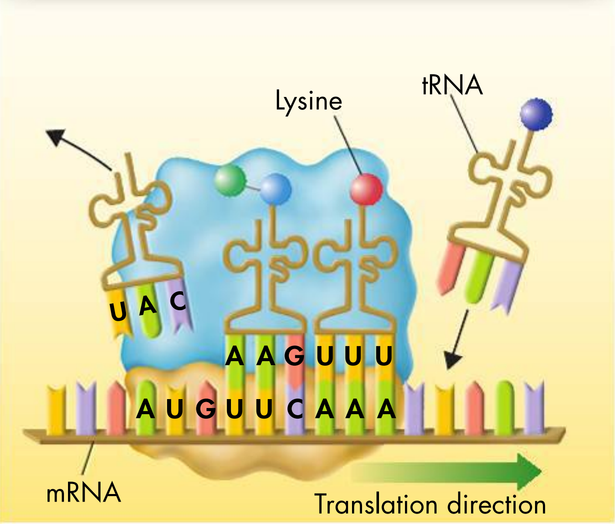
translation
a process by which the sequence of bases of an mRNA is converted into the sequence of amino acids of a protein

anticodon
a group of three bases on a tRNA molecule that are complementary to the three bases of a codon of mRNA

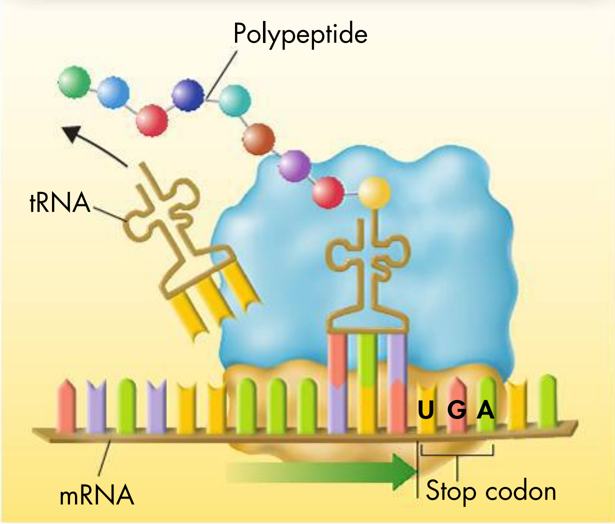
PREFIXES

The prefix *anti-* is Latin for "against." When added to science terms, it can mean "opposite." An anticodon, then, has the opposite, or complementary, base sequence of its matching codon.

B The Polypeptide "Assembly Line"
The ribosome joins the first two amino acids – methionine and phenylalanine. The bond breaks between methionine and its tRNA molecule. The tRNA then floats away from the ribosome. This allows the ribosome to bind another tRNA. The ribosome continues to move from right to left along the mRNA, binding new tRNA molecules and amino acids.



C Completing the Polypeptide
The process continues until the ribosome reaches a stop codon. Then, the polypeptide is complete. The polypeptide and the mRNA are released from the ribosome.



C ***The Chain Grows*** The polypeptide chain grows until the ribosome reaches a "stop" codon on the mRNA. Then, the ribosome releases both the newly formed polypeptide and the mRNA molecule. The process of translation is complete.

Key Question What role does the ribosome play in assembling proteins?
Ribosomes use the sequence of codons in mRNA to assemble amino acids into polypeptide chains.

The Roles of tRNA and rRNA in Translation All three kinds of RNA are put to work in the ribosome during translation. The mRNA molecule carries the coded message that directs the process. The tRNA molecules bring the correct amino acid for each codon on the mRNA. The rRNA and many proteins make up the ribosomes.

The Molecular Basis for Heredity

Gregor Mendel might have been surprised to learn that genes have instructions for putting proteins together. He might have asked what proteins have to do with traits of pea plants.

The answer is that proteins have everything to do with such traits. Remember that many proteins are enzymes. Enzymes help speed up and regulate chemical reactions. A gene that codes for an enzyme to make pigment controls flower color. Another gene makes proteins that control tissue growth in a leaf. Basically, proteins are tiny tools. Each one is designed to build or run a part of a living cell.

Once scientists learned that genes were made of DNA, other discoveries soon followed. Soon, a new scientific field called molecular biology had formed. Molecular biology tries to explain living organisms by studying them at the molecular level. It uses molecules like DNA and RNA as tools to understand living things. One of the earliest findings is now called the field's "central dogma," or basic rule. The central dogma states that information is transferred from DNA to RNA to protein. In real life, there are many exceptions to this "dogma." For example, some viruses pass information from RNA to DNA. But the central dogma is a useful rule that helps to explain how genes work. Gene expression is the way DNA, RNA, and proteins are involved in putting genetic information into action in living cells.

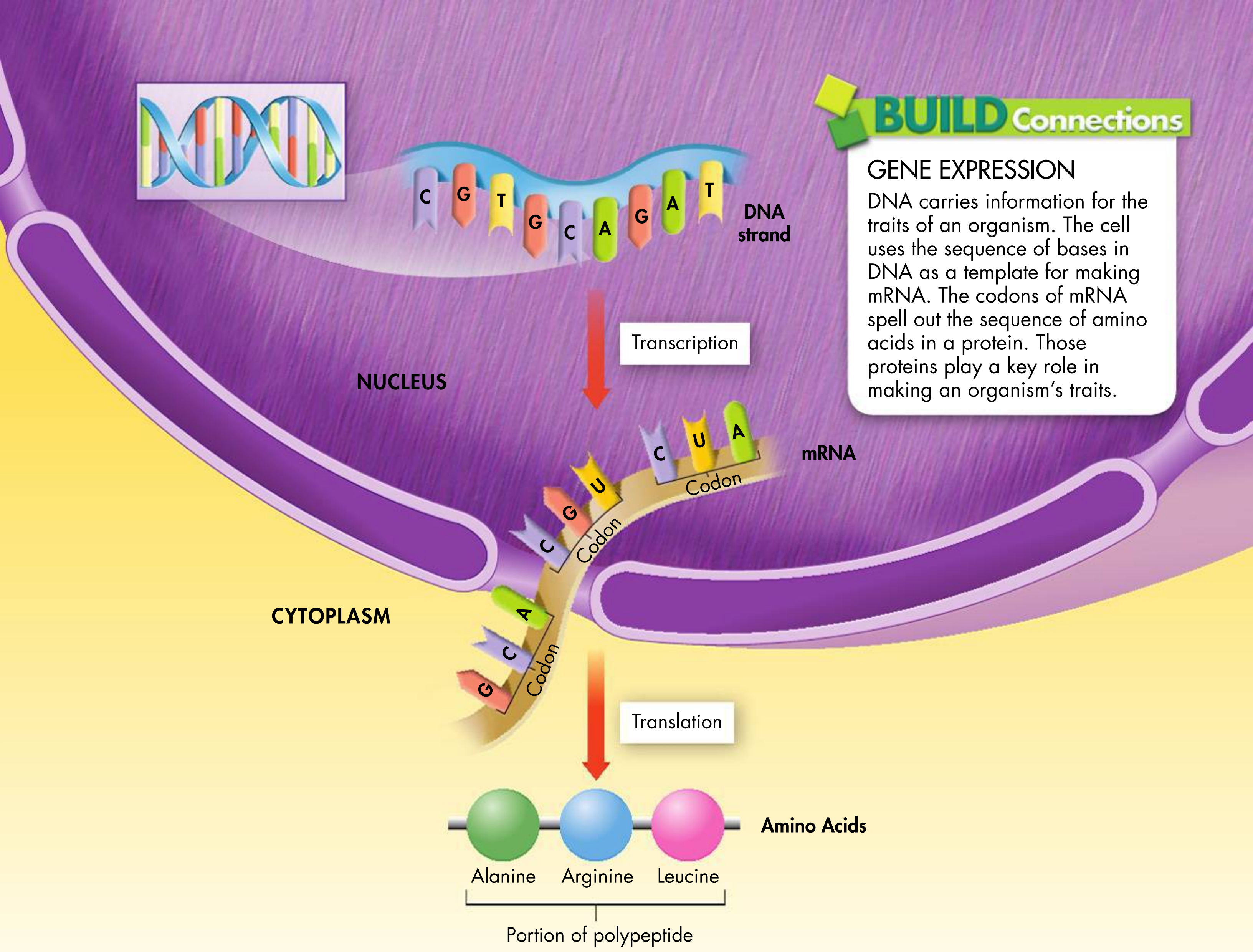
One of the most interesting discoveries of molecular biology is the genetic code. The genetic code is nearly universal to all organisms. The code is always read three bases at a time and in the same direction. Living things on Earth can be very different from each other. But they show great unity at life's most basic level, the molecular biology of the gene.

Key Question What is the "central dogma" of molecular biology? **The central dogma of molecular biology is that information is transferred from DNA to RNA to protein.**

BUILD Connections

GENE EXPRESSION

DNA carries information for the traits of an organism. The cell uses the sequence of bases in DNA as a template for making mRNA. The codons of mRNA spell out the sequence of amino acids in a protein. Those proteins play a key role in making an organism's traits.



CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete the sentence correctly.

1. A(n) _______ is a group of three bases on a tRNA molecule that are complementary to the three bases of a codon of mRNA.

Critical Thinking

2. Apply Concepts Using the Reading Codons circular table, identify the amino acids specified by codons UGG, AGG, and UGC.

3. Explain What does the term *gene expression* mean?

4. Explain How does a cell interpret the genetic code?

5. Write to Learn Answer the first clue for the chapter mystery. Include the term *codon* in your answer.

MYSTERY CLUE

What features of the genetic code make it possible for a mouse's gene to work inside the cells of a fly? (Hint: See p. 314.)

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13.3 Mutations

Key Questions

What are mutations?

How do mutations affect genes?

BUILD Understanding

Preview Visuals Before you read the lesson, look at the Point Mutations and Chromosomal Mutations figures. As you read, note the changes produced by various gene and chromosomal mutations.

In Your Workbook Complete the chart in Lesson 13.3 of your workbook.

Types of Mutations

The order of bases in DNA is like the letters of a coded message. What would happen if a few of those letters changed and, so, accidentally changed the message? Could the cell still understand the code's meaning? What effects do you think those changes would have on genes and the polypeptides for which they code?

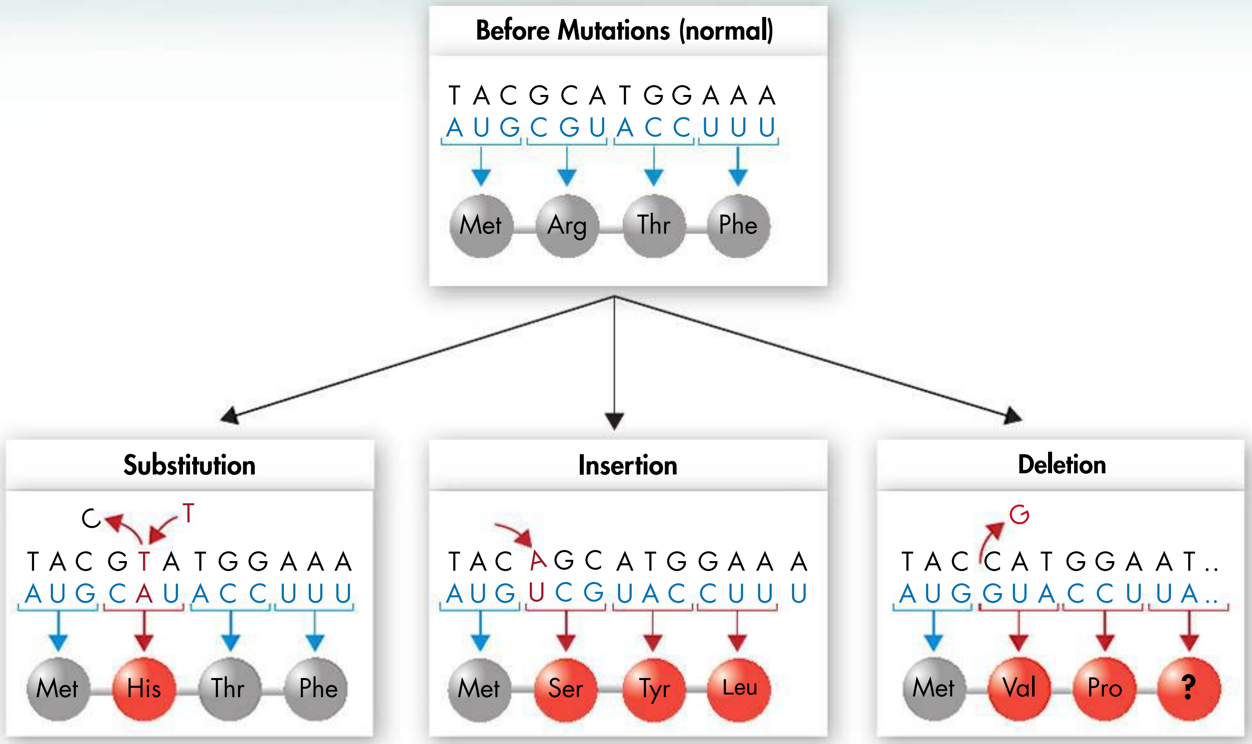
Sometimes cells do make mistakes in copying their own DNA. They insert the wrong base or skip a base as a strand is put together. These variations are called **mutations.** The word *mutation* comes from the Latin word *mutare*, meaning "to change." Mutations are changes in genetic information that can be inherited.

There are many kinds of mutations. However, all mutations fall into two basic categories. Mutations that make changes in a single gene are known as gene mutations. Mutations that make changes in whole chromosomes are known as chromosomal mutations.

Key Question What are mutations?
Mutations are changes in genetic information that can be inherited.

The shape of this flower is caused by a mutation that affects the growing areas of the flower tissue.

A genetic condition called leucism leaves this lion without pigments in its hair, skin, and eyes.



Point Mutations These diagrams show how changes in just one nucleotide can change the order of amino acids in proteins.

Gene Mutations

Gene mutations that involve changes in one or a few nucleotides are known as **point mutations.** They happen at a single point in the DNA sequence. Point mutations include substitutions, insertions, and deletions, and they usually happen during replication. If a gene in one cell is changed, the change can be passed on during cell division. Every daughter cell will have the mutation. The figure above shows how point mutations occur.

▶ ***Substitutions*** In a substitution, one base is changed to a different base. Substitutions usually affect a single amino acid. Sometimes they have no effect at all. For example, a mutation might change one codon of mRNA from CCC to CCA. The codon would still call for the amino acid proline. But changing CCC to ACC would replace proline with the amino acid threonine.

▶ ***Insertions and Deletions*** Insertions and deletions are point mutations. An insertion adds a new base to the DNA sequence. A deletion removes a base from the DNA sequence. The effects of these changes can be dramatic. Remember that the genetic code is read three bases at a time. Reading the bases three at a time happens even if a nucleotide is added or taken away. After a change, the sets shift in every codon that comes after the mutation.

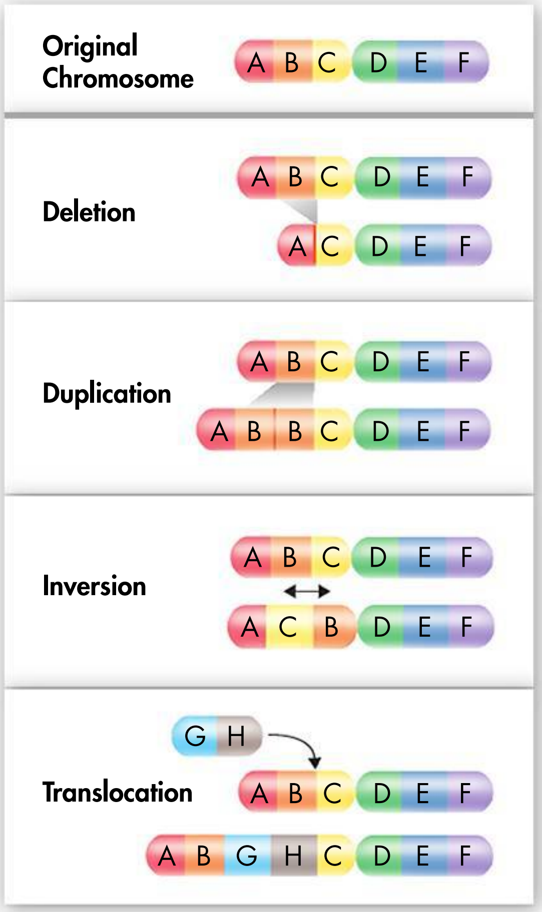
Insertions and deletions are also called **frameshift mutations** because they shift the "reading frame" of the genetic code. A shift in the reading frame can change every amino acid that follows the mutation. This change can alter a protein so much that it cannot do its job.

BUILD Vocabulary

mutation
a change in the genetic material of a cell

point mutation
a gene mutation in which a single base pair in DNA has been changed

frameshift mutation
a mutation that shifts the "reading frame" of the genetic message by inserting or deleting a nucleotide



Chromosomal Mutations Four types of mutations cause changes in whole chromosomes. The four types of chromosomal mutations are deletion, duplication, inversion, and translocation.

Chromosomal Mutations A chromosomal mutation is a change in the number or structure of chromosomes. These mutations can change the location of genes on chromosomes. They can also change the number of copies of some genes.

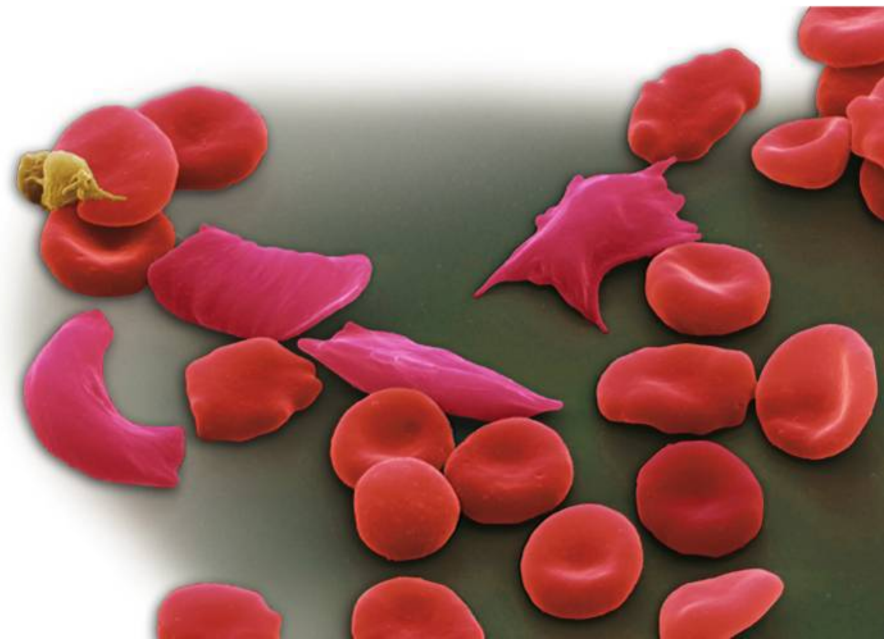
There are four types of chromosomal mutations: deletion, duplication, inversion, and translocation. Deletion happens when part or all of a chromosome is lost. Duplication happens when an extra copy of all or part of a chromosome is made. Inversion happens when parts of a chromosome change direction. Translocation happens when part of one chromosome breaks off and attaches to another one.

Effects of Mutations

Genetic material can be altered by natural events or by artificial means. The resulting mutations may or may not affect an organism. Many mutations are made by mistakes in genetic processes. For example, some point mutations are caused by mistakes in DNA replication. An incorrect base is inserted into DNA about once in every 10 million bases. However, small changes in genes can build up over time.

Mutagens Some mutations are caused by mutagens. **Mutagens** are chemical or physical agents in the environment. Chemical mutagens include some pesticides, tobacco smoke, and pollutants. Physical mutagens include X-rays and ultraviolet light. These mutagens can cause mutations at high rates. Sometimes the cell can repair the DNA. But when the cell cannot fix the DNA, the sequence changes become permanent.

Harmful and Helpful Mutations Mutations can help or harm organisms. However, most mutations have little or no effect on genes. So, there is little or no effect on the function of the proteins they make. In any case, mutations are important. Without mutations, there would be no genetic variation. Without genetic variation, species could not evolve.



Effects of a Point Mutation Sickle cell disease affects the shape of red blood cells. The round cells in the image are normal red blood cells. The crescent and star-shaped cells are sickled cells. (SEM 1700×)

▶ ***Harmful Effects*** Some of the most harmful mutations make big changes in protein shape or gene activity. The proteins made by these mutations can get in the way of biological activities. For example, some cancers are caused by mutations. Sickle cell anemia is caused by a point mutation in one of the polypeptides of hemoglobin. Hemoglobin is the oxygen-carrying protein in red blood cells. The mutant protein causes red blood cells to change shape, giving them a sickle-like appearance. These sickled cells interfere with blood flow and cause severe problems in the bloodstream.

▶ ***Helpful Effects*** Some of the changes made by mutations can help an organism or species. These mutations make genes with functions that are useful to organisms in different environments. Mutations have made many African mosquitoes resistant to the chemicals once used to kill them. This resistance may be bad news for people. However, it is very helpful to the insects. Beneficial mutations happen in people, too. For example, one mutation makes bones stronger. Another mutation increases resistance to HIV, the virus that causes AIDS.

Plant and animal breeders often make use of "good" mutations. For example, sometimes a full set of chromosomes does not separate during meiosis. The gametes made may produce triploid (3N) or tetraploid (4N) organisms. The condition in which an organism has extra sets of chromosomes is called **polyploidy.** Polyploid plants are often larger and stronger than diploid plants.

Key Question How do mutations affect genes?
The effects of mutations on genes vary widely. Some have little or no effect, and some produce beneficial variations. Some negatively disrupt gene function.

Polyploid Plants The fruit of the Tahiti lime is seedless because of polyploidy. Changes to the ploidy number of citrus plants can affect the size and strength of the trees, the quality of the fruit, and the number of seeds in their fruit.

BUILD Vocabulary

mutagen
a chemical or physical agent in the environment that interacts with DNA and may cause a mutation

polyploidy
a condition in which an organism has extra sets of chromosomes

WORD ORIGINS
The word *mutagen* is a Latin word that means "producer of change." Mutagens change an organism's genetic information.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A gene mutation in which a single base pair in DNA has been changed is a ______.

2. A mutation that shifts the "reading frame" of the genetic message by inserting or deleting a nucleotide is a ______.

3. A chemical that causes a mutation is called a ______.

Critical Thinking

4. Explain Describe the two main types of mutations.

5. Apply Concepts How do mutations affect living things?

6. Write to Learn Write the following DNA sequence GCTAATCGGCTA. Below this sequence, show how the sequence might look after a substitution mutation. Repeat this for a deletion mutation and an insertion mutation.

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13.4 Gene Regulation and Expression

Key Questions

How are prokaryotic genes regulated?

How are genes regulated in eukaryotic cells?

What controls the development of cells and tissues in multicellular organisms?

BUILD Understanding

Concept Map As you read, create a concept map from the major headings of the lesson. Then identify the important ideas in each section to complete your map.

In Your Workbook
Complete the concept map in Lesson 13.4.

Prokaryotic Gene Regulation

Think of a library filled with how-to books. Would you ever need to use all of those books at the same time? Of course not. If you wanted to know how to fix a leaky faucet, you'd find a book on plumbing. But, you would ignore the one on carpentry. Now picture a tiny bacterium like *E. coli,* which contains more than 4000 genes. These genes code for proteins that do everything from building cell walls to breaking down food. Do you think that *E. coli* uses every gene in its genetic library at the same time?

Most bacteria transcribe only the genes they need at any one time. For example, some genes produce enzymes used to digest certain types of food molecules. If these food molecules are not present, there is no need for these enzymes. As you might expect, bacteria turn these genes off when they are not needed. By controlling gene expression in this way, bacteria respond to change.

How do bacteria control genes? DNA-binding proteins in prokaryotes regulate genes by controlling transcription. Some of these proteins help switch genes on. Others turn genes off. How does an organism know when to turn a gene on or off? One way bacteria control making proteins is through operons. An **operon** is a group of genes that are regulated together. The genes in an operon have related jobs. *E. coli* provides a clear example of how this works. *E. coli* has 4288 genes that code for proteins. Three of these genes must be turned on together before the bacterium can use the sugar lactose as a food. Since these genes are operated together, they are called the *lac* operon.

Small Cell, Many Genes
This *E. coli* bacterium has more than 4000 genes. It was treated with an enzyme, which caused its DNA to spill out.

The *Lac* Operon Why must *E. coli* be able to turn the *lac* genes on and off? Lactose is made up of two simple sugars, galactose and glucose. To use lactose for food, the bacterium must first move lactose across its cell membrane. Then it has to break the bond between glucose and galactose. These jobs are done by proteins coded for by the genes of the *lac* operon. The bacterium must transcribe these genes and make the proteins if lactose is its only food source. If grown on another food source, the bacterium does not need these proteins.

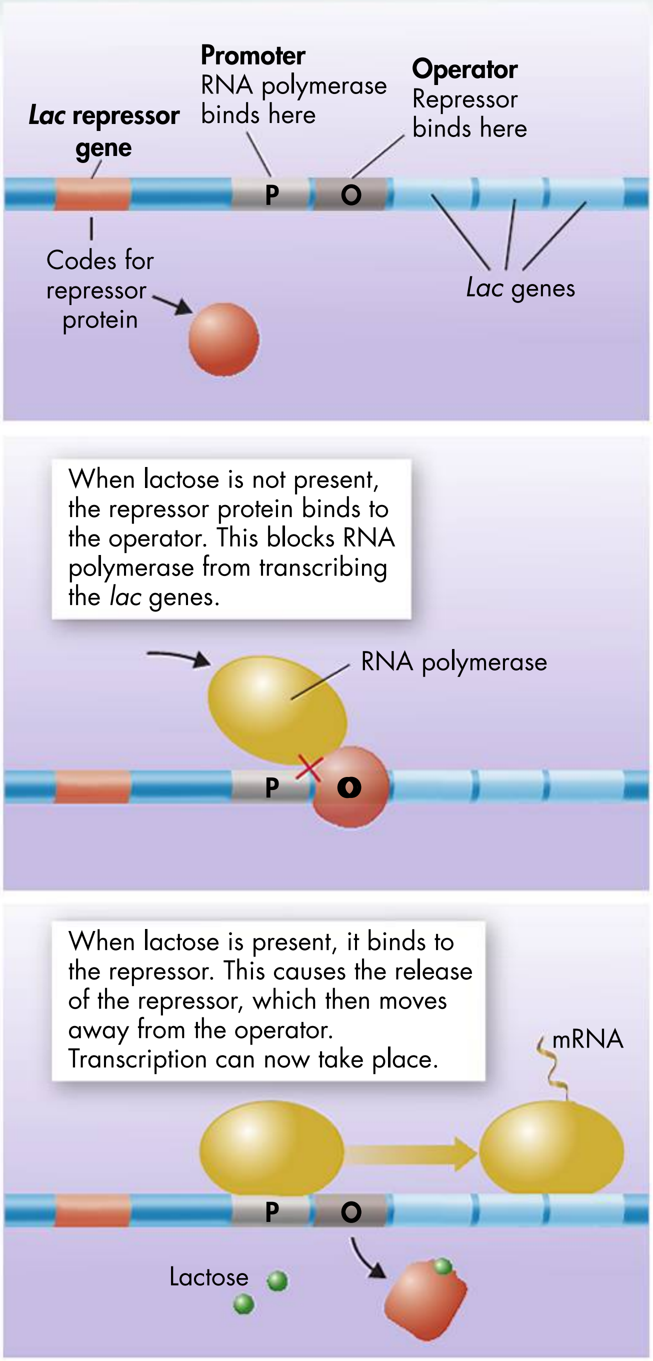
Remarkably, the bacterium almost seems to "know" when the proteins from these genes are needed. When lactose is not around, the *lac* genes are turned off by proteins. These proteins bind to DNA, blocking transcription.

Promoters and Operators On one side of the operon's three genes are two control regions. The first is a promoter (P). This is a site where RNA polymerase can bind to begin transcription. The other region is called the **operator** (O). The O site is where a DNA-binding protein known as the *lac* repressor can bind to DNA.

▶ ***The* Lac *Repressor Blocks Transcription*** When the *lac* repressor binds to the O region, RNA polymerase cannot reach the *lac* genes. RNA polymerase must bind to P to start transcription. So, the binding of the repressor protein switches the operon "off." It prevents the transcription of genes.

▶ ***Lactose Turns the Operon "On"*** If the repressor protein is always around, how can the *lac* genes ever be switched on? Besides its DNA binding site, the *lac* repressor protein has a binding site for lactose, too. When lactose is in the growth medium, it moves into the cell. It attaches to the *lac* repressor, changing the shape of the repressor protein. The change in shape causes the protein to fall off the operator. Now the repressor is no longer bound to the O site. RNA polymerase binds to the promoter and transcribes the genes of the operon. This transcription of the operon genes means that whenever lactose is present, the operon is automatically switched on.

Key Question How are prokaryotic genes regulated?
DNA-binding proteins in prokaryotes regulate genes by controlling transcription.



Gene Expression in Prokaryotes The *lac* genes in *E. coli* are turned off by repressors. They are turned on in the presence of lactose.

BUILD Vocabulary

operon
in prokaryotes, a group of adjacent genes that share a common operator and promoter and are transcribed into a single mRNA

operator
a short DNA region, adjacent to the promoter of a prokaryotic operon, that binds repressor proteins responsible for controlling the rate of transcription of the operon

RNA interference
the introduction of double-stranded RNA into a cell to inhibit gene expression

MULTIPLE MEANINGS
A machine operator controls a complicated piece of machinery. Similarly, a genetic operator controls transcription.

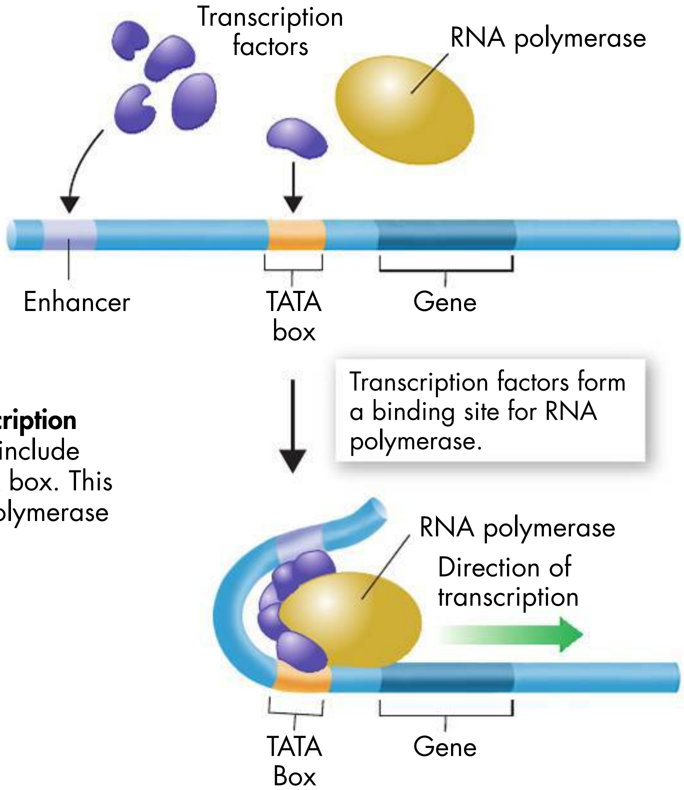
Eukaryotic Gene Regulation

Gene regulation in eukaryotes is much like gene regulation in prokaryotes, but there are differences. Most genes are controlled individually and use more complicated systems to control transcription. One important control is a piece of DNA called the TATA box. It is about 25 or 30 base pairs long and has the sequence TATATA or TATAAA. This region is usually found just in front of a gene. It binds a protein that helps move RNA polymerase into place to begin its job.

Transcription Factors Gene expression in eukaryotic cells is regulated in many ways. One way is to control transcription by using transcription factors. These proteins control gene expression by binding to regulatory DNA sequences. For example, some transcription factors make transcription easier by opening up tightly packed chromatin. Several transcription factors usually have to bind before RNA polymerase binds to the promoter region.

Promoters have many binding sites for transcription factors. Certain factors turn on many genes at once. Factors may be controlled by chemical signals such as steroid hormones. These chemical messengers enter cells and bind to receptor proteins. These "receptor complexes" then act as transcription factors that bind to DNA. This binding allows a single chemical signal to turn on many genes.

Key Question How are genes regulated in eukaryotic cells?
Transcription factors control the expression of eukaryotic genes by binding DNA sequences in regulatory regions.



The TATA Box and Transcription
Many eukaryotic genes include a region called the TATA box. This region helps put RNA polymerase in place to do its job.

Cell Specialization Why is gene regulation in eukaryotes more complicated than in prokaryotes? Every eukaryotic cell nucleus has all the genes of the body. But not all cells use every gene. This ability to selectively use genes means that nerve cells will not make enzymes that are only needed in the liver. Complex gene regulation is what makes specialization possible.

RNA Interference Other kinds of RNA are in the cell besides the major groups of RNA. Very small RNA molecules play a large role in regulating gene expression. They do so by interfering with mRNA.

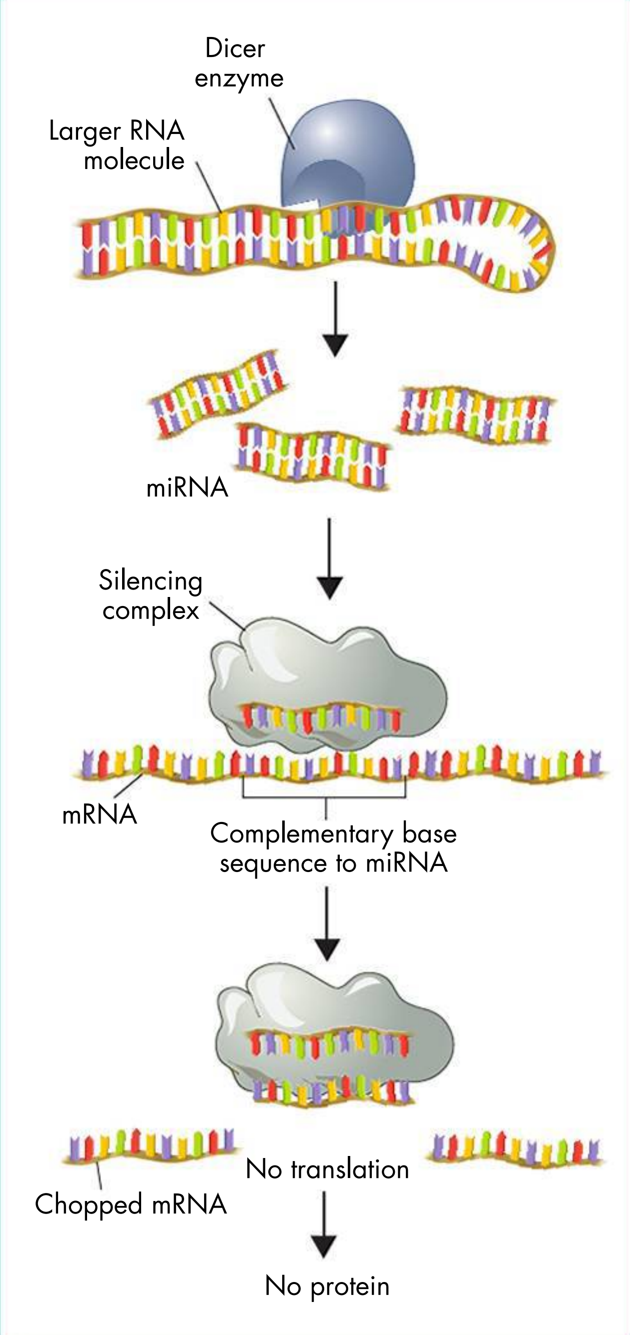
After they are made by transcription, these small RNA molecules fold into double-stranded loops. An enzyme called the “Dicer” enzyme cuts, or dices, these double-stranded loops into microRNA (miRNA). Each miRNA molecule is about 20 base pairs in length. The two strands of the loops then separate. Next, one of the miRNA pieces attaches to a group of proteins. This forms what is known as a silencing complex. This complex binds to and destroys any mRNA containing the complementary sequence to the miRNA. The miRNA sticks to mRNA molecules and stops them from passing on their protein-making instructions. Using a silencing complex to block gene expression is called **RNA interference** (RNAi).

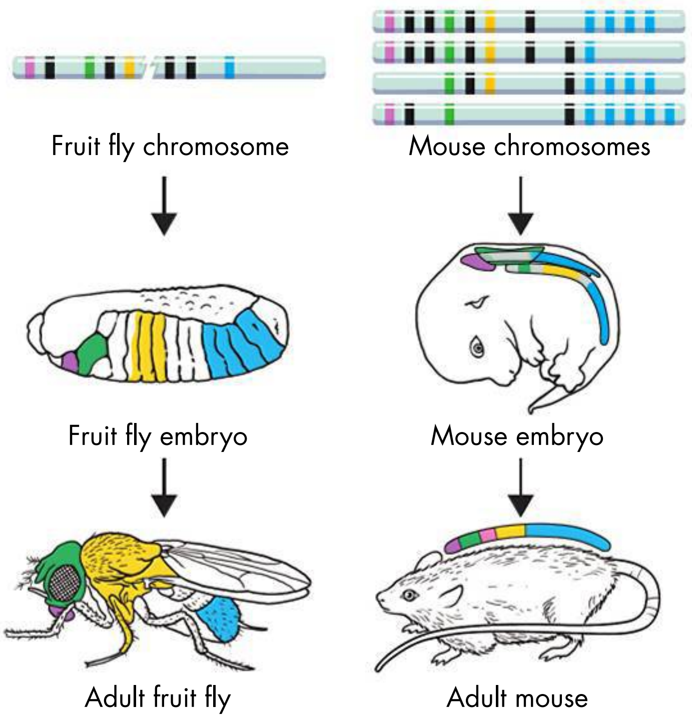
The Promise of RNAi Technology The discovery of RNAi has made it possible for researchers to switch genes on and off. They do this by inserting double-stranded RNA into cells. This technology is a powerful way to study gene expression in the laboratory. RNAi technology may also provide a way for medical scientists to turn off genes from viruses and cancer cells. So, RNAi may provide new ways to treat, and maybe even cure, diseases.

Genetic Control of Development

Controlling gene expression helps shape the way a multicellular organism develops. Each kind of specialized cell in an adult begins from the same fertilized egg cell. Different sets of genes are turned on and off as the embryo develops. Gene regulation helps cells change so that every cell can do a job. This kind of cell change and development is called cell differentiation.

Blocking Gene Expression MicroRNAs attach to mRNA molecules and stop them from passing on their protein-making instructions.





Hox Genes and Body Development
The basic body plan of a fruit fly is determined by a series of hox genes. The genes are arranged side by side on a single chromosome. Mammals, including mice, have several clusters of similar hox genes, arranged in nearly the same order. The colored areas on the fly and mouse show the approximate areas affected by genes of the corresponding colors.

Homeotic Genes In many animals, a set of master control genes regulates organs that develop in specific parts of the body. These genes are known as **homeotic genes,** and they control the identity of different body parts.

Homeobox and Hox genes All homeotic genes share a similar DNA sequence, called the homeobox sequence. Homeobox genes code for transcription factors that turn on other genes. These genes are important in cell differentiation. They control features such as the presence of wings or legs.

Flies have a group of homeobox genes known as Hox genes. These Hox genes are located side by side in a single group. They determine the identities of each part of a fly's body. A Hox gene mutation can change which organs develop in certain parts of the body. Other animals, including humans, also have Hox genes. The genes always tell cells how to differentiate. So, nearly all animals share the same basic tools for building the different parts of the body.

Environmental Influences

An organism's environment plays a role in cell differentiation, too. In all kinds of organisms, environmental factors like temperature can change gene expression. One example is the *lac* operon in *E. coli*. It is switched on only when lactose is the only food source in the bacteria's environment.

Metamorphosis is another example of how organisms can alter gene expression in response to environmental changes. Metamorphosis involves a series of changes from one life stage to another. It is usually regulated by factors inside and outside of the body. As organisms move through their life stages, their cells differentiate to make new organs. Tadpoles may speed up their metamorphosis based on the conditions around them. This more rapid metamorphosis may happen if a pond is drying up quickly or if food is becoming scarce. The environmental changes are translated into hormonal changes. The hormones act to regulate gene expression, which controls the speed of metamorphosis. Temperature and population size can also affect the speed of metamorphosis.

BUILD Vocabulary

homeotic gene
a class of regulatory genes that determine the identity of body parts and regions in an animal embryo. Mutations in these genes can transform one body part into another.

ROOT WORDS
The root *homeo* means "similar." Homeotic genes are similar to each other.

Key Question What controls the development of cells and tissues in multicellular organisms?
Master control genes are like switches that trigger particular patterns of development and differentiation in cells and tissues.

INQUIRY into Scientific Thinking

The Discovery of RNA Interference

In 1998, Andrew Fire and Craig Mello performed an experiment that helped explain how RNA interference happens. They used RNA from a large gene called unc-22, which codes for a protein found in muscle cells. They made short pieces of mRNA that matched with two parts of the gene. Then they injected the mRNA into egg cells of the worm *C. elegans*. Some of their results are shown in the table.

Injections of mRNA into *C. elegans* Eggs

Portion of Gene Used to Produce mRNA	Strand Injected	Result in Adult Worm
Unc-22 (exon 21–22)	Sense	Normal
	Antisense	Normal
	Sense + Antisense	Twitching
Unc-22 (exon 27)	Sense	Normal
	Antisense	Normal
	Sense + Antisense	Twitching

1. **Interpret Data** Which strand caused adult worms to twitch?

a. single-stranded mRNA (the "sense" strand)

b. its complementary strand ("antisense")

c. double-stranded RNA ("sense + antisense")

2. **Infer** Twitching happens when muscle cells cannot control their contractions. What does this suggest about the unc-22 protein in some of the worms?

3. **Predict** The scientists made their mRNA fragments from exons. Do you think their experiment would have worked if the fragments were made from introns? Explain your answer.

In Your Workbook Get more help for this activity in your workbook.

CHECK Understanding

Apply Vocabulary

Use the highlighted word from the lesson to complete the sentence correctly.

1. ______ are a class of regulatory genes that determine the identity of body parts and regions in an animal embryo.

Critical Thinking

2. **Review** How is the *lac* operon regulated?

3. **Explain** What is a promoter?

4. **Review** Describe how most eukaryotic genes are controlled.

5. **Compare and Contrast** How is gene regulation in prokaryotes and eukaryotes similar? How is it different?

6. **Write to Learn** Answer the third mystery clue.

MYSTERY CLUE

What do you think controls the growth and development of eyes in flies and mice? (Hint: See p. 324.)

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Pre-Lab: From DNA to Protein Synthesis

Problem What are the steps involved in making a protein?

Lab Manual Chapter 13 Lab

Skills Focus Use Models, Sequence

Connect to the Big idea One of the most important tasks in a cell is the assembly of proteins from amino acids. This task always begins on ribosomes that are located throughout a cell's cytoplasm. The directions for the assembly of proteins are stored in DNA molecules. The information is carried to the ribosomes by a form of RNA called messenger RNA, or mRNA. In this lab, you will model the transcription of DNA and the translation of mRNA.

Background Questions

a. Review Is the following sequence from a DNA or mRNA molecule? How can you tell?

CUAAUGCCCUAGGGCACU

b. Compare and Contrast How are transcription and translation similar? How are they different?

c. Sequence List the following molecules in the order in which they take part in protein synthesis: amino acid, DNA, mRNA, tRNA.

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Sequence** Describe briefly the process you will use to decode the messages.
2. **Compare and Contrast** What role do stop codons play in protein synthesis? What are they used for in the coded messages?
3. **Predict** Which six letters will not appear in the coded messages? Give a reason for your answer.

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Visit Chapter 13 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Watch the Untamed Science explorers as they search for examples of how mutations have benefitted a species.

Art in Motion Watch how RNA is processed to make mRNA.

Art Review Review your understanding of different types of mutations with this drag-and-drop activity.

InterActive Art Build your understanding of transcription and translation with these animations.

Visual Analogy Compare DNA and RNA to the master plans and blueprints of a builder.

Tutor Tube Tune into the tutor to find out why proteins are so important!

13 CHAPTER Summary

13.1 RNA

- There are three main differences between RNA and DNA. The sugar in RNA is ribose instead of deoxyribose. RNA is generally single-stranded and not double-stranded. RNA contains uracil in place of thymine.
- RNA is made through a process called transcription. In transcription, stretches of DNA serve as templates to make complementary RNA molecules.

RNA (p. 308)
messenger RNA (p. 309)
ribosomal RNA (p. 309)
transfer RNA (p. 309)
transcription (p. 309)

13.2 Ribosomes and Protein Synthesis

- The genetic code is a code for making proteins. The genetic code is read three "letters" at a time. Each "word" is three bases long and corresponds to a single amino acid.
- Ribosomes use the sequence of codons in mRNA to put together amino acids into polypeptide chains. Long, functional polypeptide chains are proteins.
- The central dogma of molecular biology is that information is passed from DNA to RNA to protein. This means that the code used to make DNA, RNA, and proteins is almost universal among organisms.

polypeptide (p. 311)
genetic code (p. 311)
codon (p. 311)
translation (p. 312)
anticodon (p. 313)

13.3 Mutations

- Mutations are changes in genetic information that can be inherited. These changes in the genetic code can affect individuals. If the change is passed to offspring, it can affect whole species.
- The effects of mutations on genes vary widely. Some have little or no effect. Some make beneficial variations that are passed on to offspring. Some negatively disrupt gene function and harm the organism.

mutation (p. 316)
point mutation (p. 317)
frameshift mutation (p. 317)
mutagen (p. 318)
polyploidy (p. 319)

13.4 Gene Regulation and Expression

- DNA-binding proteins in prokaryotes regulate genes by controlling transcription.
- Transcription factors control the expression of eukaryotic genes by binding DNA sequences in regulatory regions.
- Master control genes are like switches that turn on and off development and differentiation in cells. The environment also can turn gene expression on or off.

operon (p. 320)
operator (p. 321)
RNA interference (p. 323)
homeotic gene (p. 324)

13 CHECK Understanding

Assess the Big idea: Information and Heredity

Write and answer the question below.

Q: How does information flow from DNA to RNA to direct the synthesis of proteins?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs. To help you begin, read the **Hints** below the questions.

1. **Why does controlling an organism's proteins control its characteristics?**

   Hint Proteins help your body processes function.

   Hint Many of the body's parts are made of protein.

2. **How might a point mutation in a gene affect proteins?**

   Hint Genes are transcribed into mRNA.

   Hint mRNA is translated into protein using tRNA and rRNA.

3. **Why is a TATA box necessary for a eukaryotic gene to be expressed properly?**

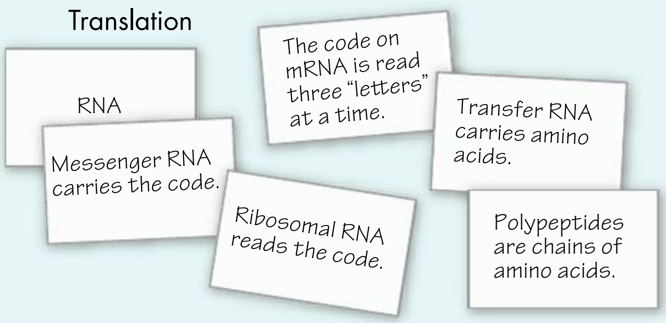
   Hint A TATA box is usually found just before a gene.

   Hint A TATA box binds transcription factor proteins that help position RNA polymerase.

Foundations for Learning Wrap-Up

Activity 1 Working with a partner, figure out which important facts you both chose to record. Examine which facts one partner recorded that the other did not record. Each partner can explain the importance of his or her unmatched facts.

Activity 2 In groups of three, use the material in your Important Facts Envelopes to create information collages. (Be sure each person's initials are on the back of each fact.) Then, spread the facts out on a table, and put the facts in groups, such as "Translation," "Transcription," "or "Prokaryotes." Explain why each fact belongs in a particular group.



13.1 RNA

Understand Key Concepts

1. Which of the following describes RNA?
   a. RNA is usually double-stranded and contains the base thymine.
   b. RNA is usually single-stranded and contains the base uracil.
   c. RNA is longer than DNA and uses five bases to encode information.
   d. RNA is made in the nucleus of eukaryotic cells and stays there to carry out its functions.
2. The process by which the genetic code of DNA is copied into a strand of RNA is called
   a. translation.
   b. transcription.
   c. transformation.
   d. replication.
3. How does the enzyme that makes RNA know where to start transcribing the DNA?

Think Critically

4. **Apply Concepts** Suppose you start with the DNA strand ACCGTCAC. What would a messenger RNA strand transcribed from this DNA strand look like?

Test-Taking Tip

Use Scratch Paper Question 4 asks you to write the messenger RNA sequence that would be transcribed from the DNA sequence ACCGTCAC. Write the DNA sequence on scratch paper. Write the letters that represent the RNA bases directly underneath the DNA letters:

ACCGTCAC

UGGCAGUG

Once you have the right sequence, transfer it to your answer sheet.

13.2 Ribosomes and Protein Synthesis

Understand Key Concepts

5. In messenger RNA, each codon calls for a particular
   a. nucleotide.
   b. enzyme.
   c. amino acid.
   d. promoter.
6. The process of making proteins on the ribosome based on instructions from messenger RNA is called
   a. transcription.
   b. transformation.
   c. translation.
   d. molecular biology.
7. What is a codon?
8. How do anticodons work?

Think Critically

9. **Applying Concepts** A code on a DNA molecule for a specific amino acid is CTA. What would the messenger RNA codon be? What would the transfer RNA anticodon be?

13.3 Mutations

Understand Key Concepts

10. Changes in DNA sequences that affect genetic information are known as
    a. replications.
    b. mutations.
    c. transformations.
    d. translations.
11. A substance that can cause a change in the DNA code of an organism is called a
    a. toxin.
    b. mutagen.
    c. nitrogenous base.
    d. nucleotide.
12. Name and give examples of two major types of mutations.
13. How does a deletion mutation differ from a substitution mutation?

Think Critically

14. **Analyze** Can mutations have a positive effect? Explain your answer.

13 CHECK Understanding

13.4 Gene Regulation and Expression

Understand Key Concepts

15. An expressed gene
- **a.** functions as a promoter.
- **b.** is transcribed into RNA.
- **c.** codes for just one amino acid.
- **d.** is made of mRNA.

16. Blocking gene expression in eukaryotes with microRNA strands is called RNA
- **a.** transcription.
- **b.** translation.
- **c.** interference.
- **d.** digestion.

17. How is gene expression controlled in prokaryotes?

18. What is a homeobox gene?

Think Critically

19. Explain How is cell differentiation controlled?

Connecting Concepts

Use Science Graphics

Use the data table to answer questions 20 and 21.

Codon Translation

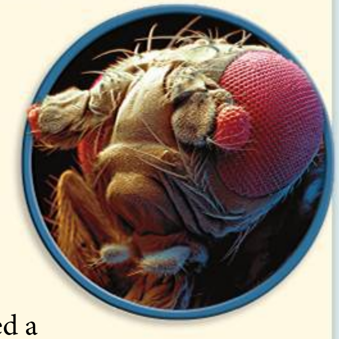
Amino Acid	mRNA Codons
Alanine (Ala)	GCA, GCG, GCU, GCC
Valine (Val)	GUA, GUG, GUU, GUC
Leucine (Leu)	CUA, CUG, CUU, CUC, UUA, UUG

20. Relate Cause and Effect The table shows mRNA codons for three amino acids. Suppose a substitution mutation occurred at the third nucleotide position of the codons for alanine. What would happen to the resulting protein?

21. Infer The three amino acids shown in the table have very similar—but not identical—properties. What substitution mutations could cause one of these amino acids to be switched for another? What might be the result?

solve the CHAPTER MYSTERY

MOUSE-EYED FLY



Years ago scientists discovered a fly gene they called eyeless. Mutations that turn off this gene cause flies to develop without eyes. Scientists later discovered a mouse gene, called *Pax6*, that was similar to eyeless. Transplanting an activated *Pax6* gene into a fruit fly causes eyes to grow in odd places. These eye growths happen even though mouse eyes and fly eyes are very different.

How can the *Pax6* gene perform the same role in animals that are so different? It probably began very early in the history of life. Then eyes were just patches of light-sensitive cells. They were found on the skin of the common ancestors of all animals. Master control genes like *Pax6* kept working as those organisms evolved and diversified. But their functions changed. All animals, including insects, worms, sea urchins, and humans, share many genes like *Pax6*.

1. Explain How are fly eyes and mouse eyes similar? How are they different?

2. Infer The *Pax6* and eyeless genes do not code for parts of the actual eye. These genes code for transcription factors. Think about the effect of *Pax6* when it is inserted into a fly. Why does it make sense that *Pax6* is a transcription factor?

UntamedScience **Never Stop Exploring Your World.** Finding the solution to the mouse-eyed fly is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

Standardized Test Prep

Multiple Choice

1. How does RNA differ from DNA?
A RNA contains uracil and deoxyribose.
B RNA contains ribose and thymine.
C RNA contains uracil and ribose.
D RNA contains adenine and ribose.

2. How would the DNA sequence GCTATA be transcribed to mRNA?
A GCUAUA **C** CGAUAU
B CGATAT **D** GCUTUT

Questions 3—4

Use the chart below to answer the questions.

First Base in Code Word	Second Base in Code Word: A	G	U	C	Third Base in Code Word
A	Lys	Arg	Ile	Thr	A
A	Lys	Arg	Met	Thr	G
A	Asn	Ser	Ile	Thr	U
A	Asn	Ser	Ile	Thr	C
G	Glu	Gly	Val	Ala	A
G	Glu	Gly	Val	Ala	G
G	Asp	Gly	Val	Ala	U
G	Asp	Gly	Val	Ala	C
U	"Stop"	"Stop"	Leu	Ser	A
U	"Stop"	Trp	Leu	Ser	G
U	Tyr	Cys	Phe	Ser	U
U	Tyr	Cys	Phe	Ser	C
C	Gln	Arg	Leu	Pro	A
C	Gln	Arg	Leu	Pro	G
C	His	Arg	Leu	Pro	U
C	His	Arg	Leu	Pro	C

3. Which of the following codons signifies the end of translation?
A CAA **C** AUC
B UGA **D** CCA

4. Which of the chains of amino acids corresponds to the nucleotide sequence UCAAGCGUA?
A glu-cys-pro **C** thr-arg-met
B glu-asp-"stop" **D** ser-ser-val

5. In eukaryotes, functional messenger RNA molecules are made from
A exons spliced together after introns are removed.
B introns spliced together after exons are removed.
C exons spliced together with introns.
D long pieces of RNA shortened by the Dicer enzyme.

6. Promoters are
A genes that code for individual proteins.
B proteins that bind with DNA and prevent transcription.
C DNA sequences near operons that regulate transcription.
D small molecules that bind with repressor proteins.

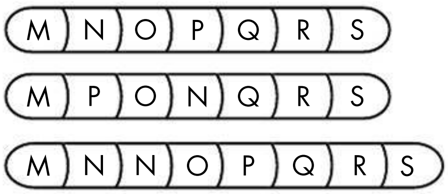
Questions 7—8

Use the diagrams below to answer the questions.

Normal Chromosome

Mutant 1

Mutant 2



7. Mutant 1 is a(n)
A deletion. **C** inversion.
B translocation. **D** duplication.

8. Mutant 2 is a(n)
A deletion. **C** inversion.
B translocation. **D** duplication.

Open-Ended Response

9. What is the function of the *lac* repressor system in *E. coli*?

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9
See Lesson	13.1	13.1	13.2	13.2	13.1	13.1	13.3	13.3	13.4

14 Human Heredity

Big idea **Information and Heredity**

Q: How can we use genetics to study human inheritance?

Notice that none of these students look alike. The diversity of traits in the human race comes from DNA.

BIOLOGY.com Search Chapter 14 GO • Flash Cards

INSIDE:

- 14.1 Human Chromosomes
- 14.2 Human Genetic Disorders
- 14.3 Studying the Human Genome

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

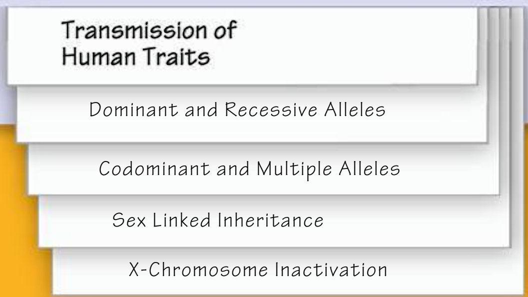
THE CROOKED CELL

When Ava visited her Uncle Eli in the hospital, he seemed tired and pale. He told Ava he had sharp pains in his bones. "I've got sickle cell disease," Uncle Eli said, short of breath. "I just hope it doesn't run in your side of the family." That evening, Ava checked the Internet for information about her uncle's disease. She saw photos of red blood cells shaped like the letter *C*. They were not like the healthy, round blood cells of a normal individual. Ava learned that these sickle-shaped cells are rigid and sticky. In blood vessels, they form clumps that can block blood flow and cause organ damage. "Am I at risk for carrying the sickle cell trait?" Ava wondered. To find out, she would need to investigate her family history—and her own cells.

Read for Mystery Clues As you read this chapter, look for clues that would help Ava discover whether she might carry the sickle cell trait. Then, solve the mystery.

FOUNDATIONS for Learning

Every main idea in the chapter is made clear by a series of smaller, supporting ideas. As you read through the chapter, make layered books for the main ideas you find. Write the main idea on the first page of the book. Then, write the supporting ideas on the pages that follow. Each page should include a supporting idea and notes about that idea. At the end of the chapter are two activities that help you answer the question: How can we use genetics to study human inheritance?



14.1 Human Chromosomes

Key Questions

What is a karyotype?

What patterns of inheritance do human traits follow?

How can pedigrees be used to analyze human inheritance?

BUILD Understanding

Spider Map Before you read, create a spider map of the major headings in the lesson. As you read, look for the main ideas and supporting details in each lesson.

In Your Workbook Go to your workbook for help creating spider maps. Complete the spider map in Lesson 14.1.

Karyotypes

What makes us human? We could try looking inside the cell with a microscope for the answer. But human cells look similar to cells from any other animal. To find what makes us human, we have to look deeper into the cell. That means we must look at the human **genome.** A genome is the full set of genetic information that an organism carries in its DNA. Remember that genes are on chromosomes. Chromosomes are bundles of DNA and protein found in the nuclei of eukaryotic cells.

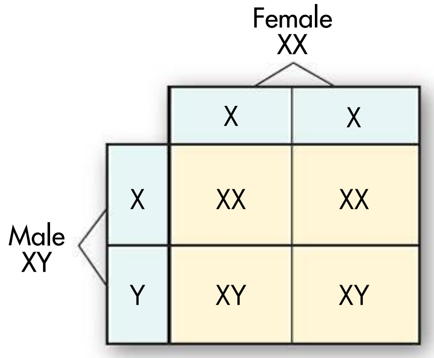
To see human chromosomes clearly, cell biologists take pictures of cells during mitosis. The chromosomes are condensed and can be seen clearly at this time. Scientists then cut out the chromosomes from the photographs. They arrange the chromosome images into a picture known as a **karyotype** (KAR ee uh typ). A karyotype shows the complete diploid set of chromosomes. They are lined up together in pairs and arranged from largest to smallest. A typical human cell has 46 chromosomes, arranged in 23 pairs.

Key Question What is a karyotype?
A karyotype shows the complete diploid set of chromosomes. They are grouped in pairs and arranged from largest to smallest.

Sex Chromosomes Two of the 46 chromosomes in the human genome are known as **sex chromosomes** because they determine an individual's sex. Females have two copies of the X chromosome. Males have one X chromosome and one Y chromosome. All egg cells carry a single X chromosome. Half of all sperm cells carry an X chromosome and half carry a Y chromosome. The X chromosome has more than 1200 genes. The Y chromosome is smaller, and has about 140 genes.

A Human Karyotype The nucleus of a human body cell has 23 pairs of chromosomes. These chromosomes have been cut out of a photograph and arranged to make a karyotype.

Autosomal Chromosomes The whole human genome has 46 chromosomes. There are 2 sex chromosomes. The other 44 are autosomal chromosomes, or *autosomes*. Most of the genetic information in the cell is on the autosomes.



Sex Ratios Human egg cells have one X chromosome. Sperm cells have either one X chromosome or one Y chromosome. Half the offspring will be male. Half will be female.

Transmission of Human Traits

Scientists have learned many things about human genetics in recent years by studying DNA. Human genes, like the genes of other organisms, follow Mendelian patterns of inheritance.

Dominant and Recessive Alleles Many human traits follow a pattern of simple dominance. For example, a gene known as MC1R helps determine skin and hair color. A person with red hair usually has two recessive alleles for this gene. Dominant alleles for the MC1R gene help produce darker hair colors.

Codominant and Multiple Alleles Some alleles for human genes are codominant. One example is the ABO blood group, the set of alleles that determines your blood type. There are three alleles: I^A, I^B, and i. Alleles I^A and I^B are codominant. They make protein markers called antigens on the surface of red blood cells. People with alleles I^A and I^B make both A and B antigens, so they are blood type AB. The i allele is recessive. People with alleles I^AI^A or I^Ai make only the A antigen. They have blood type A. Those with I^BI^B or I^Bi alleles are type B. Those with two i alleles (ii) make no antigen. They have blood type O.

Key Question What patterns of inheritance do human traits follow?
Many human traits follow a pattern of simple dominance. The alleles for many human genes are codominant.

Blood Groups

Phenotype (Blood Type)	Genotype	Antigen on Red Blood Cell	Safe Transfusions	
			To	From
A	I^AI^A or I^Ai	A	A, AB	A, O
B	I^BI^B or I^Bi	B	B, AB	B, O
AB	I^AI^B	A and B	AB	A, B, AB, O
O	ii	None	A, B, AB, O	O

Human Blood Groups This table shows the relationship between genotype and phenotype for the ABO blood groups. It also shows which blood types can safely be transfused into people with other blood types.

BUILD Vocabulary

genome
the entire set of genetic information that an organism carries in its DNA

karyotype
a photograph of the complete diploid set of chromosomes grouped together in pairs, arranged in order

sex chromosome
one of two chromosomes that determines an individual's sex

sex-linked gene
a gene located on a sex chromosome

pedigree
a chart that shows the presence or absence of a trait according to the relationships within a family across several generations

ROOT WORDS
The prefix *karyo-* comes from the Greek word *karyon*, which means "nut or kernel." In biology, this prefix refers to the nucleus of a cell. The word *type* means "characteristic." So a karyotype shows the chromosomes that are characteristic of a cell's nucleus.

X-Chromosome Inactivation
Female calico cats are tricolored, meaning they have three colors. The spot color on their fur is controlled by a gene on the X chromosome. Spots can be either orange or black. Their color depends on which X chromosome is turned off in that patch of skin.

Sex-Linked Inheritance The genes located on X and Y chromosomes show a pattern of inheritance called sex-linkage. A **sex-linked gene** is a gene on a sex chromosome. Only males have the genes on the Y chromosome. Since only males have a Y chromosome, boys inherit it from their father. The X chromosome comes from their mother. The fact that males have only one X chromosome can cause genetic problems.

For example, humans have three genes for color vision on their X chromosome. A defective allele for any of these genes results in colorblindness. A male's only copy of each allele is on his X chromosome. If he has one of these defective alleles, he will be unable to tell certain colors apart. Females have two X chromosomes, so they have two alleles for each of the color-vision genes. Since the defective alleles are recessive, in a female both copies of the recessive allele must be present to produce colorblindness. Because of this, colorblindness and other sex-linked recessive disorders show up much more often in males than in females.

Key Question What patterns of inheritance do human traits follow? **Because the X and Y chromosomes determine sex, the genes located on them show a pattern of inheritance called sex-linkage.**

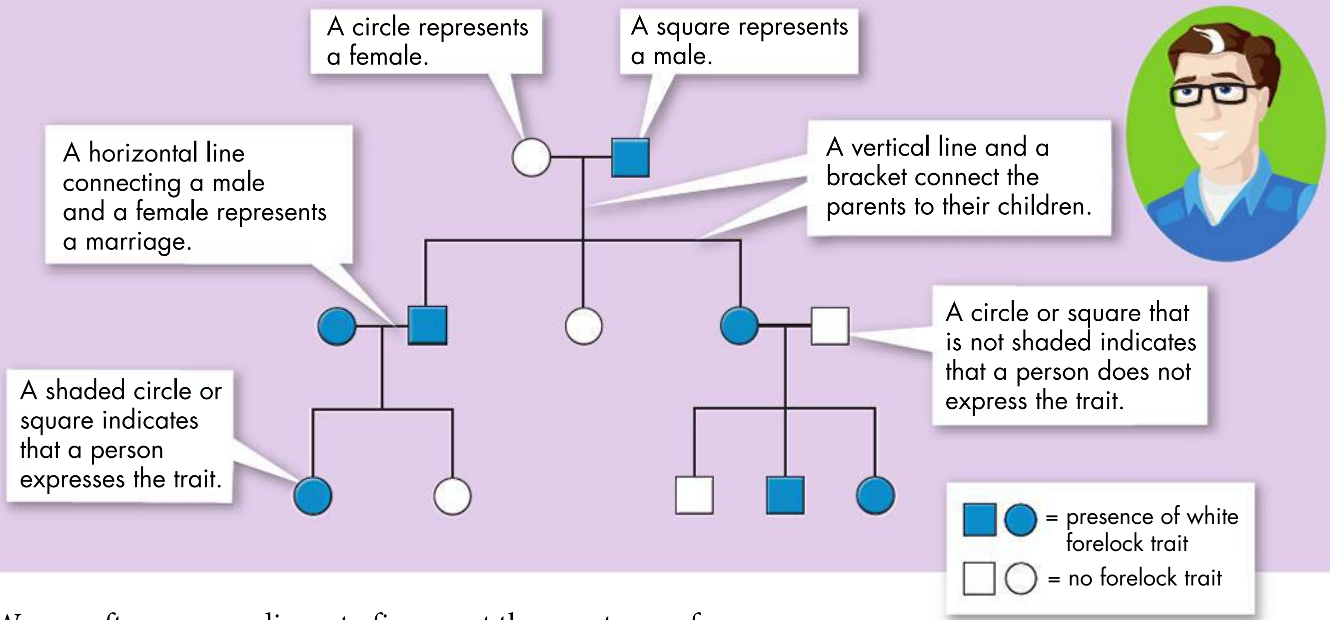
X-Chromosome Inactivation One X chromosome is enough for cells in males. But what about cells in females? A cell only needs one X chromosome to function normally. Female cells adjust to having two X chromosomes by randomly inactivating genes on one of them. The inactive chromosome makes a dense area in the nucleus called a Barr body.

X-chromosome inactivation also occurs in other female mammals. For example, cats have a gene that controls the color of coat spots on their X chromosome. One X chromosome may have an allele for orange spots. The other may have an allele for black spots. Different X chromosomes are inactivated in various parts of a female's skin. This causes a mixture of orange and black spots in her fur. Male cats have just one X chromosome, so their spots are only one color.

Human Pedigrees

You can use Mendel's basic laws of genetics to find out if a trait is dominant or recessive. These same laws help you find out if the gene for that trait is autosomal or sex-linked. You can use a chart called a **pedigree** to show the pattern of inheritance for a trait. A pedigree shows the presence or absence of a trait according to the relationships between parents, siblings, and offspring.

The pedigree on the next page shows how one human trait passes through three generations of a family. At the top of the chart is a grandfather who had the white forelock trait. Two of his three children inherited the trait. Three grandchildren have the trait, but two do not.



Pedigree Example This diagram shows what the symbols in a pedigree represent.

We can often use a pedigree to figure out the genotypes of family members. In the pedigree above, the allele for the white forelock trait is dominant. So, someone without the trait must have two recessive alleles. The grandfather at the top of the chart has this trait. So do two of his children. But the third child does not have a white forelock. So, the grandfather must be heterozygous for this trait.

Key Question How can pedigrees be used to analyze human inheritance? **The information learned from pedigrees helps determine the nature of genes and alleles associated with inherited human traits.**

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A ________ contains all the instructions that are needed to build an organism.

2. An organism's paired chromosomes arranged in order from largest to smallest is called a ________.

Critical Thinking

3. Explain What does a pedigree show?

4. Predict Suppose a woman with type O blood and a man with type AB blood have children. What are the children's possible genotypes?

5. Write to Learn Answer the first clue of the mystery.

MYSTERY CLUE

Two sickle cell alleles are needed to produce sickle cell disease. Males and females develop sickle cell disease in equal frequencies. What do these statements suggest about the location of the gene responsible for the disorder? (Hint: See p. 336.)

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INQUIRY
into Scientific Thinking

How Is Colorblindness Transmitted?

1. Copy the data table below into your notebook.

Trial	Colors	Sex of Individual	Number of X-linked Alleles for Colorblindness	Colorblind? (Yes/No)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

2. Label one plastic cup Mother and a second plastic cup Father.
3. The white beans represent X chromosomes.
    - Use a black marker to make a dot on each of 2 white beans. The dot represents the X-linked allele for colorblindness.
    - Place 1 marked bean into each plastic cup.

4. Place 1 more white bean into the cup labeled Mother.
5. Red beans represent Y chromosomes. Place 1 red bean into the cup labeled Father.
6. Close your eyes and pick one bean from each cup. This represents how each parent contributes a sex chromosome to a fertilized egg.
7. Record the data about the beans you picked.
    - Record the colors of the 2 beans in your data table.
    - Record the sex of an individual who would carry this pair of sex chromosomes.
    - Record how many X-linked alleles the individual has.
    - Put the beans back in the cups they came from.
    - Determine whether the individual would have colorblindness.
8. Repeat steps 6 and 7 for a total of 10 pairs of beans.

Analyze and Conclude

1. **Relate Cause and Effect** How do human sex chromosomes keep the numbers of males and females roughly equal?

2. **Calculate** Calculate the class totals for each data column.

a. How many females were colorblind?

Number of colorblind females = ________

Percentage of females who were colorblind = ________

b. How many males were colorblind?

Number of colorblind males = ________

Percentage of males who were colorblind = ________

3. **Interpret Data** How did the genotype of the parents affect your results?

In Your Workbook Get more help for this activity in your workbook.

14.2 Human Genetic Disorders

From Molecule to Phenotype

Have you ever heard the expression "It runs in the family"? Family and friends may have said that about your smile or the shape of your ears. But what could this mean when they talk about genetic diseases and disorders? What is a genetic disorder?

We know that genes are made of DNA. We also know that they interact with the environment to make an individual's characteristics, or phenotype. The link between molecule and trait is often that simple and direct. Genotype and phenotype are directly connected, since changes in a gene's DNA sequence can change proteins. Changes in the proteins cells make may directly affect one's phenotype. In other words, there is a molecular basis for genetic disorders.

Disorders Caused by Individual Genes Thousands of genetic disorders are caused by changes in individual genes. These changes often affect specific proteins that do important jobs.

▶ ***Sickle-Cell Disease*** This disorder is caused by a flawed allele for a polypetide in hemoglobin. Hemoglobin is the oxygen-carrying protein in red blood cells. The polypeptide made from the flowed allele makes hemoglobin molecules stick together at times. The attached molecules make long fibers that force the cells to be shaped like a sickle. This shape gives the disorder its name. Normal red blood cells are flexible. They can squeeze through tiny capillaries—the narrowest blood vessels in the body. Sickle-shaped cells are more rigid and tend to get stuck in the capillaries. If the blood stops moving through the capillaries, then damage to cells, tissues, and even organs can happen.

▶ ***Huntington's Disease*** Huntington's disease is caused by a dominant allele for a protein found in brain cells. The allele for this disease has a long string of bases. In the string, the codon CAG repeats over and over again, more than 40 times. CAG codes for the amino acid glutamine. No one knows for sure why this long string of glutamine causes the disease. People who have Huntington's disease suffer from decreasing mental abilities and uncontrollable movements. The symptoms usually do not appear until middle age. The greater the number of CAG codon repeats, the earlier the disease appears, and the more severe its symptoms are.

Key Questions

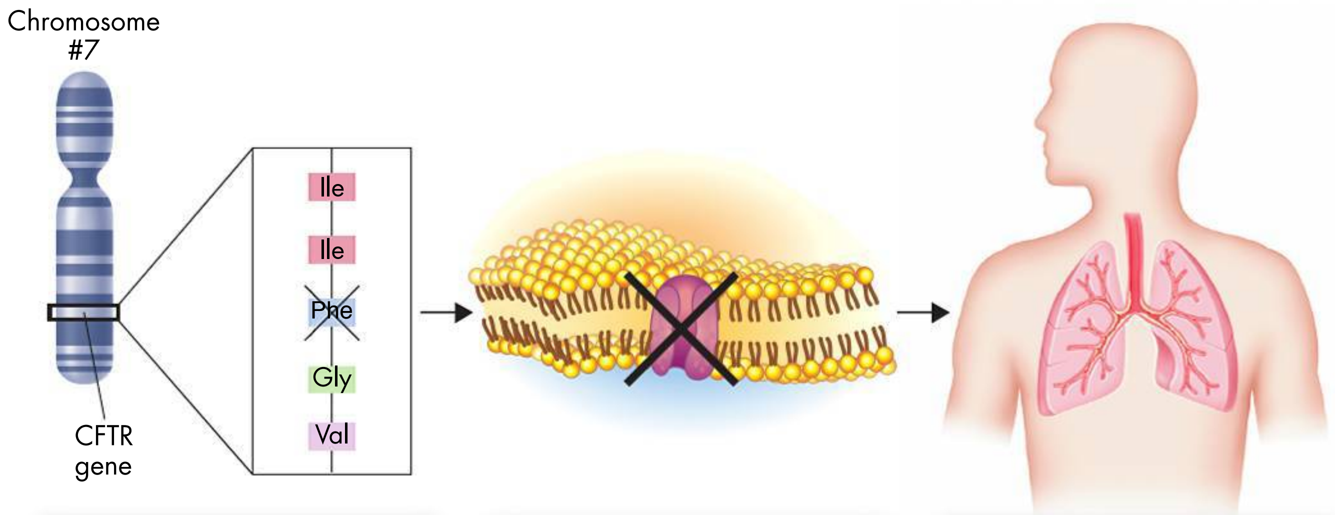
How do small changes in DNA molecules affect human traits?

What are the effects of errors in meiosis?

BUILD Understanding

Two-Column Chart Before you read, make a two-column chart. In the first column, write three questions you have about genetic disorders. As you read, fill in answers to your questions in the second column.

In Your Workbook Go to your workbook to learn more about making a two-column chart. Complete the chart in Lesson 14.2.



1 The most common allele that causes cystic fibrosis is missing 3 DNA bases. So the amino acid phenylalanine is missing from the CFTR protein.

2 Normal CFTR is a chloride ion channel in cell membranes. Abnormal CFTR cannot transport ions aross the cell membrane.

3 The cells in the person's airways cannot transport chloride ions. So the airways become clogged with a thick mucus.

Mutations Cause Cystic Fibrosis
CF is usually caused by the deletion of three bases in the DNA of a single gene. So, the body does not make normal CFTR. CTFR is a protein needed to transport chloride ions.

▶ ***Cystic Fibrosis*** Known as CF for short, cystic fibrosis is usually caused by the deletion of three bases in one gene. This gene codes for a protein called CFTR. The loss of these bases removes one amino acid from CFTR. This causes the protein to fold incorrectly, so the protein cannot do its job.

The CF allele is recessive, so two copies of the defective allele are needed to cause the disorder. People with one normal copy of the CF allele are unaffected by CF. Children with CF have trouble digesting food. They also make thick, heavy mucus that blocks their lungs and airways.

Key Question How do small changes in DNA molecules affect human traits?
Changes in a gene's DNA sequence can change proteins by altering their amino acid sequences. This may directly affect a person's phenotype.

Genetic Advantages Diseases such as sickle cell disease and CF are still common in human populations. Why are the alleles for these diseases still around if they can kill those who have them? Sometimes having just one recessive allele can be an advantage.

A parasite that lives in red blood cells causes a disease called malaria. But the parasite cannot live in sickled blood cells. People with one copy of the sickle cell allele are resistant to the parasite. This resistance gives them a big advantage against malaria.

More than 1000 years ago, terrible epidemics of typhoid fever spread through cities in Europe. Typhoid is caused by a bacterium that enters the body through cells in the digestive system. The protein made by the CF allele helps block this bacterium from entering the cells. People with a single CF allele were less likely to die from typhoid.

BUILD Vocabulary

nondisjunction
an error in meiosis in which the homologous chromosomes fail to separate properly

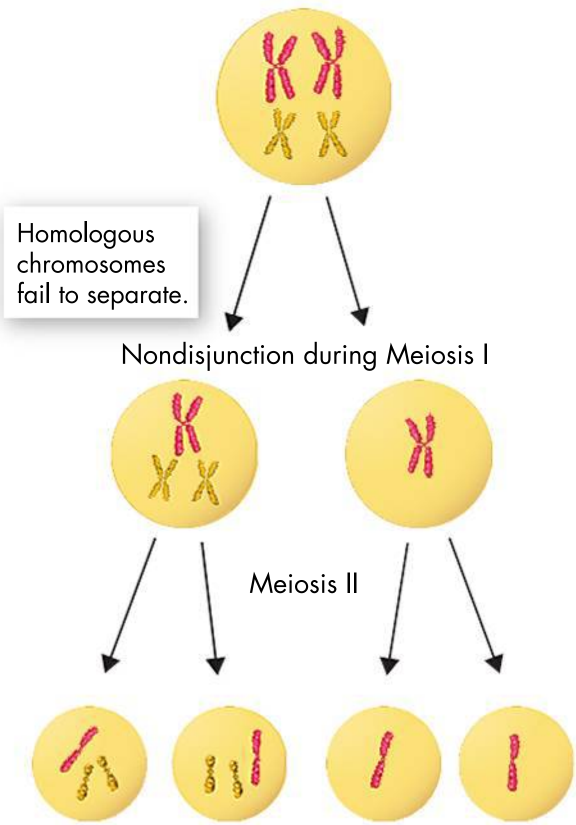
PREFIXES
The prefix *non-* is a negative prefix that means "not." Adding a negative prefix gives a new word that means the opposite of the root word. The word *disjunction* means "coming apart." So *nondisjunction* means "not coming apart."

Chromosomal Disorders

Meiosis usually works perfectly. Each human gamete, or sex cell, gets exactly 23 chromosomes. But occasionally something goes wrong. The most common error in meiosis occurs when homologous chromosomes do not separate. This mistake is called nondisjunction. **Nondisjunction** means "not coming apart."

If nondisjunction happens during meiosis, gametes can end up with the wrong number of chromosomes. This can lead to disorders. For example, if two copies of an autosomal chromosome fail to separate during meiosis, an individual may be born with three copies of that chromosome. This condition is called a trisomy. Down syndrome is trisomy of chromosome number 21. People with Down syndrome often have mental retardation and other birth defects.

Nondisjunction of sex chromosomes also causes problems. A female who inherits only one X chromosome usually has Turner's syndrome. Her sex organs do not develop at puberty, so she cannot have offspring. A male with an extra X chromosome has Klinefelter's syndrome. The extra chromosome interferes with meiosis, so the male usually cannot reproduce. There is no evidence of someone being born without any X chromosomes. So the genes on this chromosome are necessary for an embryo to survive and develop.



Nondisjunction This failure of meiosis causes gametes to have an abnormal number of chromosomes.

Key Question What are the effects of errors in meiosis?
If nondisjunction occurs during meiosis, gametes may receive an abnormal number of chromosomes. This change can lead to a disorder of chromosome numbers.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete the sentence correctly.

1. When homologous chromosomes do not separate properly during meiosis, it is called ________.

Critical Thinking

2. **Explain** How can a small change in a person's DNA cause a genetic disorder?

3. **Apply Concepts** How does nondisjunction cause chromosomal disorders?

4. **Write to Learn** Answer the second clue in the mystery. Think about how proteins are made.

MYSTERY CLUE

Sickle cell disease occurs because a single amino acid is different. This difference causes a change in one of the hemoglobin proteins. What could produce this change? (Hint: See p. 340.)

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14.3 Studying the Human Genome

Key Questions

What techniques are used to study human DNA?

What were the goals of the Human Genome Project, and what have we learned so far?

BUILD Understanding

Preview Visuals Before you read Lesson 3, look at the illustrations on the following page. Think of three questions you have about the illustrations.

In Your Workbook Write your questions in the chart in Lesson 14.3. As you read, write the answers to your questions.

BUILD Vocabulary

restriction enzyme
an enzyme that cuts DNA at a sequence of nucleotides

gel electrophoresis
a procedure used to analyze DNA fragments by placing a mixture of DNA fragments at one end of a porous gel and applying an electrical voltage to the gel

WORD ORIGINS

The root word *phoresis* is from the Greek *phorein*, which means "to carry." In electrophoresis, an electric current carries suspended particles through a medium.

Manipulating DNA

Only a few decades ago, computers were big machines found only in laboratories or universities. Today, many people carry small, powerful computers to school and work. Decades ago, the human genome was unknown. Now, we can see our entire genome on the Internet. How long will it be before having a copy of your own genome is as common as carrying a cell phone?

Since discovering the genetic code, biologists have dreamed of reading the human genome. For a long time, it seemed impossible because working with molecules as large as DNA is difficult. Then scientists discovered tools to cut, separate, and replicate DNA. Now they can read the base sequences in DNA from any cell.

Cutting DNA To study DNA, scientists first cut it into smaller pieces using bacterial enzymes called **restriction enzymes.** Restriction enzymes cut a DNA molecule into exact pieces called restriction fragments. Different enzymes cut DNA in different places, and into pieces of different sizes.

Separating DNA After DNA is cut, scientists use a technique called **gel electrophoresis** to separate and analyze the fragments of DNA. A mixture of DNA fragments is put at one end of a gel. An electric current makes the DNA move toward one end of the gel. Smaller DNA fragments move faster and farther than large ones. The result is a pattern of bands on the gel. The pattern is based on the size of the DNA fragments.

Reading DNA After the DNA fragments have been separated, researchers read, or sequence, the DNA. Single-stranded DNA fragments are put in a test tube with DNA polymerase. Then the bases, A, T, G, and C, are added. DNA polymerase uses the bases to make many new DNA strands. Some of the bases are labeled with a chemical dye. When a dye-labeled base is added to a new DNA strand, the synthesis of that strand stops. When all the synthesis is done, the result is a series of color-coded DNA strands. The strands are different lengths. Researchers can then separate these strands by size on a gel. The order of colored bands on the gel tells the exact sequence of bases in the DNA.

Key Question What techniques are used to study human DNA? **Scientists use tools that cut, separate, and then replicate DNA base by base. Now they can read the base sequences in DNA from any cell.**

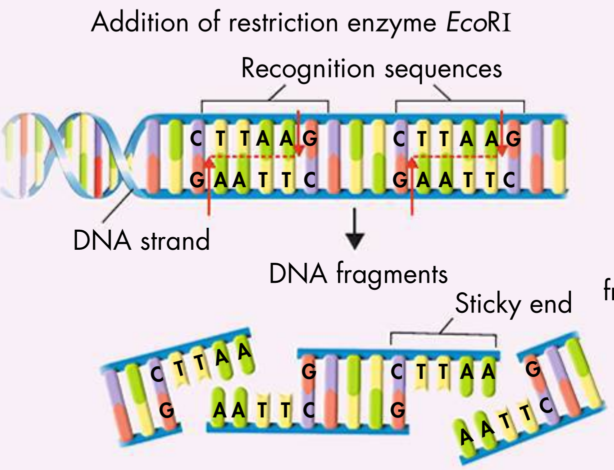
BUILD Connections

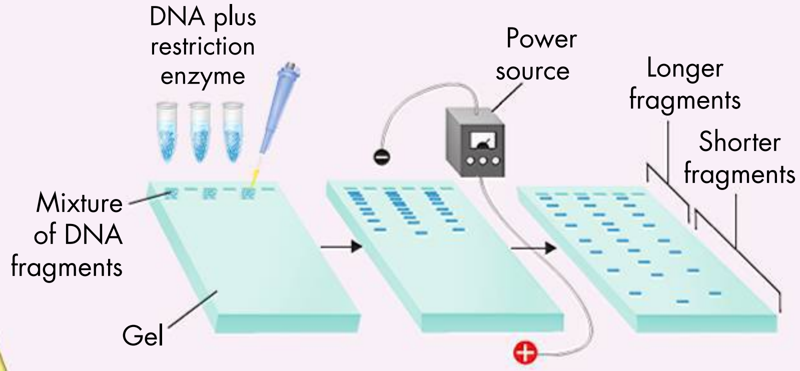
HOW SCIENTISTS MANIPULATE DNA

Scientists use tools to cut, separate, replicate, and sequence DNA. Knowing the sequence of DNA allows us to study specific genes.

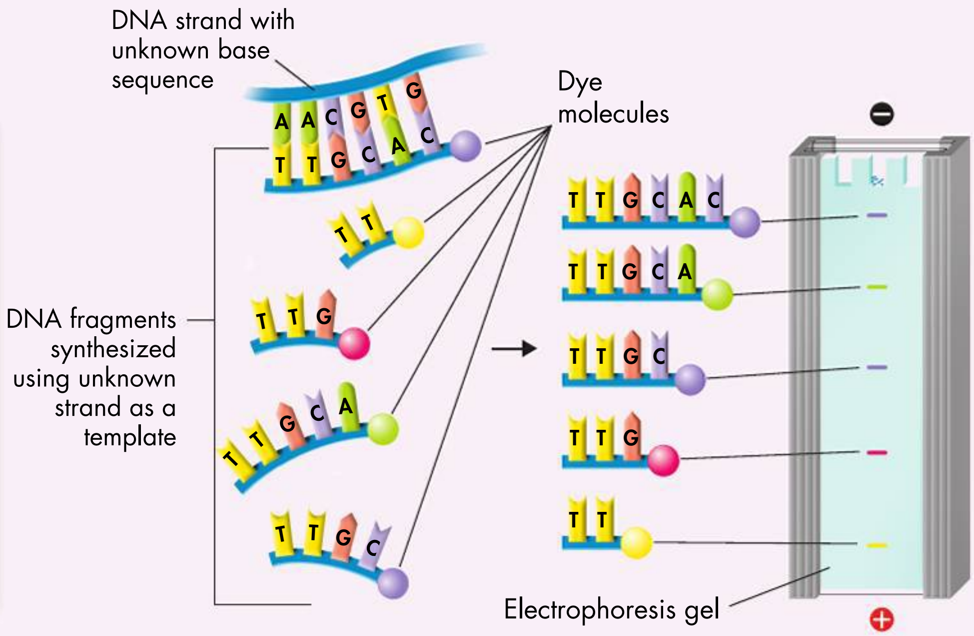
Cutting DNA
A restriction enzyme is like a key that fits only one lock. The *Eco*RI restriction enzyme can only recognize the base sequence GAATTC. It cuts each strand of DNA between the G and A bases. This cut leaves single-stranded overhangs with the sequence AATT. The overhangs are called "sticky ends." The ends can bond, or "stick," to a DNA fragment with the complementary base sequence.

Separating DNA
Gel electrophoresis is used to separate DNA fragments. The fragments are first cut by restriction enzymes. Then, the fragments are put into wells on a gel. The gel is like a slice of gelatin. An electric voltage moves the shorter fragments faster than the longer fragments. Within an hour or two, the fragments all separate. Fragments of the same size show up as a band on the gel.



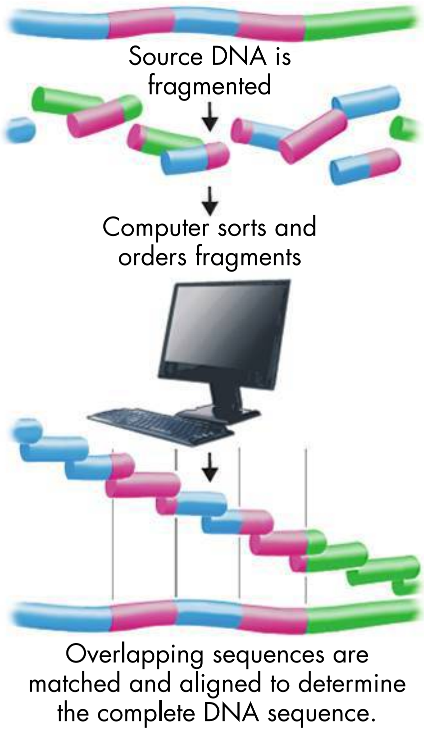


Reading DNA
Some dye-labeled bases are mixed in with the regular bases added to make the new DNA. Each time a labeled base is added to the strand, DNA replication for that strand stops. Each kind of base is labeled with a different color. This labeling results in color-coded DNA fragments of different lengths. Gel electrophoresis is used to separate the fragments. Then scientists can "read" the DNA sequence from the gel.



Base sequence as "read" from the order of the bands on the gel from bottom to top: **T G C A C**

Shotgun Sequencing
This method rapidly sorts DNA fragments by using overlapping base sequences.



The Human Genome Project

In 1990, the United States and other countries began the 13-year Human Genome Project. The project had two main goals. One goal was to sequence all 3 billion base pairs of human DNA. The other was to identify all human genes. DNA sequencing was at the center of the Human Genome Project. How do scientists handle a sequencing project that big? First, they break up the whole genome into smaller pieces. Next, they determine the base sequences in regions of a DNA strand that are far apart. These regions act as markers, like mile markers on a long highway. Using the markers, researchers can find and return to specific places in the DNA.

Sequencing and Identifying Genes Once researchers have marked the DNA strands, they cut them into random fragments. Then they determine the base sequence of each fragment. Computer programs put the fragments in order using the markers. This is called "shotgun sequencing." Scientists are now using this information to identify genes.

Comparing Sequences Most people have almost identical genomes. On average, only one base in 1200 will not match between two people. These single base differences are called SNPs (pronounced "snips"), which stands for single nucleotide polymorphisms. Some sets of closely linked SNPs occur together often. Scientists hope to be able to use these SNPs to identify various diseases and conditions.

Sharing Data The Human Genome Project was completed in 2003. Copies of the human genome DNA sequence are now available on the Internet. One of the key research areas of the project was a new field called **bioinformatics.** By 2003, scientist had determined the entire sequence. Scientists in this field use computer tools to collect, organize, and interpret biological data. Bioinformatics also began a similar field of study known as **genomics**—the study of whole genomes.

Key Question What were the goals of the Human Genome Project, and what have we learned so far?
The Human Genome Project had two main goals. One was to sequence all 3 billion base pairs of human DNA. The other was to identify all human genes.

What We Have Learned In 2000, scientists announced that a working copy of the human genome was complete. By 2003, scientists had determined the entire sequence. Scientists had learned that the human genome contains three billion nucleotide bases. They found surprises, too. Only about 2 percent of our genome has codes for making proteins. Many chromosomes have large areas with very few genes. The scientists discovered that much of our genome is made up of genetic code from viruses. The project also identified genes linked to many diseases and disorders. Finally, the project found three million locations where single base pairs are different in humans.

BUILD Vocabulary

bioinformatics
the application of mathematics and computer science to store, retrieve, and analyze biological data

genomics
the study of whole genomes, including genes and their functions

ROOT WORDS
The root word *informatics* refers to the creation, development, and operation of databases and other computing tools to collect, organize, and interpret data. The prefix *bio-* refers to life sciences. In bioinformatics, life science data are collected in databases.

Key Question What were the goals of the Human Genome Project, and what have we learned so far?

The Human Genome Project pinpointed genes. It matched some sequences in those genes with many diseases and disorders. It also identified about three million places where single-base DNA differences occur in humans.

New Questions The scientists in this project knew that their data could cause ethical, legal, and social problems. The problem areas include privacy, fairness in the use of and access to the data, and medical issues. In May 2008, the Genetic Information Nondiscrimination Act was passed into law. The act makes sure that U.S. companies cannot discriminate on the basis of information they learn from genetic tests.

What's Next There is much more to learn about the human genome. The 1000 Genomes Project began in 2008. It studies the genomes of 1000 people and builds a careful list of human variation. Data from the project will be used in studies of development and disease. The information may hold the key to successful research on new drugs. It may also lead to therapies to save human lives and keep people healthy.

Announcements
The first details of the human genome appeared in two well-known scientific journals in February 2001, *Science* and *Nature* (shown here).

CHECK Understanding

Apply Vocabulary

Use the highlighted terms from the lesson to complete each term correctly.

1. A scientist can use a ________ to cut a strand of DNA at a specific place.

2. ________ is the process that uses electrical current to separate DNA fragments by size.

3. ________ is a field of study that grew out of bioinformatics and includes the study of genes and their functions.

Critical Thinking

4. **Explain** What is the Human Genome Project?

5. **Apply Concepts** How might the Human Genome Project be used to benefit humankind?

6. **Write to Learn** Answer the third clue to the chapter mystery. How many bases are involved in the mutation?

MYSTERY CLUE

Scientists used SNPs to locate the sickle cell allele in genes that code for hemoglobin proteins. What does this tell you about the sickle cell mutation? (Hint: See p. 344.)

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Forensics Lab

GUIDED INQUIRY

Pre-Lab: Using DNA to Identify Human Remains

Problem How can pedigrees help scientists identify human remains?

Lab Manual Chapter 14 Lab

Skills Focus Analyze Data, Draw Conclusions

Connect to the Big idea The nucleus is not the only location in a cell where DNA can be found. DNA is also found in the mitochondria of cells. This mitochondrial DNA, or mtDNA, exists as small loops, rather than long strands. Unlike nuclear DNA, mtDNA is inherited only from the mother. Thus, except for mutations, the sequence of nucleotides in mtDNA remains constant over many generations.

Less than one percent of a cell's DNA is mtDNA, but in that percentage are many copies of the small mtDNA molecules. So when forensic scientists cannot collect a suitable sample of nuclear DNA, they look for mtDNA. Usable mtDNA can often be found even after a body decays or is burned. In this lab, you will explore how mtDNA was used to help confirm the identity of bones that scientists thought belonged to members of the Romanov family.

Background Questions

a. **Review** What is a pedigree?

b. **Explain** In a pedigree, what does a circle represent? What does a square represent?

c. **Infer** How do you know that mtDNA isn't sorted and recombined during meiosis?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Infer** The tsar and tsarina had five children. Did all seven family members have the same mtDNA? Give a reason for your answer.

2. **Predict** To confirm that bones belonged to the tsar's children, which living relative would be more useful—a relative of the tsar or a relative of the tsarina? Why?

The Romanovs ruled Russia for 300 years until the Bolshevik Revolution of 1918 resulted in the execution of Tsar Nicholas II and his family.

3. **Infer** If two people have the same mtDNA, what can you infer about their biological relationship?

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Visit Chapter 14 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video The Untamed Science crew identifies the chromosomes that carry genes for colorblindness.

Art in Motion View a short animation that explains nondisjunction.

Art Review Review your understanding of karyotypes with this drag-and-drop activity.

InterActive Art Learn all about pedigrees and how to make them with this animation.

Tutor Tube Why do traits sometimes "skip a generation"? Tune in to the tutor to find out.

14 CHAPTER Summary

14.1 Human Chromosomes

- A karyotype shows the complete diploid set of chromosomes. They are grouped in pairs and arranged from largest to smallest.
- Many human traits follow a pattern of simple dominance. The alleles for other human genes are codominant.
- Because the X and Y chromosomes determine sex, the genes located on them show a pattern of inheritance called sex-linkage.
- The information learned from pedigrees helps determine the nature of genes and alleles associated with inherited human traits.

genome (p. 334)
karyotype (p. 334)
sex chromosome (p. 334)
sex-linked gene (p. 336)
pedigree (p. 336)

14.2 Human Genetic Disorders

- Changes in a gene's DNA sequence can change proteins by altering their amino acid sequences. This change may directly affect a person's phenotype.
- If nondisjunction happens during meiosis, gametes may receive an abnormal number of chromosomes. This change can lead to a disorder of chromosome numbers.

nondisjunction (p. 341)

14.3 Studying the Human Genome

- Scientists use tools that cut, separate, and then replicate DNA base by base. Now they can read the base sequences in DNA from any cell.
- The Human Genome Project had two main goals. One was to sequence all 3 billion base pairs of human DNA. The other was to identify all human genes.
- The Human Genome Project pinpointed genes. It matched some sequences in those genes with many diseases and disorders. It also identified about 3 million locations where single-base DNA differences occur in humans.

restriction enzyme (p. 342)
gel electrophoresis (p. 342)
bioinformatics (p. 344)
genomics (p. 344)

14 CHECK Understanding

Assess the Big idea: Information and Heredity

Write an answer to the question below.
Q: How can we use genetics to study human inheritance?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs. To help you begin, read the **Hints** below the questions.

1. **How are sex-linked traits inherited?**

   Hint Females have two copies of the alleles on the X chromosome.

   Hint Sex-linked traits are controlled by alleles on the X chromosome.

2. **How can a substitution mutation in a gene affect the ability of a cell to function properly?**

   Hint A substitution mutation replaces one DNA base with another base in a codon.

   Hint A change in a DNA base may change the amino acid coded for by the codon.

3. **Describe the tools and processes scientists use to manipulate DNA.**

   Hint Restriction enzymes cut DNA into short fragments at known locations.

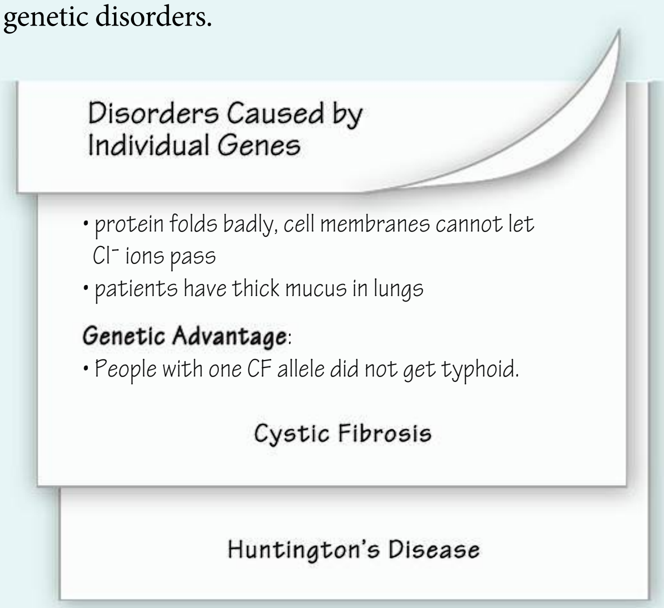
   Hint Gel electrophoresis separates DNA fragments by their size.

Foundations for Learning Wrap-Up

Use the layered books you made as you read this chapter as tools to study and review the concepts of the chapter.

Activity 1 Exchange a layered book you made with a partner who made a similar book. Read the books aloud to each other and compare them. Add notes to each book, and correct any errors you find.

Activity 2 Look through your layered books and find one about the Human Genome Project or genetic disorders. With a partner, make notes on the book about either social or ethical problems that came up because of the Human Genome Project. Or make notes about a genetic advantage of having one of the genetic disorders.



14.1 Human Chromosomes

Understand Key Concepts

1. A normal human diploid zygote contains
   a. 23 chromosomes. **c.** 44 chromosomes.
   b. 46 chromosomes. **d.** XXY chromosomes.

2. A chart that traces the inheritance of a trait in a family is called a(n)
   a. pedigree. **c.** genome.
   b. karyotype. **d.** autosome.

3. An example of a trait that is determined by multiple alleles is
   a. cystic fibrosis. **c.** Down syndrome.
   b. ABO blood groups. **d.** colorblindness.

4. Could a person with blood type alleles I^A and I^B have blood type A? Explain your answer (refer to the table on page 335).

Think Critically

5. **Predict** If a male is born colorblind, what do we know about his mother?

14.2 Human Genetic Disorders

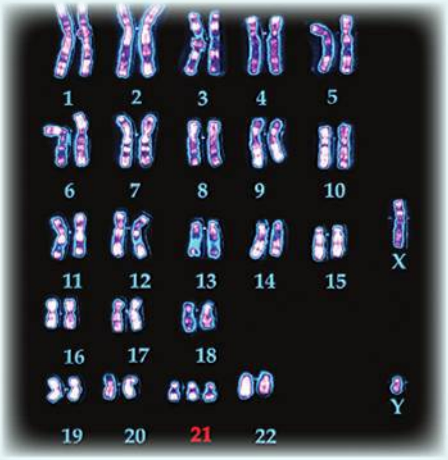
Understand Key Concepts

6. A mutation involving a change in a single DNA base pair
   a. will definitely result in a genetic disease.
   b. will have no effect on the organism's phenotype.
   c. will produce a positive change.
   d. may have an effect on the organism's phenotype.

7. Cystic fibrosis is caused by
   a. nondisjunction of an autosome.
   b. a small change of three base pairs in DNA.
   c. nondisjunction of a sex chromosome.
   d. deletion of an entire gene from a chromosome.

8. What is a chromosomal disorder?

9. Analyze the human karyotype below. Which chromosomal disorder does it show?



Think Critically

10. **Infer** Can a genetic counselor use a karyotype to identify a carrier of cystic fibrosis? Explain your answer.

14.3 Studying the Human Genome

Understand Key Concepts

11. The human genome consists of approximately how many DNA base pairs?
    a. 30,000 **c.** 300,000,000
    b. 3,000,000 **d.** 3,000,000,000

12. If you sequence short pieces of DNA and then use a computer to find overlapping sequences that map to a much longer DNA fragment, you are using
    a. genomics.
    b. hapmaps.
    c. shotgun sequencing.
    d. "sticky ends."

14 CHECK Understanding

13. Cutting DNA into small pieces that can be sequenced is done by
    a. restriction enzymes. **c.** gel electrophoresis.
    b. DNA polymerase. **d.** RNA polymerase.

Test-Taking Tip

Choose Among Similar Answers Sometimes eliminating a known incorrect answer only helps a little. In question 13, we can eliminate **c** because it does not involve a cutting process. We also know that cutting is done with enzymes. But we still have three enzymes as possible answers. The names of the enzymes give us clues. We eliminate **d** because it refers to RNA. Since we know that polymerases build strands of DNA, this means that the only possible correct answer is **a.**

14. Describe the tools and processes that scientists use to manipulate human DNA.

Think Critically

15. **Explain** What is bioinformatics?

Connecting Concepts

Use Science Graphics

Use the data table to answer questions 16–17.

Chromosomes and Phenotypes

Sex Chromosomes	Fruit Fly Phenotype	Human Phenotype
XX	Female	Female
XY	Male	Male
X	Male	Female
XXY	Female	Male

16. **Interpret Tables** Which organism requires a Y chromosome for maleness?
17. **Predict** Do you think the genes on the Y chromosome are necessary for survival? Explain your answer.

solve the CHAPTER MYSTERY

THE CROOKED CELL

Ava looked into her family's medical history. She found out that Uncle Eli's mother (Ava's grandmother) also had sickle cell disease. However, Uncle Eli's father did not. One of Ava's uncle's four children also had the disease. But Ava's father, who is Eli's only sibling, does not have sickle cell disease. Ava's mother does not have sickle cell disease, either. Ava's two siblings also show no signs of the disease.

1. **Apply Concepts** Does sickle cell disease follow a simple dominance pattern of heredity? Give evidence from the chapter and its clues to support your answer.
2. **Draw Conclusions** Think about your answer to question 1. What can you conclude about the inheritance of sickle cell disease in Ava's family? What might be Ava's chances of being a carrier of the sickle cell trait?
3. **Classify** What kind of medical test could Ava request that would help determine whether or not she has the sickle cell trait? Explain your answer.

UntamedScience™ **Never Stop Exploring Your World.** Finding out about Ava's risk of sickle cell disease is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Which of the following disorders can be observed in a human karyotype?
A colorblindness
B trisomy 21
C cystic fibrosis
D sickle cell disease

2. Which of the following disorders is a direct result of nondisjunction?
A sickle cell disease **C** Huntington's disease
B Turner's syndrome **D** cystic fibrosis

3. A woman is homozygous for A^- blood type. A man has AB^- blood type. What is the probability that the couple's child will have type B^- blood?
A 0% **C** 75%
B 50% **D** 100%

4. Cystic fibrosis is a genetic disorder caused by a
A single base substitution in the gene for hemoglobin.
B deletion of an amino acid from a chloride channel protein.
C defective gene found on the X chromosome.
D trisomy of chromosome 21.

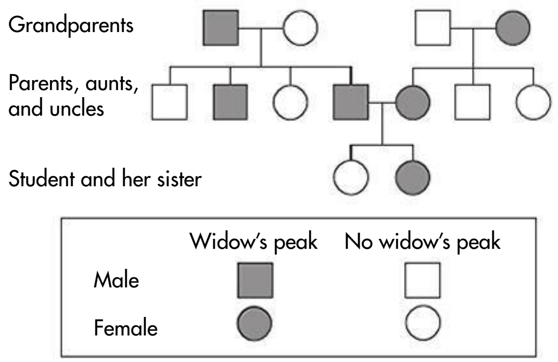
5. The technique used to separate DNA strands of different lengths is
A gel electrophoresis.
B shotgun sequencing.
C restriction enzyme digestion.
D bioinformatics.

6. The study of whole genomes, including genes and their functions, is called
A bioinformatics.
B information science.
C life science.
D genomics.

7. DNA can be cut into shorter sequences by proteins known as
A haplotypes.
B polymerases.
C restriction enzymes.
D restriction fragments.

Questions 8–9

A student traced the recurrence of a widow's peak hairline in her family. Based on her interviews and observations, she drew the pedigree shown below.



8. Which pattern of inheritance is consistent with the pedigree?
A sex-linked inheritance
B complete dominance
C codominance
D multiple alleles

9. What are the probable genotypes of the student's parents?
A Mother—Ww; Father—ww
B Mother—ww; Father—ww
C Mother—WW; Father—Ww
D Mother—Ww; Father—Ww

Open-Ended Response

10. Explain how the gene for sickle cell disease, which is a harmful gene when it is homozygous, can be beneficial when it is heterozygous.

If You Have Trouble With . . .

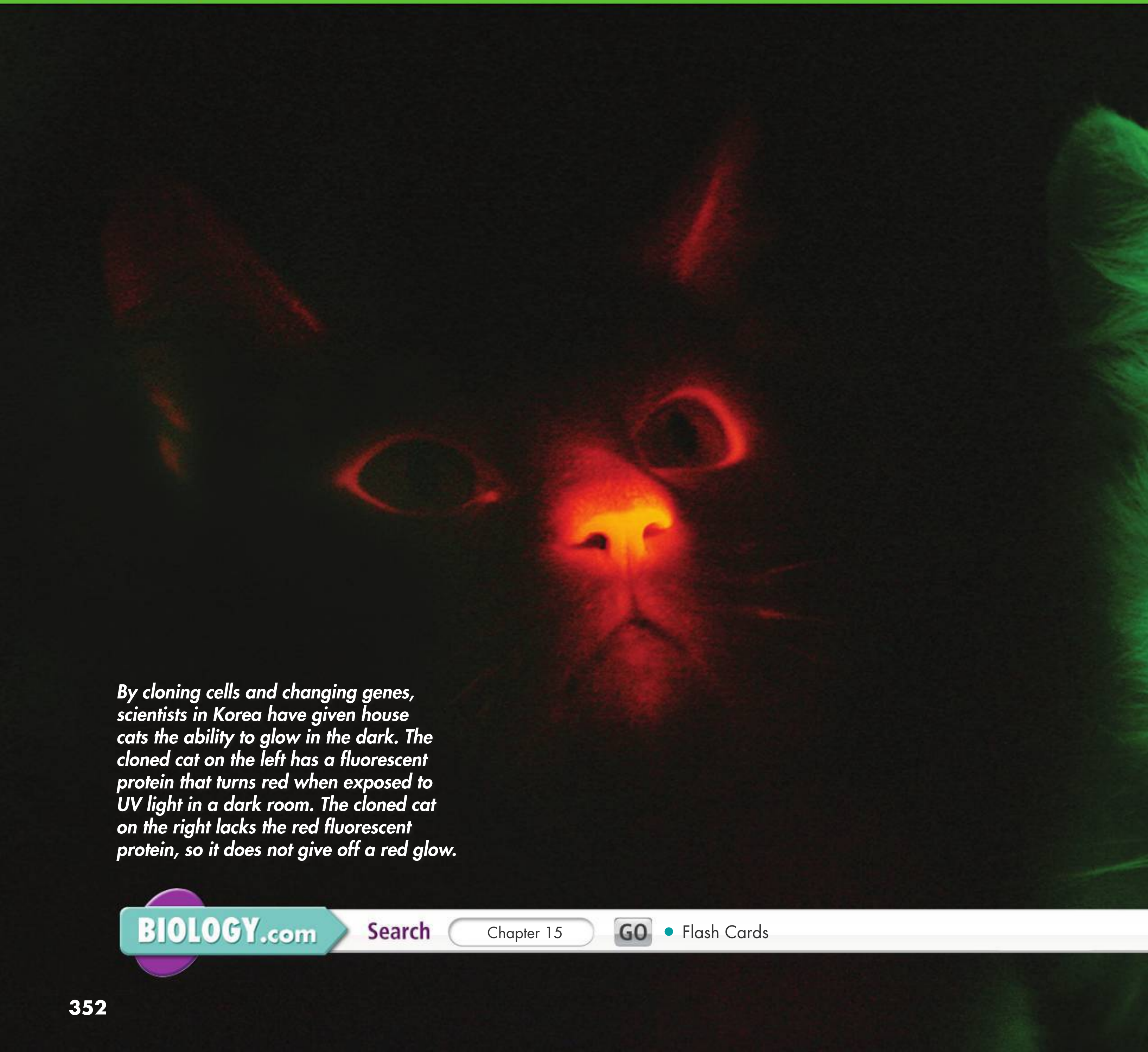
Question	1	2	3	4	5	6	7	8	9	10
See Lesson	14.1	14.2	14.1	14.2	14.3	14.3	14.3	14.1	14.1	14.2

15 Genetic Engineering

Big idea

Science as a Way of Knowing

Q: How and why do scientists manipulate DNA in living cells?



By cloning cells and changing genes, scientists in Korea have given house cats the ability to glow in the dark. The cloned cat on the left has a fluorescent protein that turns red when exposed to UV light in a dark room. The cloned cat on the right lacks the red fluorescent protein, so it does not give off a red glow.

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INSIDE:

- Untamed Science Video
- Chapter Mystery

CHAPTER
MYSTERY

A CASE OF MISTAKEN IDENTITY

In the summer of 1998, an elderly Indiana woman was brutally attacked. It was dark, and she couldn't see who hurt her. Soon afterward, police found a man only a few blocks from the victim's house. He was unconscious. His clothing was stained with blood. There were also scratches on his forearms. The man said that he had passed out following a drunken fight. He couldn't remember what had happened afterward. The blood type of the stains on his clothing matched the victim's blood type. The police thought they had their man.

Hours later, the police knew they had the wrong suspect. They began to search again for the real attacker, who was later caught, tried, and convicted.

Read for Mystery Clues As you read this chapter, look for clues to help you determine how the police knew they had the wrong suspect. Then, solve the mystery.

FOUNDATIONS for Learning

Before you read the chapter, make two six-sided cubes. First, draw a flat cube in the shape below. Then, cut the paper and fold it into a cube. As you read the chapter, write the vocabulary words on the sides of the cubes. Write one vocabulary word per side. At the end of the chapter are two activities that use the word cubes to help you answer the question: How and why do scientists manipulate DNA in living cells?

15.1 Selective Breeding

Key Questions

What is selective breeding used for?

How do people increase genetic variation?

BUILD Understanding

KWL Chart Use a KWL chart to organize your notes for this lesson. Before you begin reading, write down what you already know (K) about selective breeding. Write what you want to know (W) in the chart. Then after you read the lesson, go back and add notes about what you have learned (L).

In Your Workbook Go to your workbook to see an example of a KWL chart. Complete the KWL chart for Lesson 15.1.

Selective Breeding

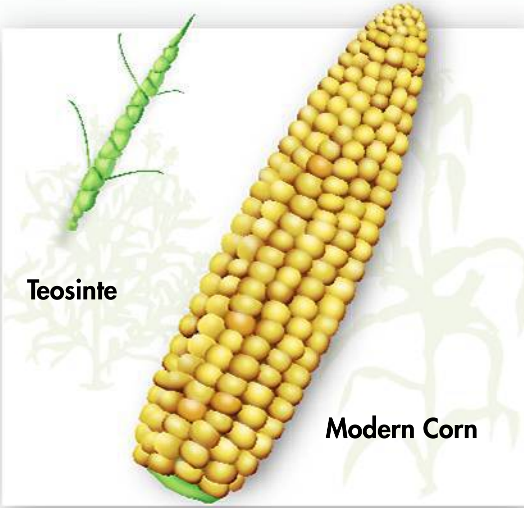
You've had popcorn at the movies. You've probably made it at home, too. Where does it come from? Believe it or not, popcorn was one of the first organisms humans improved for our own benefit. Corn as we know it was first grown as a crop at least 6000 years ago by Native Americans living in what is now Mexico. A tiny kernel of popped corn found in a cave in New Mexico is more than 5000 years old!

Humans have bred many organisms for our own benefit. Visit a dog show, and what do you see? You see dogs of all shapes and sizes. There are tiny Chihuahuas and huge Great Danes. There are Labrador retrievers with short coats and poodles with curly hair. You can see wolfhounds with long noses and bulldogs with short noses. The differences among breeds of dogs are so great that someone might think they are different species. They're not, of course, but where did these big differences come from?

The answer is selective breeding. Humans have kept and bred dogs for thousands of years. Humans are always looking to make animals that are better hunters, better retrievers, or better companions. We've done so by **selective breeding,** letting only those animals with desired characteristics produce the next generation.

Dog Breeds There are more than 150 dog breeds. New breeds are still being developed.

For thousands of years, we have produced new varieties of plants and animals. We did this by selectively breeding for particular traits. Long before Europeans came to the New World, Native Americans had selectively bred teosinte (tee oh SIN tee). Teosinte is a wild grass native to central Mexico. Teosinte was selectively bred to make corn. Corn is a far more productive and nutritious plant than teosinte. Corn is also now one of the world's most important crops. The two most common methods of selective breeding are hybridization and inbreeding.



Corn From Teosinte Modern corn was selectively bred from teosinte at least 6000 years ago. Over time, the hard case around the kernel disappeared, which left the rows of soft kernels that we enjoy today.

Hybridization American botanist Luther Burbank may have been the greatest selective breeder of all time. He developed more than 800 kinds of plants. As one of his tools, Burbank used hybridization. **Hybridization** is crossing organisms that have different traits to bring together the best of both organisms. The offspring made by such crosses are called hybrids. Hybrids are often hardier than either parent. Many of Burbank's hybrid crosses mixed the disease resistance of one plant with the food-making ability of another. The results were new lines of plants that had the traits farmers needed to make more food.

Inbreeding Breeders often use a method called inbreeding to keep desired characteristics in a line of organisms. **Inbreeding** is the continued breeding of individuals with similar characteristics. Many breeds of dogs are inbred. Inbreeding helps keep the characteristics that make each breed unique and helps make sure that those characteristics are preserved. Although inbreeding may seem like a good way to keep certain characteristics, it's risky business. Inbred organisms are genetically very similar. Therefore, inbreeding increases the probability that organisms may inherit alleles that lead to genetic disorders. For example, inherited hip problems are common to many breeds of dogs.

Key Question What is selective breeding used for?
Selective breeding takes advantage of naturally occurring genetic variation. Humans use selective breeding to pass wanted traits on to the next generation of organisms.

Increasing Variation

The great variety found in wild plants and animals makes selective breeding possible. But sometimes breeders want more variation than they find in the wild. Breeders can add to the genetic variation in a population by introducing mutations.

When scientists change the genetic makeup of an organism, they are using biotechnology. **Biotechnology** is the use of a technological process, invention, or method on living organisms. Selective breeding is one form of biotechnology important in farming and medicine, but there are many others.

BUILD Vocabulary

selective breeding
a method of breeding that allows only those organisms with desired characteristics to produce the next generation

hybridization
a breeding technique that involves crossing dissimilar individuals to bring together the best traits of both organisms

inbreeding
the continued breeding of individuals with similar characteristics to maintain the derived characteristics of a kind of organism

biotechnology
the process of manipulating the organisms, cells, or molecules to produce specific products

PREFIXES
Remember that the prefix *bio-* refers to living things. Also remember that *technology* refers to scientific tools. Biotechnology uses the tools of science to study and alter living things.

Bacterial Mutations Mutations are changes in DNA that parents can pass to offspring. Mutations often happen on their own. However, breeders can also make mutations happen using radiation and chemicals. Many mutations hurt or kill the organism. Some do not. With luck and patience, breeders can grow mutants that have new, helpful characteristics. This way of making mutants has been very useful with bacteria. Because they are small, millions of bacteria can be treated with radiation or chemicals at the same time. Since so many bacteria are treated, the chances of making a useful mutant are good. This technique has let scientists develop hundreds of useful kinds of bacteria. For example, scientists are working to make bacteria that can clean up radioactive substances and metal pollution.

Polyploid Crops

Plant	Probable Ancestral Haploid Number	Chromosome Number	Ploidy Level
Domestic oat	7	42	6N
Peanut	10	40	4N
Sugar cane	10	80	8N
Banana	11	22, 33	2N, 3N
Cotton	13	52	4N

Ploidy Numbers Polyploid plants are often larger than other plants. So, farmers grow many polyploid varieties of crops on purpose. This table shows some polyploid crops.

Polyploid Plants Drugs that keep chromosomes from separating during meiosis have been very useful in plant breeding. These drugs can make cells that have many times the normal number of chromosomes. Plants grown from these cells are called polyploid because they have many sets of chromosomes. Polyploidy is rare in animals. Plants, however, are much more likely than animals to survive with extra sets of chromosomes. Polyploidy can quickly make new kinds of plants that are larger and stronger than their diploid relatives. Scientists have made some important crop plants, including bananas and many varieties of citrus fruits, in this way.

Key Question How do people increase genetic variation?
Breeders can increase the genetic variation in a population by introducing mutations, which are the ultimate source of biological diversity.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. ________ is the process of crossing two individuals that are not genetically alike.

Critical Thinking

2. **Explain** How can breeders introduce mutations?

3. **Review** What is the relationship between genetic variation and mutations?

4. **Apply Concepts** Suppose you are a geneticist trying to develop a sunflower with red petals and a short stem. As you compare the sunflowers you have on hand, what genetic variations would you look for?

5. **Write to Learn** Answer the following question in two or three sentences: How is selective breeding a kind of biotechnology?

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15.2 Recombinant DNA

Copying DNA

Suppose you have an electronic game you want to change. If the game depends on a coded program in a computer microchip, you'd need to get the existing program out of the microchip. Then, you'd have to read the program and change it to your new program code. Finally, you would put the changed code back into the microchip. Believe it or not, this is very similar to genetic engineering.

How do you change an organism? Until recently, plant and animal breeders had to work with variations that already existed in nature. Now, scientists can transfer genes for particular traits from one organism to another. How does this gene transfer happen? Scientists first take DNA from cells. The DNA is then cut into pieces using restriction enzymes. Restriction enzymes cut DNA at specific base sequences. From a large DNA molecule, these enzymes may produce hundreds or even thousands of pieces. These pieces can then be separated by size.

If we were to cut DNA from the human genome, we might end up with millions of pieces of DNA. How do we find the DNA of a single gene among millions of pieces? It is kind of like finding a needle in a haystack. There is a huge pile of hay and one needle. Actually, you can find a needle in a haystack. You can toss the hay in front of a powerful magnet until something sticks. The hay won't stick, but a needle made of iron or steel will. Believe it or not, this method is similar to the way scientists find specific genes.

Finding Genes Douglas Prasher, a biologist, wanted to find a specific gene in a jellyfish. The gene codes for a molecule called green fluorescent protein, or GFP. This natural protein in the jellyfish absorbs energy from light and makes parts of the jellyfish glow.

To find the gene, Prasher studied the amino acid sequence of part of the GFP protein. Then, he figured out which mRNA sequence would make that protein. That mRNA sequence told him the DNA sequence of the gene. By making a piece of RNA that would match that DNA sequence, Prasher made the DNA "magnet" to find the GFP gene.

Key Questions

How do scientists copy the DNA of living organisms?

How is recombinant DNA used?

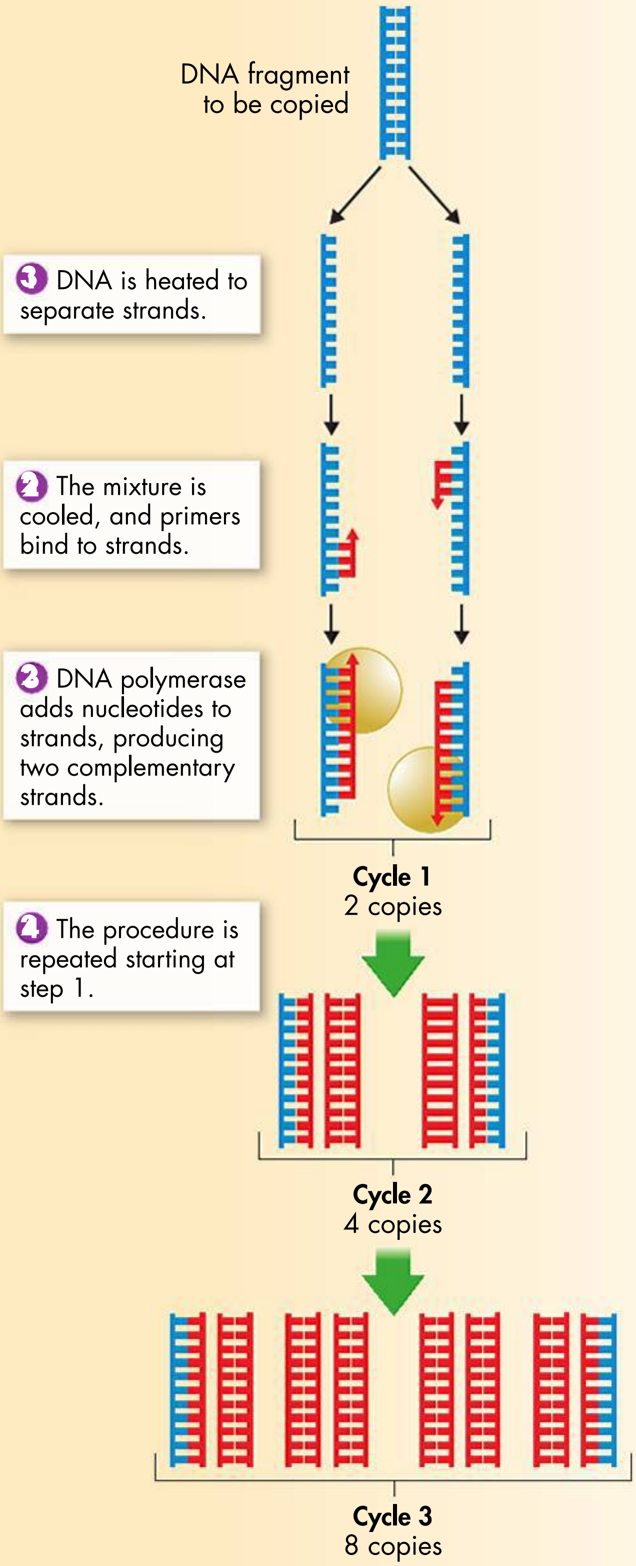
How can genes from one organism be inserted into another organism?

BUILD Understanding

Preview Visuals Before you read, preview the PCR Method figure. Write down any questions you have about the figure. As you read, find answers to your questions.

In Your Workbook Go to your workbook for help with previewing visuals.

Fluorescent Gene The Pacific Ocean jellyfish gives off a bluish glow. A protein in the jellyfish absorbs the blue light and makes green fluorescence. This protein, called GFP, is now used in genetic engineering.



The PCR Method Polymerase chain reaction is used to make multiple copies of a gene. This method is useful even when only tiny amounts of DNA are available.

Polymerase Chain Reaction Once they find a gene, biologists often need to make many copies of it. To do this, biologists use a technique known as **polymerase chain reaction (PCR).** At one end of the original piece of DNA, a biologist adds a short piece of DNA that complements a portion of the sequence. At the other end, the biologist adds another short piece of complementary DNA. These short pieces are known as primers because they prepare, or prime, a place for DNA polymerase to start working.

The first step in using the PCR method to copy a gene is to use heat to separate the strands of a piece of DNA. Then, as the DNA cools, primers bind to the single strands. Next, DNA polymerase starts copying the DNA between the primers. These copies become templates used to make even more copies of the gene. In this way, just a few dozen cycles of copying the DNA can make billions of copies of a gene.

Key Question How do scientists copy the DNA of living organisms?
The first step in using the polymerase chain reaction method to copy a gene is to heat a piece of DNA, which separates its two strands. Then, as the DNA cools, primers bind to the single strands. Next, DNA polymerase starts copying the region between the primers. These copies can serve as templates to make more copies.

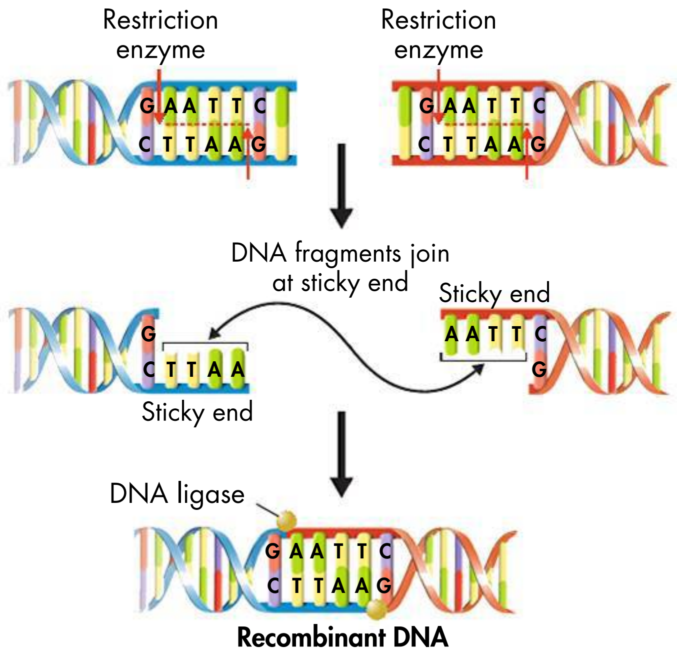
Changing DNA

Do you remember reading about Griffith's experiments on bacterial transformation? During transformation, a cell takes in DNA from outside the cell. Then that added DNA becomes part of the cell's own genome. Today, biologists know that Griffith's mixture of heat-killed bacteria had pieces of DNA in it. When he mixed those pieces of DNA with live bacteria, a few bacteria took up the DNA. Those bacteria cells changed. Griffith could do this only with DNA taken from other bacteria.

Combining DNA Fragments Today, scientists can make the DNA for any gene whose sequence they know. They can then put those genes into living cells. Changing genes for a practical purpose is called genetic engineering. How do scientists do this?

First, they build a DNA sequence with the gene or genes they want to put into a cell. Machines known as DNA synthesizers can make short pieces of DNA. These pieces made in a lab can then be joined to natural pieces of DNA using enzymes such as DNA ligase (LY gays). These enzymes join DNA molecules together. These same enzymes make it possible to take a gene from one organism and attach it to the DNA of another organism. DNA molecules made this way are called **recombinant DNA.** This technology works because any pair of complementary DNA sequences is likely to bond. They will bond even if each sequence comes from a different organism. Recombinant-DNA technology makes it possible to change the genetic makeup of living organisms. By working with DNA in this way, scientists can study how genes are put together and how they work.

Key Question How is recombinant DNA used?
Recombinant-DNA technology—joining together DNA from two or more sources—makes it possible to change the genetic composition of living organisms.

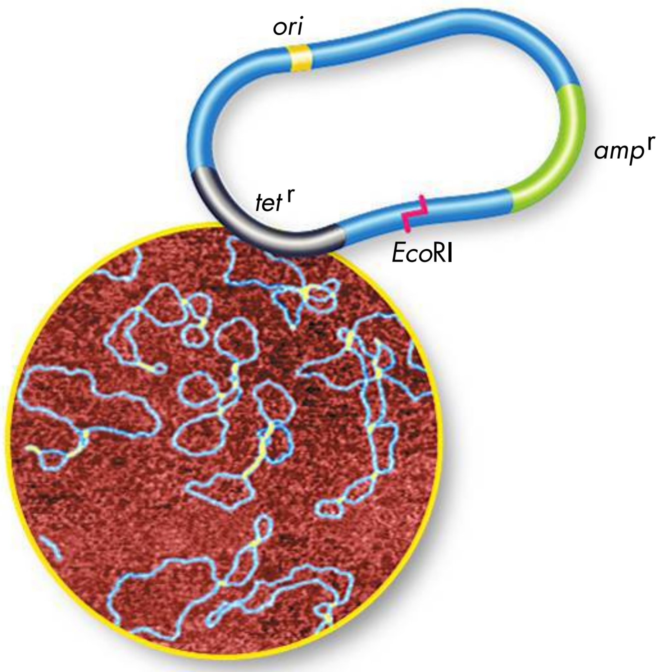


Joining DNA Pieces Together Recombinant DNA molecules are made up of DNA from different sources. Restriction enzymes cut DNA at specific sequences, making "sticky ends." Sticky ends are single-stranded bases of DNA at the end of a piece of DNA. DNA ligase allows two single-stranded pieces that are complementary to each other to stick together.

Plasmids and Genetic Markers

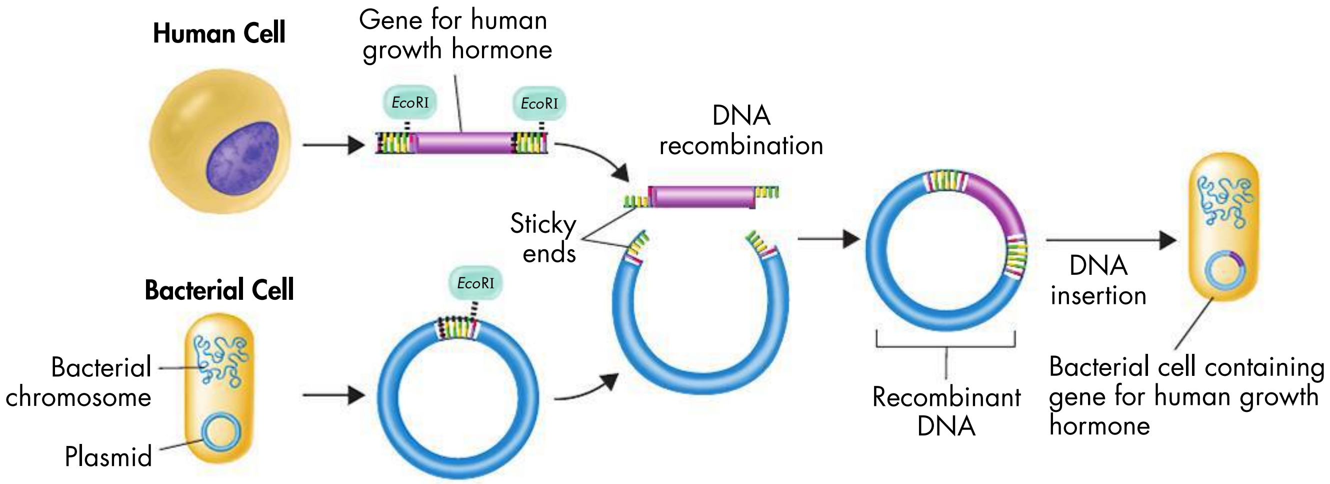
Scientists working with recombinant DNA soon learned a few useful tricks. In addition to their own large chromosomes, some bacteria have small circular DNA molecules called **plasmids.** One reason plasmids are useful is that they have their own replication "start" signals. That way, when the cell copies its own DNA, it copies the plasmid, too.

Plasmids are often used in recombinant DNA studies. Scientists insert a desired piece of DNA into a plasmid. Then they use transformation to add the recombinant plasmid to bacteria. The bacteria will then copy the new DNA along with the rest of the cell's genome.



TEM 75,000×

A Plasmid Map Plasmids used for genetic engineering have a start signal, called the origin of replication (*ori*). They have a restriction enzyme cutting site, such as *Eco*R1. They also have genetic markers, like the antibiotic resistance genes *tet*r and *amp*r shown here.



Plasmid DNA Transformation Scientists can insert a piece of DNA into a plasmid if both the plasmid and piece of DNA have been cut by the same restriction enzyme. In this example, the gene for human growth hormone is added to a bacterial cell. First a human gene is inserted into bacterial DNA. Then the new combination of genes is put back into a bacterial cell. The cell then copies the recombinant DNA over and over again.

Transforming Bacteria How do scientists transform bacteria? First, a piece of DNA is joined to a plasmid. The plasmid DNA has a signal that starts replication. The plasmid also has one or more genetic markers. A genetic marker allows a scientist to identify which bacteria carry the plasmid. An example of a genetic marker is a gene for antibiotic resistance. This gene keeps the bacteria alive in the presence of antibiotics. Researchers mix recombinant plasmids with bacteria. Only about one cell in a million may take up the plasmids, but that's more than enough. After transformation, the bacteria are treated with an antibiotic. Only those few cells that have been transformed survive, because only they carry the antibiotic-resistance gene.

Transgenic Organisms

Most living things share the same genetic code. So, scientists can make organisms that are transgenic. **Transgenic** organisms have genes from other organisms. They can be made by putting recombinant DNA into the genome of a host. The DNA molecules used for transformation of plant and animal cells have genetic markers so scientists can tell which cells have been transformed. Genetic engineers can make transgenic plants, animals, and microorganisms. By studying the traits of a genetically changed organism, scientists can learn about the function of the transferred gene. This has helped us learn much more about genes.

Transgenic Plants Many plant cells can be transformed using *Agrobacterium*. This bacterium inserts a small DNA plasmid that makes tumors in a plant's cells. Scientists can turn off the plasmid's tumor-making gene and replace it with a piece of recombinant DNA. The recombinant plasmid can then be used to transform plant cells.

Transgenic Animals Scientists can transform animal cells, too. The egg cells of many animals are large enough that DNA can be injected into the nucleus. Once the DNA is in the nucleus, enzymes help insert the new DNA into the chromosomes of the host cell.

BUILD Vocabulary

polymerase chain reaction a technique that allows biologists to make many copies of a gene

recombinant DNA DNA produced by combining DNA from different sources

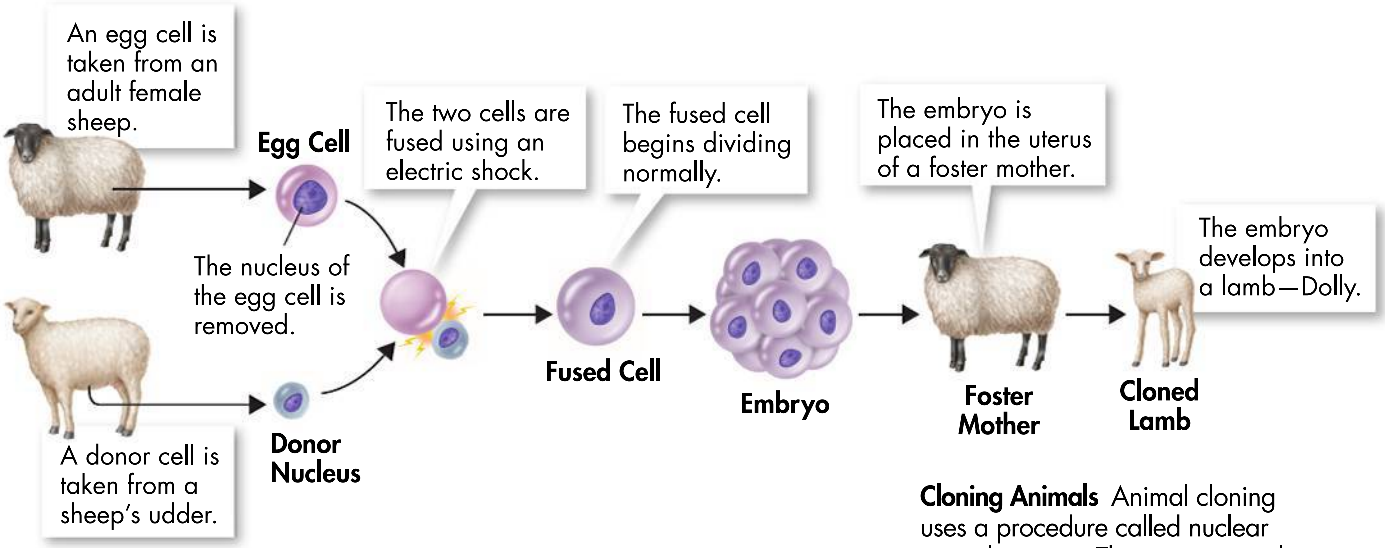
plasmid a small, circular piece of DNA located in the cytoplasm of many bacteria

transgenic a term used to refer to an organism that contains genes from other organisms

clone a member of a population of genetically identical cells produced from a single cell

PREFIXES

The prefix *trans-* means "cross." Genes in transgenic organisms have crossed from one organism to another.



Cloning Animals Animal cloning uses a procedure called nuclear transplantation. The process combines an egg cell with a donor nucleus to make an embryo.

DNA molecules can also be made with two ends that can recombine with specific sequences in the host chromosome. Once they do, the host gene found between those two sequences is replaced with a new gene. This kind of gene replacement has helped scientists figure out the roles of genes in many organisms.

Key Question How can genes from one organism be inserted into another organism? **Transgenic organisms can be produced by the insertion of recombinant DNA into the genome of a host organism.**

Cloning A **clone** is a member of a group of genetically identical cells made from a single cell. Cloning uses a single cell from an adult organism to grow a new individual. That individual, then, is genetically identical to the organism from which the cell was taken.

Cloned colonies of bacteria and other microorganisms are easy to grow. Multicellular organisms, such as animals, are harder to grow. In 1997, Scottish scientist Ian Wilmut announced that he had made a sheep, called Dolly, by cloning. The figure above shows the process.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. ______ are small rings of DNA found in bacteria and yeast.

Critical Thinking

2. **Infer** Why would a scientist want to know the sequence of a DNA molecule?

3. **Explain** How do scientists use recombinant DNA?

4. **Write to Learn** Answer the first mystery clue.

MYSTERY CLUE

How could restriction enzymes be used to analyze the DNA evidence found on the suspect? (Hint: See page 357.)

BIOLOGY.com Search Lesson 15.2 GO • Lesson Assessment

15.3 Applications of Genetic Engineering

Key Questions

How can genetic engineering benefit agriculture and industry?

How can recombinant-DNA technology improve human health?

How is DNA used to identify individuals?

BUILD Understanding

Main Idea and Details Chart
Taking notes is a way to organize the information you read. One way to take notes is to make a main idea and details chart while you read. Include details or evidence that supports each important idea.

In Your Workbook
Go to your workbook for more about using a main idea and details chart to organize information.

Agriculture and Industry

Have you eaten any corn, potatoes, or soy products recently? If so, then you have probably eaten something that was modified by genetic engineering. Everything we eat and much of what we wear come from living organisms. Researchers have used genetic engineering to try to improve the products we get from plants and animals.

GM Crops Since 1996, genetically modified (GM) plants have become an important part of our food supply. One type of modification has already been very useful to agriculture. It uses bacterial genes that make a protein called Bt toxin. This toxin is harmless to humans and most other animals. However, it kills the insects that eat it. So, plants with the Bt gene do not have to be sprayed with pesticides. They make more food per acre than unmodified plants, too. Scientists are also adding other traits to crops. Some are making plants that are resistant to viruses. Others are making crops that are slower to rot and spoil.

GM Animals Transgenic animals are also becoming more important to our food supply. For example, many dairy farms now raise cows that have been injected with hormones made by recombinant-DNA techniques. The hormones help the cows make more milk. Pigs can be genetically modified so they make leaner meat and cleaner wastes. Using growth-hormone genes, scientists have made transgenic salmon that grow much more quickly than wild salmon. This makes the fish easier to farm.

Key Question How can genetic engineering benefit agriculture and industry? **Ideally, genetic modification could lead to better, less expensive, and more nutritious food as well as less harmful manufacturing processes.**

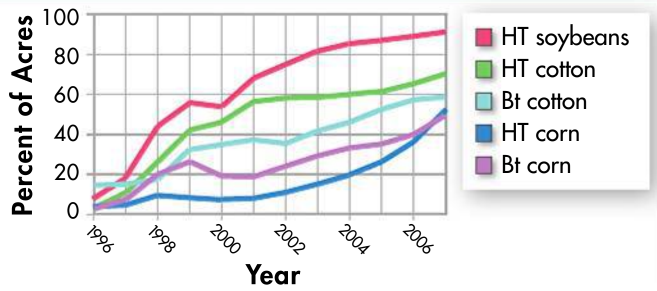
Antibacterial Goat Milk
Scientists are working to add a gene for a natural antibiotic to the DNA of goats. Milk from these goats may help prevent infections in young children who drink it.

INQUIRY
into Scientific Thinking

Genetically Modified Crops in the United States

U.S. farmers have started using many GM crops. Soybeans, cotton, and corn have been modified to tolerate herbicides and resist insect damage. The graph at the right shows the extent to which these crops were adopted between 1996 and 2007. The modified traits shown here include herbicide tolerance (HT) and insect resistance (Bt).

Genetically Modified Crops in the U.S.



1. **Analyze Data** Which two crops were most widely and rapidly adopted?
2. **Draw Conclusions** Why do you think the levels of adoption fell at certain points over the period?
3. **Explain** Why can't the line showing the adoption of modified soybeans continue to grow past the 100 percent mark of the graph?
4. **Infer** What would happen to herbicide-tolerant plants when farmers sprayed herbicide on the crops to kill weeds growing near them?

In Your Workbook Get more help for this activity in your workbook.

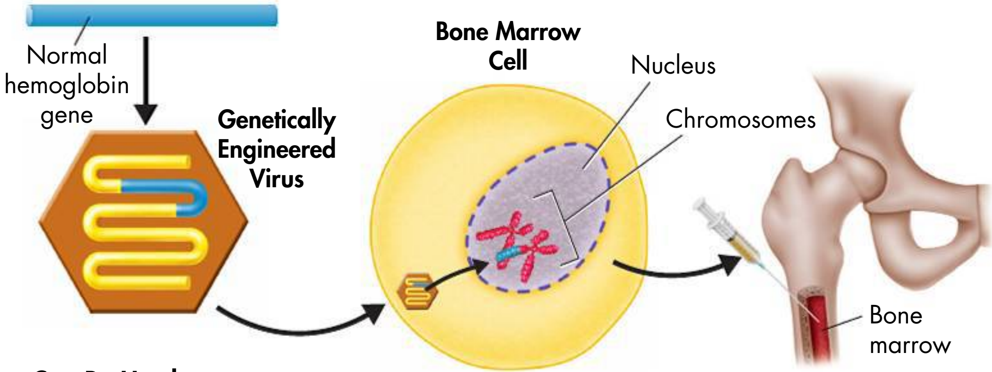
Health and Medicine

In a way, biotechnology has always been a part of medicine. Early physicians used substances from plants and animals to cure their patients. In the twentieth century, the use of vaccinations saved countless lives. Today, recombinant-DNA technology is the source of some of the most important and exciting advances in the prevention and treatment of disease.

Preventing Disease One interesting development in transgenic technology is golden rice. This rice contains increased amounts of provitamin A. A lack of provitamin A causes infant blindness and other problems. There is hope that provitamin A-rich golden rice will help prevent these problems. Some scientists are making transgenic plants and animals that make human antibodies to fight disease. Several laboratories have made transgenic sheep and pigs that make important human proteins in their milk. Many of these proteins can be taken from the milk and used as medicines in people.

Medical Research Transgenic animals are often used as test subjects in medical research. They can sometimes model human diseases caused by defective genes. Scientists can study a disease and then use the models to test new drugs that may help treat the disease.

Vitamin-Rich Rice Golden rice is a GM plant that has high levels of provitamin A. Two genes engineered into the rice genome help the grains produce and accumulate provitamin A.



How Gene Therapy Can Be Used
Gene therapy uses normal genes to add to or replace defective genes or to boost a normal function like immunity.

Treating Disease Recombinant DNA can be used to make important proteins that can save human lives. Products now made in genetically engineered bacteria include insulin to treat diabetes, blood-clotting factors for hemophiliacs, and human growth hormone.

Scientists are now trying to learn how to fix faulty genes in people. **Gene therapy** is the process of changing a gene to treat a disease or disorder. In gene therapy, a missing or faulty gene is replaced with a normal, working gene. This process lets the body make the protein or enzyme it needs. How are genes added to human cells? First, scientists make a virus that cannot reproduce and hurt people. Then they put DNA that has the working gene into their modified virus. Next, they infect the patient's cells with the virus carrying the gene. With luck, the virus will insert the healthy gene into the cells that need it and correct the problem.

Genetic Testing Suppose a couple wants to have children. Could they find out if they are carrying an allele for a genetic disorder? Genetic tests are now available for diagnosing hundreds of different disorders. For example, the CF allele has slightly different DNA sequences than the normal allele. So, genetic tests use a piece of DNA that is complementary to a defective allele to find that allele. Other genetic tests search for changes in cutting sites of restriction enzymes.

Examining Active Genes By studying which genes are active in cells, scientists can learn how cells work. Active genes make mRNA. So, scientists use a test to see what kinds of mRNA are in different kinds of cells. DNA microarray technology lets scientists learn the activity levels of thousands of genes at once. A **DNA microarray** is a glass slide to which spots of sequenced, single-stranded DNA have been tightly attached. Scientists then get mRNA from a cell they want to study. They make and label single-stranded DNA from the mRNA. Then, they add their labeled DNA to the wells of the array. They can tell which of the genes of the cell are active because the wells with those genes will also have labeled DNA.

Key Question How can recombinant-DNA technology improve human health?
Today recombinant-DNA technology is the source of some of the most important and exciting advances in the prevention and treatment of disease.

BUILD Vocabulary

gene therapy
a process of changing a gene to treat a medical disease or disorder. An absent or faulty gene is replaced by a normal working gene.

DNA microarray
the glass slide or silicon chip that carries thousands of different kinds of single-stranded DNA fragments arranged in a grid

DNA fingerprinting
a tool used by biologists to determine whether two samples of genetic material are from the same person

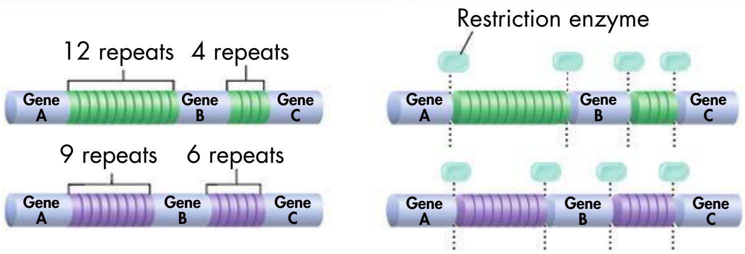
forensics
the scientific study of crime scene evidence

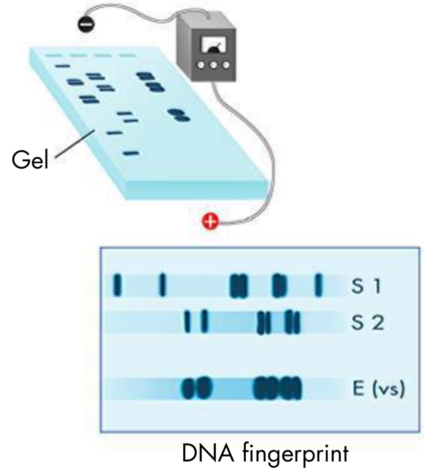
USING PRIOR KNOWLEDGE
You may have learned that physical therapy is a way to help people recover from physical problems. Gene therapy helps people recover from genetic disorders.

1 Chromosomes contain many regions with repeated DNA sequences that do not code for proteins. These vary from person to person. Here, one sample has 12 repeats between genes A and B, while the second sample has 9 repeats between the same genes.

2 Restriction enzymes are used to cut the DNA into fragments containing genes and repeats. Note that the repeat fragments from these two samples are of different lengths.

3 The restriction fragments are separated according to size using gel electrophoresis. The DNA fragments containing repeats are then labeled using radioactive probes. This labeling produces a series of bands–the DNA fingerprint.





Identifying Individuals
DNA fingerprinting is useful in solving crimes. The diagram shows how scientists match DNA evidence from a crime scene with two possible suspects.

Personal Identification

The human genome is so complex that no individual has DNA exactly like another individual. Identical twins are the only exception. Molecular biology has used this fact to make a powerful tool called DNA fingerprinting that is used to identify individuals. **DNA fingerprinting** analyzes pieces of DNA that may have little or no function in a cell. However, these pieces, called restriction fragments, vary widely from one person to another. How do scientists make a DNA fingerprint? DNA samples can be taken from blood or any other tissue. Then, restriction enzymes cut the DNA into pieces. Next, gel electrophoresis separates the pieces by size. A DNA probe finds the fragments that have highly variable regions. This is shown as a series of DNA bands on the gel. If enough enzymes and probes are used, the pattern of bands from one person is unlike anyone else's pattern of bands.

Forensic Science DNA fingerprinting has been used in the United States since the late 1980s. It has been of great help in **forensics**—the scientific study of crime scene evidence. DNA fingerprinting has helped solve crimes, convict criminals, and even overturn guilty verdicts. To date DNA evidence has saved more than 110 persons who were sentenced to death for crimes they didn't commit.

DNA forensics is used in wildlife conservation as well. African elephants are a highly vulnerable species. Poachers kill the animals illegally for their valuable tusks. To stop the ivory trade, African officials now use DNA fingerprinting to identify the herds from which the ivory has been taken.

Identifying Individuals
The pattern on this DNA fingerprint can belong to only one person.

Establishing Relationships How can we figure out who is the biological father of a child? DNA fingerprinting makes it easy to find alleles carried by the child that do not match those of the mother. Any such alleles must come from the child's biological father. The alleles will show up in the father's DNA fingerprint.

When genes are passed from parent to child, genetic recombination mixes up the molecular markers used for DNA fingerprinting. So, ancestry can be difficult to trace. There are two ways to solve this problem. The Y chromosome never undergoes crossing over, and only males carry it. So, Y chromosomes pass directly from father to son with few changes. The small DNA molecules found in mitochondria pass from mother to child with few changes. Mitochondria are organelles that release energy from sugar to power cells. They also carry DNA. It rarely changes. The DNA in mitochondria is passed from mother to child in the cytoplasm of the egg cell. These genetic markers can be used to trace ancestry over many generations.

Because mitochondrial DNA (mtDNA) is passed directly from mother to child, your mtDNA is the same as your mother's mtDNA, which is the same as her mother's mtDNA. This means that if two people have an exact match in their mtDNA, then there is a very good chance that they share a common maternal ancestor. Y-chromosome analysis has been used in the same way and has helped researchers settle longstanding historical questions.

Key Question How is DNA used to identify individuals?
DNA fingerprinting analyzes sections of DNA that may have little or no function but that vary widely from one individual to another.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. An absent or faulty gene is replaced by a normal working gene using ______.
2. The study of blood or other crime scene evidence is ______.

Critical Thinking

3. **Apply Concepts** What is golden rice, and how has it helped people?
4. **Explain** What are the steps in DNA fingerprinting?
5. **Write to Learn** Write a paragraph that answers the chapter mystery clue.

MYSTERY CLUE

What kind of evidence do you think investigators collected at the crime scene? What kinds of tests would they have run on this evidence? What would the tests have to show before the suspect was released? (**Hint:** See p. 365.)

BIOLOGY.com Search Lesson 15.3 GO • Lesson Assessment

15.4 Ethics and Impacts of Biotechnology

Profits and Privacy

Who owns your genes? Could someone else use the information in your genes? When biotechnology and drug companies develop GM plants and animals, they protect their discoveries and innovations with patents. A patent is a legal tool that gives an individual or company the exclusive right to profit from its innovations for a number of years.

Patenting Life When you think about patents, you might think about an inventor protecting a new machine. However, molecules and DNA sequences can be patented, too. One fifth of the known genes in the human genome have been patented. Even laboratory techniques like PCR have been patented.

The ability to patent is meant to encourage new discovery. After all, patent holders have a good chance of making money. Sometimes, though, patent holders demand high fees that block other scientists from doing their research.

Now think about the information held in your own genome. Do you have exclusive rights to your DNA? Should you, like patent holders, be able to keep your genetic information confidential? When it comes to your own DNA, how much privacy are you entitled to?

Key Question What privacy issues does biotechnology raise? **Do you have exclusive rights to your DNA? Should you, like patent holders, be able to keep your genetic information confidential?**

Genetic Ownership People who serve in the U.S. armed forces give a DNA sample when they begin serving. Those DNA samples are used, if needed, to identify the remains of people who die in the line of duty. But what if the government wants to use a person's DNA sample for other tests? What if health-insurance companies want to refuse coverage to people who have a gene that makes them more likely to get an illness? The U.S. Congress debated these issues. The Genetic Information Nondiscrimination Act was signed into law in 2008. This act protects Americans against discrimination based on their genetic information.

Key Questions

- ***What privacy issues does biotechnology raise?***
- ***Are GM foods safe?***
- ***Should genetic modifications to humans and other organisms be closely regulated?***

BUILD Understanding

Two-Column Table As you read the lesson, think about the ethical issues involved in genetic engineering. Write the positives in a column titled Pros. Write the negatives in a column titled Cons.

In Your Workbook Go to your workbook to learn more about using a two-column table.

Unknown Identities The Tomb of the Unknowns in Arlington National Cemetery holds the remains of unknown American soldiers. DNA testing now helps identify the remains of all U.S. military personnel who die in the line of duty.

Safety of Transgenics

GM crops are controversial. People argue about the safety of using them. Are the foods from GM crops the same as those prepared from traditionally bred crops?

Pros of GM Foods The companies making seeds for GM crops would say that GM plants are better and safer than other crops. Farmers choose them because they have higher yields. They use less land and energy and help lower costs. They are insect resistant. So, they need fewer chemicals and help reduce pollution. Careful studies have not supported concerns about their safety. These studies seem to show that GM foods are safe to eat.

Cons of GM Foods Critics point out that no studies have tested whether long-term use of these foods might cause danger. Some worry that the insect resistance in GM plants may also hurt helpful insects. Herbicide-resistant plants allow farmers to use more weed killers, increasing pollution. Company patents on costly GM seeds may put small or poor farmers out of business.

Labeling Foods
Some people want GM foods labeled so consumers can decide whether or not to use GM products.

In the United States, federal regulations treat GM foods and non-GM foods the same. So, GM foods do not have to face extra safety tests before entering the U.S. market. No additional labeling is required to identify a product as genetically modified unless its ingredients are very different from its non-GM counterpart. Some states, however, have introduced state legislation to require the labeling of GM foods. This would give consumers a choice.

Key Question Are GM foods safe? **Careful studies of such foods have provided no scientific support for concerns about their safety, and it does seem that foods made from GM plants are safe to eat. Even if GM food itself presents no hazards, there are many serious concerns about the unintended consequences that a shift to GM farming and ranching may have on agriculture.**

Ethics of the New Biology

You've seen how easy it is to move genes from one organism to another. For example, the GFP gene can be taken from a jellyfish and spliced onto genes coding for important cellular proteins. This ability has led to significant new discoveries about how cells function.

The same GFP technology was used to make fluorescent zebra fish. Experiments moving the GFP gene have taught scientists much about cells and proteins. But, just because we have the technology to change an organism's characteristics, should we?

It would be great if genetic engineering led to cures for genetic diseases. However, should biologists try to make people taller or change their sex or looks? What will happen to the human species when we can design our bodies or those of our children? What will happen if biologists want to clone human beings? In a democratic nation, everyone is responsible for making sure that the tools science has given us are used wisely. This means that you need to be ready to help decide what should and should not be done with the human genome.

Key Question Should genetic modifications to humans and other organisms be closely regulated?
The issue: Just because we have the technology to modify an organism's characteristics, are we justified in doing so?

Gaining More Understanding
These fluorescent zebra fish were originally bred to help scientists find environmental pollutants. Today, the techniques used to produce such fish are widely used in research. Fluorescent labels are helping researchers to understand cancer and other diseases.

CHECK Understanding

Critical Thinking

1. **Apply Concepts** How could biotechnology affect your privacy?
2. **Explain** What are genetically modified foods?
3. **Form an Opinion** Should a vegetarian be concerned about eating a GM plant that contains DNA from a pig gene? Support your answer with details from the text.
4. **Explain** What are the main concerns about genetic engineering discussed in this chapter?
5. **Write to Learn** Answer the question in the mystery clue below.

MYSTERY CLUE

What privacy considerations, if any, should investigators have taken into account when obtaining the DNA evidence? (Hint: See p. 367.)

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Forensics Lab

GUIDED INQUIRY

Pre-Lab: Using DNA to Solve Crimes

Problem How can DNA samples be used to connect a suspect to a crime scene?

Materials gel block, electrophoresis chamber, buffer solution, 250-mL beaker, metric ruler, DNA samples, micropipettes with metal plungers, 9-volt batteries, electric cords, staining tray, DNA stain, 100-mL graduated cylinder, clock or timer

Lab Manual Chapter 15 Lab

Skills Focus Measure, Compare and Contrast, Draw Conclusions

Connect to the Big idea Scientists who worked on the Human Genome Project had to develop methods for sequencing and identifying genes. Those methods have since been used for many other applications. For example, genetically altered bacteria are used to produce large amounts of life-saving drugs. Another example is the use of DNA evidence to solve crimes. In this lab, you will prepare and compare DNA "fingerprints," or profiles.

Background Questions

a. **Review** What characteristic of the human genome makes DNA a powerful tool for solving crimes?

b. **Review** What do the segments of DNA that are used to make DNA profiles have in common?

c. **Apply Concepts** When forensic scientists want to determine whether two DNA samples come from the same person, they analyze more than one section of DNA. Why would the results be less reliable if the scientists compared only one section of DNA?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Control Variables** Why must you use a new pipette to load each DNA sample?
2. **Relate Cause and Effect** Why will the DNA samples separate into bands as they move through the gel?
3. **Infer** Why is purple tracking dye added to the DNA samples?

BIOLOGY.com Search Chapter 15 GO

Visit Chapter 15 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Pigeon breeding helps the Untamed Science crew unravel the mysteries of genetic engineering.

Art in Motion View a short animation that brings bacterial transformation to life.

Art Review Review your understanding of DNA fingerprinting with this drag-and-drop activity.

InterActive Art Build your understanding of key chapter concepts with these animations.

15 CHAPTER Summary

15.1 Selective Breeding

- Humans use selective breeding, which takes advantage of naturally occurring genetic variation, to pass wanted traits on to the next generation of organisms.
- Breeders can increase the genetic variation in a population by introducing mutations, which are the ultimate source of biological diversity.

selective breeding (p. 354)
hybridization (p. 355)
inbreeding (p. 355)
biotechnology (p. 355)

15.2 Recombinant DNA

- The first step in using the polymerase chain reaction method to copy a gene is to heat a piece of DNA, which separates its two strands. Then, as the DNA cools, primers bind to the single strands. Next, DNA polymerase starts copying the region between the primers. These copies can serve as templates to make still more copies.
- Recombinant-DNA technology is the joining together of DNA from two or more sources. This technology makes it possible to change the genetic makeup of living organisms.
- Transgenic organisms can be produced by the insertion of recombinant DNA into the genome of a host organism.

polymerase chain reaction (p. 358)
recombinant DNA (p. 359)
plasmid (p. 359)
transgenic (p. 360)
clone (p. 361)

15.3 Applications of Genetic Engineering

- Ideally, genetic modification could lead to better, less expensive, and more nutritious food as well as to less harmful manufacturing processes.
- Recombinant-DNA technology is advancing the prevention and treatment of disease.
- DNA fingerprinting analyzes sections of DNA that may have little or no function within the cell. However, these sections vary widely from one individual to another.

gene therapy (p. 364)
DNA microarray (p. 364)
DNA fingerprinting (p. 365)
forensics (p. 365)

15.4 Ethics and Impacts of Biotechnology

- Should you, like patent holders, be able to keep your genetic information confidential?
- Careful studies of GM foods have provided no scientific support for concerns about their safety.
- There are many concerns about unintended consequences that a shift to GM farming and ranching may have on agriculture.
- Just because we have the technology to modify an organism's characteristics, are we justified in doing so?

15 CHECK Understanding

Assess the Big idea — Science as a Way of Knowing

Write an answer to the question below.

Q: How and why do scientists manipulate DNA in living cells?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs long. To help you begin, read the **Hints** below each of the questions.

1. **How do breeders produce genetic variations that are not found in nature?**

   Hint Some treatments can cause mutations.

   Hint Some treatments can change the numbers of chromosomes in an organism.

2. **Describe what happens during a polymerase chain reaction.**

   Hint A polymerase chain reaction makes many copies of a gene.

   Hint Each new copy made can serve as a template to make more genes.

3. **Your friend suggests that genetic engineering makes it possible for biologists to produce an organism with any combination of characteristics—an animal with the body of a frog and the wings of a bat, for example. Do you think this is a reasonable statement? Explain your answer.**

   Hint All organisms share the same genetic code.

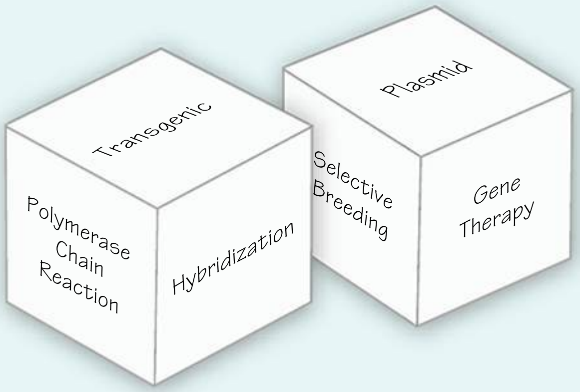
   Hint Organisms have millions of genes.

Foundations for Learning Wrap-Up

Use the cubes you made as you read the chapter. The cubes will help you review what you have learned about genetic engineering.

Activity 1 Working with a partner, take turns rolling one of the cubes. Read the word on top of the cube. Say the definition of the word. Your partner will tell you if you are correct. If you don't know the definition, you lose your turn. Continue until you have defined all the words at least once. The first player to get all the definitions correct is the winner.

Activity 2 Working with a partner, use both cubes. Take turns rolling both cubes. Tell how the words from the tops of the cubes are related. For example, for the cubes below, you could say, "Scientists use *plasmids* to make *transgenic* plants."



15.1 Selective Breeding

Understand Key Concepts

1. Crossing individuals with different traits to bring together their best characteristics is called
   a. domestication.
   b. inbreeding.
   c. hybridization.
   d. polyploidy.

2. Crossing individuals with similar characteristics so that those characteristics will appear in their offspring is called
   a. inbreeding.
   b. hybridization.
   c. recombination.
   d. polyploidy.

3. Taking advantage of naturally occurring variations in organisms to pass wanted traits on to future generations is called
   a. selective breeding.
   b. forensics.
   c. gene therapy.
   d. mutation.

4. What is polyploidy? When is this condition useful?

Think Critically

5. **Compare and Contrast** Hybridization and inbreeding are important methods used in selective breeding. How are the methods similar? How are they different?

Test-Taking Tip

Use Graphic Organizers Sometimes a question, such as question 5, asks you to compare and contrast two processes. Before you begin writing your answer, organize your ideas with a Venn diagram. Label one circle Hybridization. Label the other Inbreeding. Where the circles overlap, write Both.

15.2 Recombinant DNA

Understand Key Concepts

6. Organisms that have genes from other organisms are called
   a. transgenic.
   b. mutagenic.
   c. donors.
   d. clones.

7. A member of a population of genetically identical cells produced from a single cell is a
   a. clone.
   b. plasmid.
   c. mutant.
   d. sequence.

8. How does a transgenic plant differ from a hybrid plant?

Think Critically

9. **Apply Concepts** Describe one or more advantages of producing insulin and other proteins through genetic engineering.

15.3 Applications of Genetic Engineering

Understand Key Concepts

10. Which of the following characteristics is often genetically engineered into crop plants?
    a. improved flavor
    b. resistance to herbicides
    c. different colors
    d. thicker stems

Think Critically

11. **Infer** Suppose a human's bone marrow was removed, changed genetically, and returned to his body. Would the change be passed on to the patient's children? Explain your answer.

15 CHECK Understanding

15.4 Ethics and Impacts of Biotechnology

Understand Key Concepts

12. The right to profit from a new genetic technology is protected by

a. getting a copyright for the method.

b. discovering a new gene.

c. obtaining a patent.

d. publishing its description in a journal.

13. Which of the following is most likely to be used in a court case to determine who the father of a particular child is?

a. microarray analysis **c.** gene therapy

b. DNA fingerprinting **d.** genetic engineering

Think Critically

14. Explain What is one argument used by critics of genetically modified foods?

Connecting Concepts

Use Science Graphics

Use the table below to answer question 15.

DNA Restriction Enzymes

Enzyme	Recognition Sequence
*Bgl*III	A G A T C T T C T A G A
*Eco*RI	G A A T T C C T T A A G
*Hind*III	A A G C T T T T C G A A

15. Apply Concepts Copy the following DNA sequence and write its complementary strand ATGAGATCTACGGAATTCTCAAGCTTCGA ATCG. Where will each restriction enzyme in the table cut the DNA strand?

solve the CHAPTER MYSTERY

A CASE OF MISTAKEN IDENTITY

The first suspect was lucky: Twenty years earlier, it would have been an open-and-shut case. But by 1998, DNA fingerprinting was widely available. After the police took the suspect into custody, forensic scientists tested the DNA in the bloodstains on his shirt. Within a few hours, they knew they had the wrong suspect. Before long, the police caught the real attacker, who was then tried in a court and convicted of the crime.

1. Infer How did the investigators determine that the person they took into custody was not a suspect?

2. Apply Concepts Red blood cells don't have a nucleus; white blood cells do. Did the DNA evidence from the bloodstains come from the red blood cells, the white blood cells, or both? Explain your answer.

3. Predict What if the initial suspect was related to the victim? Would that have changed the result? Why or why not?

4. Predict What if this crime happened before DNA fingerprinting was discovered? What do you think the police would have done after they took in the first suspect?

UntamedScience™ **Never Stop Exploring Your World.** Finding the solution to the case of mistaken identity is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Polyploidy may produce new types of organisms that are larger and stronger than their diploid relatives in
A animals.
B plants.
C bacteria.
D fungi.

2. Which of the following characteristics does NOT apply to a plasmid?
A made of DNA
B found in bacterial cells
C has circular loops
D found in animal cells

3. To separate DNA fragments from one another, scientists use
A polymerase chain reaction.
B DNA microarrays.
C gel electrophoresis.
D restriction enzymes.

4. Recombinant DNA technology involves
A cutting DNA into nucleotides.
B selective breeding.
C joining DNA from two or more sources.
D producing a cloned organism.

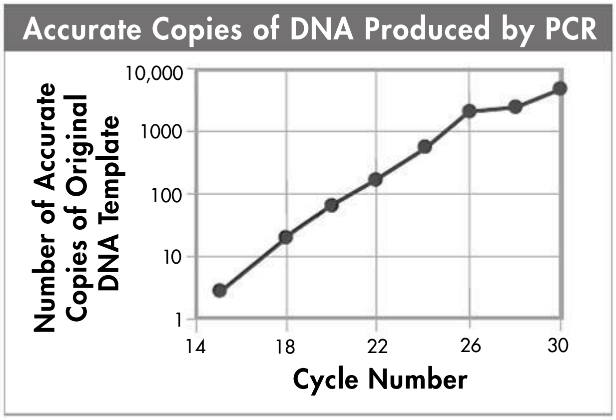
5. The expression of thousands of genes at one time can be followed using
A polymerase chain reaction.
B plasmid transformation.
C restriction enzymes.
D DNA microarrays.

6. Genetically engineered crop plants can benefit farmers by
A increasing crop yield.
B introducing chemicals into the environment.
C increasing an animal's resistance to antibiotics.
D changing the genomes of other crop plants.

7. Genetic markers allow scientists to
A clone animals.
B separate strands of DNA.
C make antibiotics.
D identify transformed cells.

Questions 8–9

The graph below shows the number of accurate copies of DNA produced by polymerase chain reaction.



8. What can you conclude about cycles 18 through 26?
A PCR produced accurate copies of template DNA at an exponential rate.
B The amount of DNA produced by PCR doubled with each cycle.
C The DNA copies produced by PCR were not accurate copies of the original DNA template.
D The rate at which PCR produced accurate copies of template DNA fell in later cycles.

9. Based on the graph, which of the following might have happened between cycles 26 and 28?
A PCR stopped producing accurate copies of the template.
B The rate of reaction slowed.
C All of the template DNA was used up.
D A mutation occurred.

Open-Ended Response

10. Why are bacteria able to make human proteins when a human gene is inserted in them with a plasmid?

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	15.1	15.2	15.2	15.2	15.3	15.4	15.2	15.2	15.2	15.3

Unit Project

Genetics Collage

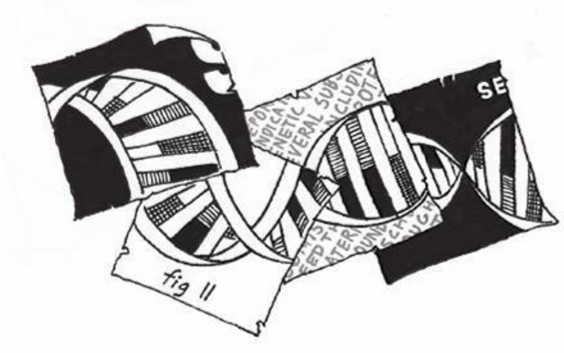
Genetics is a fascinating field of study and is becoming increasingly important to society. A local genetics laboratory in your town wants to increase public awareness of the importance of genetics. To do so, it has decided to hold a scholarship competition. The scholarship will go to the student(s) who create the best educational collage related to topics in genetics.

Your Task Use magazine and newspaper clippings, Internet sources, and art materials to make a colorful collage. The images should relate to three central questions.

1) Why is DNA important to a cell?
2) Why is DNA important to you, as a human being?
3) Why is DNA important to society as a whole?

Be sure to

- communicate answers to the above questions in the images, words, and phrases you choose.
- carefully design your collage so that it is clear and organized.

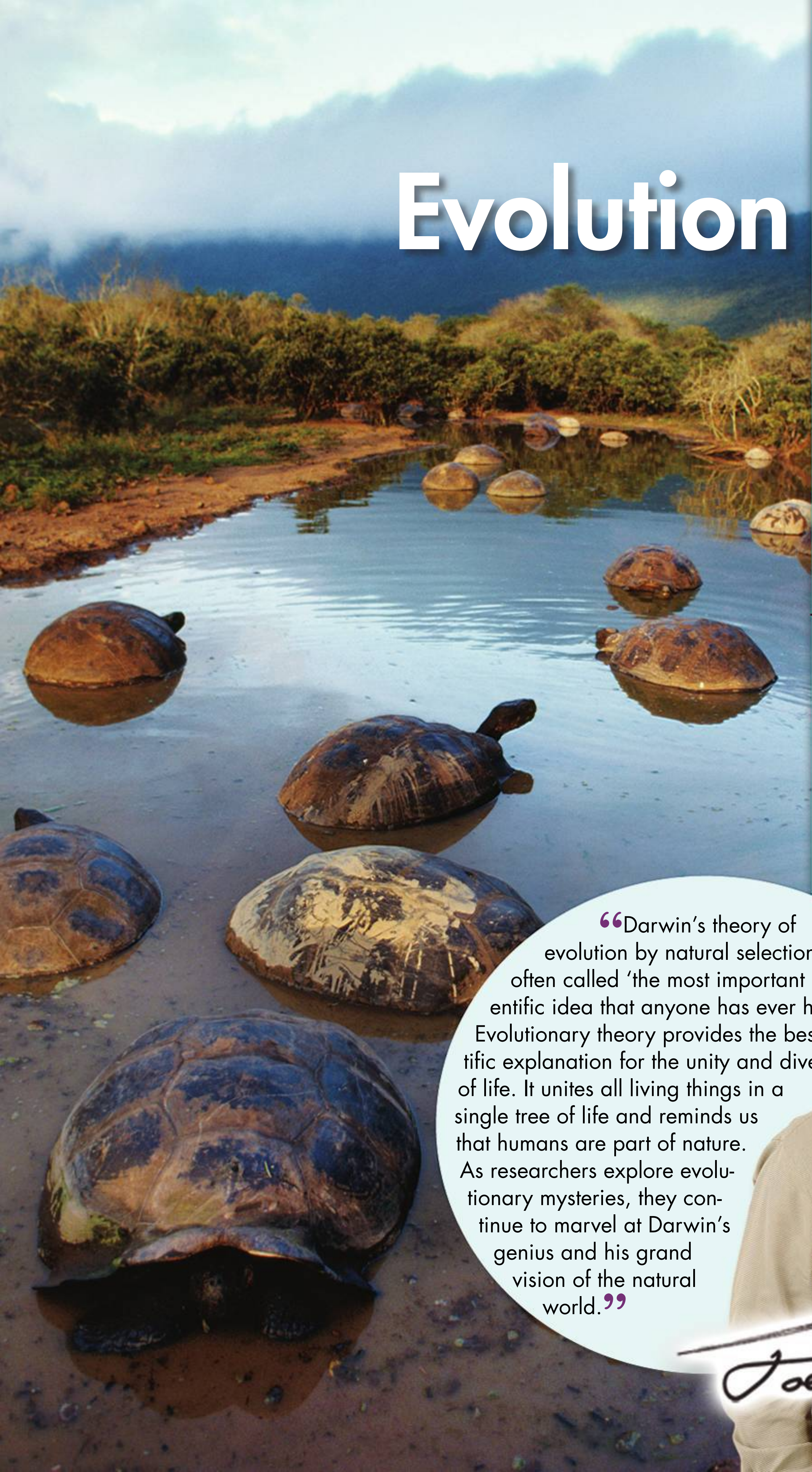


Reflection Questions

1. **Score your collage using the rubric below. What score did you give yourself?**
2. **What did you do well in this project?**
3. **What about your collage needs improvement?**
4. **What could a person who didn't know much about DNA learn from your collage?**

Assessment Rubric

Score	Scientific Content	Quality of Collage
4	Collage includes many important and thoughtful images related to the three central questions. Student demonstrates a deep understanding of genetics topics.	The collage is clear, organized, and creative.
3	Collage includes important images related to the three central questions. Student demonstrates an adequate understanding of genetics topics.	The collage is well designed and organized.
2	Collage is missing some important ideas and/or includes several insignificant ideas. Student demonstrates a limited level of understanding of genetics topics.	The collage could be better designed and organized.
1	Collage is missing several important ideas. Student demonstrates significant misunderstandings.	The collage is unclear and lacks a solid design.



Evolution

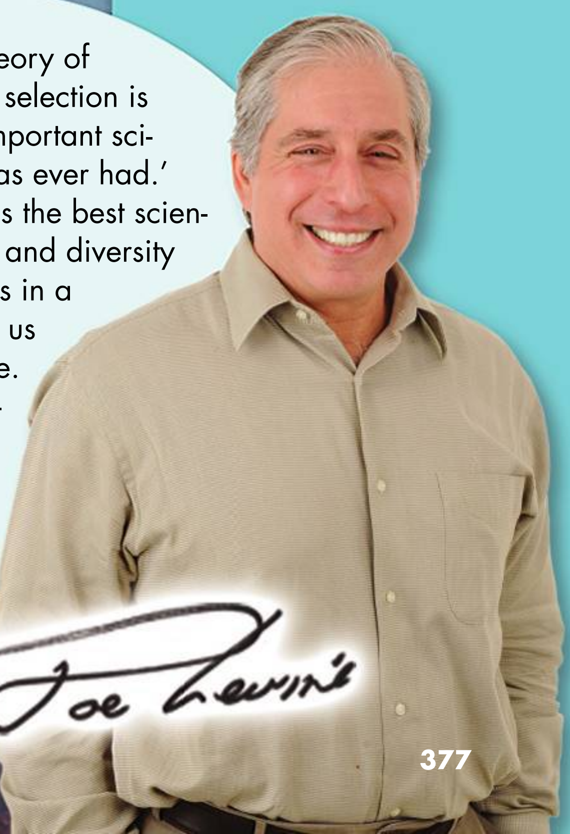
UNIT 5

Chapters

INTRODUCE the Big ideas

- **Evolution**
- **Unity and Diversity of Life**

“Darwin's theory of evolution by natural selection is often called ‘the most important scientific idea that anyone has ever had.’ Evolutionary theory provides the best scientific explanation for the unity and diversity of life. It unites all living things in a single tree of life and reminds us that humans are part of nature. As researchers explore evolutionary mysteries, they continue to marvel at Darwin's genius and his grand vision of the natural world.”



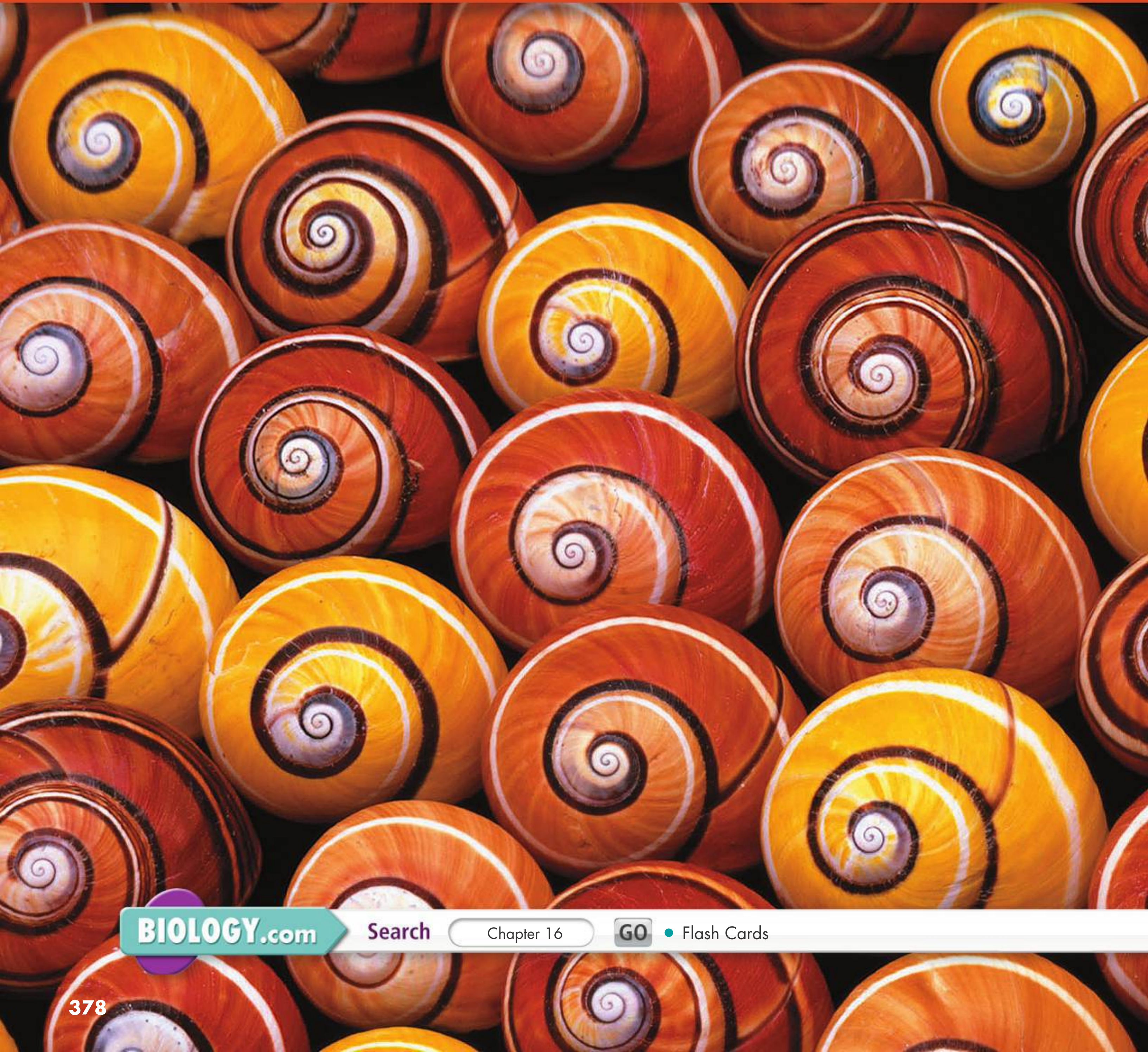
Joe Levine

16 Darwin's Theory of Evolution

Big idea

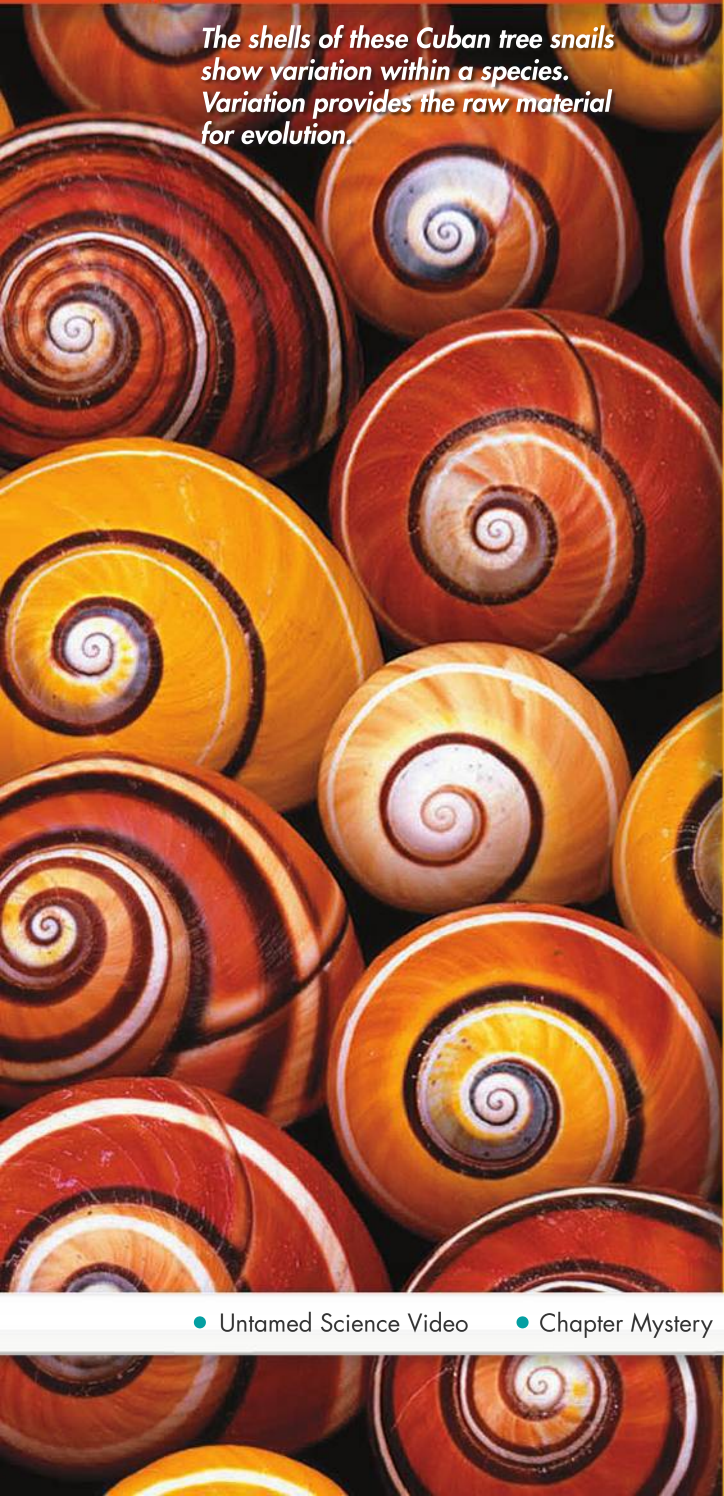
Evolution

Q: What is natural selection?



BIOLOGY.com Search Chapter 16 GO • Flash Cards

INSIDE:



The shells of these Cuban tree snails show variation within a species. Variation provides the raw material for evolution.

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

SUCH DIFFERENT HONEYCREEPERS

Imagine walking in the misty rain forest on an island in Hawaii. This is home for birds found nowhere else on Earth. A red and black bird flies to a nearby branch. The bird is an 'i'iwi. It uses its long, curved beak to get the nectar from the flowers of a tree.

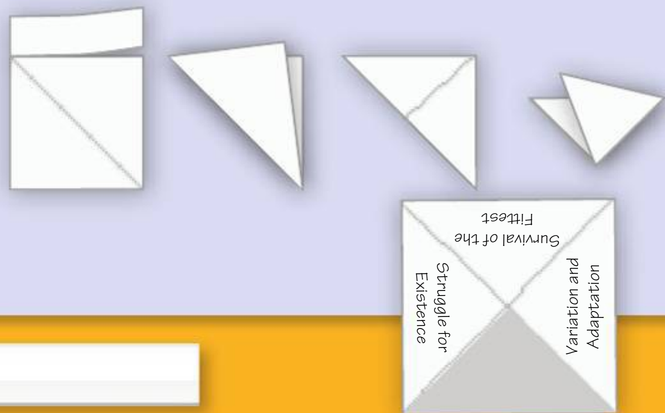
The 'i'iwi is one of a number of species of Hawaiian honeycreepers. The different species eat different foods. Some eat nectar. Others eat insects, seeds, or fruit. Many honeycreepers eat only the seeds or nectar of plants that are unique to Hawaii.

How did all these birds get to Hawaii? How did they come to eat such specialized foods?

Read for Mystery Clues As you read this chapter, look for clues that help explain the number and diversity of Hawaiian honeycreepers. Then, solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

Cut a stiff piece of paper so it is square. Fold the square diagonally to make a triangle. Fold that triangle again to make a smaller triangle. Open the paper. You will see an X. Color in one quarter; you will not write on this part of the paper. Three triangular sections now remain. Label each with one of these topics: Struggle for Existence, Variation and Adaptation, and Survival of the Fittest. As you read, take notes about each of these topics on the back of the correct triangle. At the end of the chapter are two activities that will use your notes to help answer the question: What is natural selection?



16.1 Darwin's Voyage of Discovery

Key Questions

What was Charles Darwin's contribution to science?

What three patterns of biodiversity did Darwin note?

BUILD Understanding

Preview Visuals Before you read, look at the map of Darwin's trip on the next page. Describe the path that the ship took around the world.

In Your Workbook Go to your workbook to learn about previewing visuals.

BUILD Vocabulary

evolution
change over time; the process by which modern organisms have descended from ancient organisms

RELATED WORD FORMS
The noun *evolution* is related to the verb *evolve*, which means "to change over time."

Darwin's Big Journey

If you had met young Charles Darwin, you would not have guessed that he would grow up to be a famous scientist. As a boy, Darwin was not a top student. He would rather watch birds or read for pleasure than study. Yet he would go on to develop one of the most important scientific theories of all time.

Darwin's Time Charles Darwin was a naturalist and scientist from England. He grew up in the early 1800s, a time when the scientific view of the world was changing. Geologists were learning that the world was very, very old. They also suggested that the world we see today is constantly changing. Biologists were saying that life on Earth had also changed. The process of change over time is called **evolution.**

Sailing Around the World While still a young man, Darwin was invited to sail around the world on a ship called the *Beagle*. The captain and his crew would be mapping the coast of South America during the five-year journey. Darwin planned to collect plant and animal specimens along the way. At the time, no one knew how important the trip would be. Darwin's observations during the journey would lead to his theory of evolution.

Darwin's Work Darwin's theory explains how modern organisms evolved over millions of years. It also tells how modern organisms came from shared, or *common*, ancestors. But Darwin's work does more than explain life's history. Evolution reminds us that life is always changing. An understanding of evolution helps us to explain and find ways to overcome many challenges we face today. These challenges include drug-resistant bacteria and deadly new viruses.

Key Question What was Charles Darwin's contribution to science? **Darwin developed a theory of evolution that explains how modern organisms evolved over long periods of time from common ancestors.**

Observations Aboard the *Beagle*

The time Darwin spent studying birds and collecting bugs prepared him for his long trip around the world. On his trip, he studied and took notes about the amazing new plants and animals he saw. Darwin was surprised by the many different kinds of organisms he found. In just one day, he collected 68 species of beetles in the South American forest.

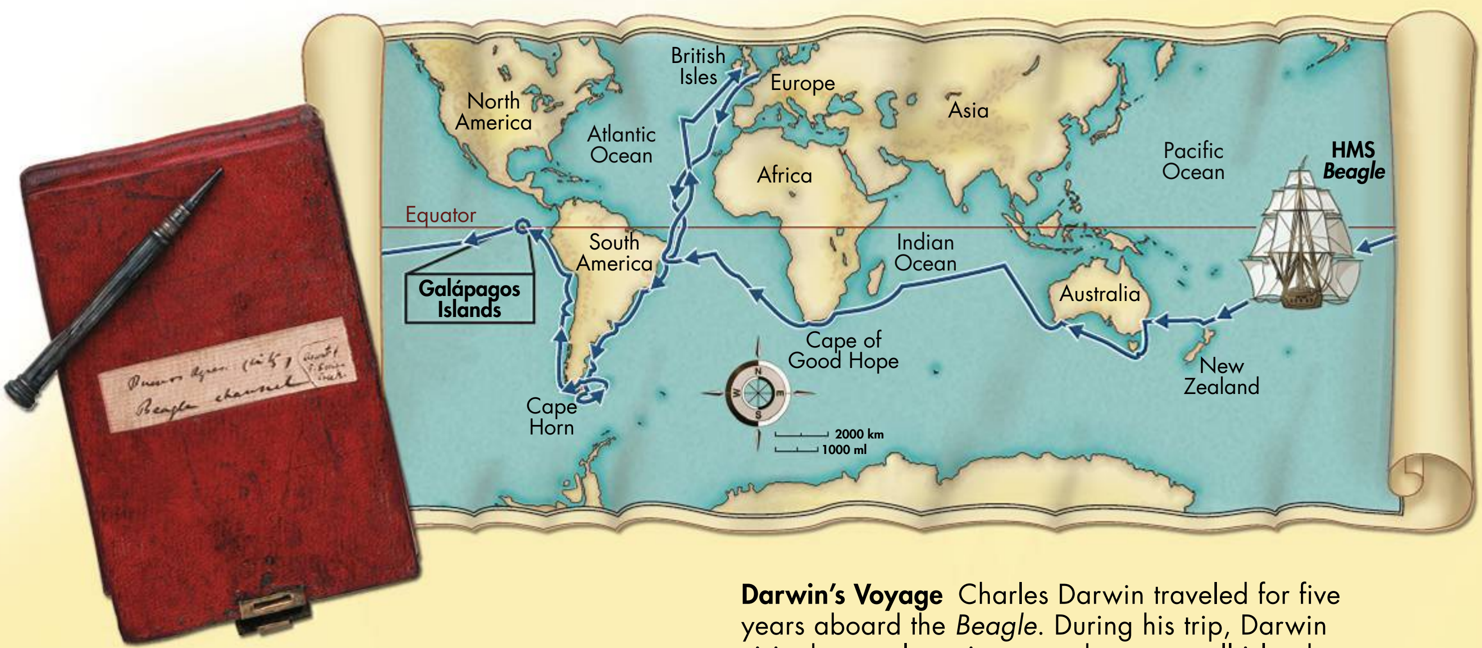
Darwin wanted to do more than just collect bugs and birds. He wanted to make sense of what he found. As he traveled, he noticed three patterns of biological diversity:

1. Species vary around the world.
2. Species vary locally.
3. Species vary over time.

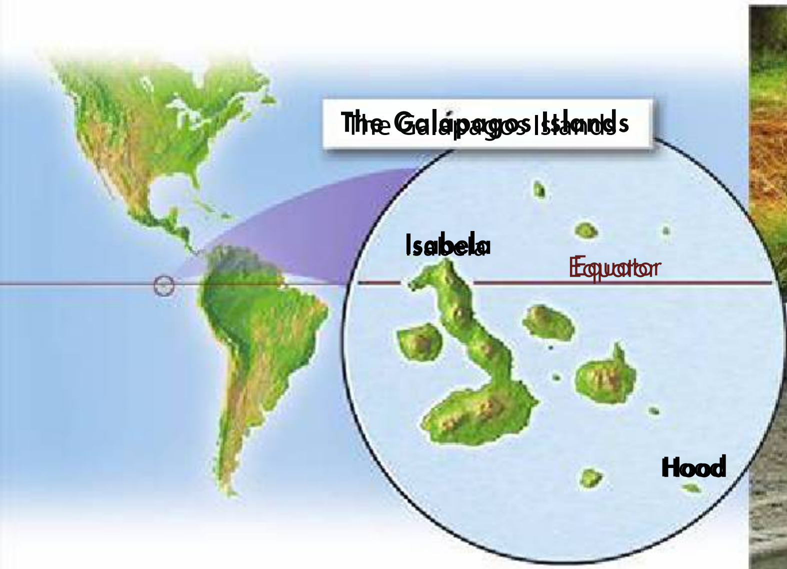
Species Vary Around the World Darwin visited habitats in South America, Australia, and Africa. In the grasslands of South America, he found large, flightless birds called rheas. Rheas look and act a lot like ostriches. Yet ostriches live only in Africa. Rheas live only in South America. In Australia's grasslands, Darwin found another flightless bird called the emu. He wondered why there were no large, flightless birds living in the grasslands of the northern parts of the world.

Darwin also noticed habitats in Australia that were ideal for rabbits. Why did no rabbits live there? And why were there no kangaroos in England? What did these patterns of distribution mean?

Key Question What did Darwin notice about biodiversity around the world? **Places around the world that had similar habitats often had different animals that were ecologically similar.**



Darwin's Voyage Charles Darwin traveled for five years aboard the *Beagle*. During his trip, Darwin visited several continents and many small islands.



Tortoise Diversity The tortoises of the Galápagos Islands have shells with different shapes. The shapes are related to the environment on the island where the tortoise lives.

Isabela Island Tortoise Tortoises from Isabela Island have dome-shaped shells and short necks. Vegetation on this island is abundant and close to the ground.

Hood Island Tortoise The shells of Hood Island tortoises are curved and open around their long necks and legs. This helps them to reach the island's sparse, high vegetation.

Species Vary Locally Darwin was puzzled over patterns he saw on a local level, too. For example, there were two kinds of rheas living in South America. One lived in the grasslands of Argentina. A different-looking rhea lived in the colder environment further south. Could their differences be related to their different environments?

The Galápagos Islands off the west coast of South America were also full of puzzles. The islands were small and close to each other, but often had different environments. Darwin noticed differences in the large land turtles called tortoises that lived on the islands. At first he did not think much about them. Then someone showed him that each island had its own type of tortoise with a unique shell. He wondered about the connection between environment and the features of an organism.

Darwin also noticed several kinds of small brown birds on the different Galápagos islands. The birds' beaks looked so different from each other that Darwin thought they were unrelated. Darwin sent samples of the birds to experts in England. Later he would learn how closely related—and important—these little birds were.

Key Question What did Darwin notice about biodiversity within a local area? **Darwin noticed that different, related species often lived in different habitats within a local area.**

Species Vary Over Time Darwin also collected fossils. **Fossils** are the preserved remains of ancient organisms. Some fossils Darwin collected did not look like living organisms. But others did. For example, the extinct glyptodont lived where armadillos live today. The glyptodont looked like a giant armadillo. Why did glyptodonts and armadillos look alike? Why did glyptodonts disappear?

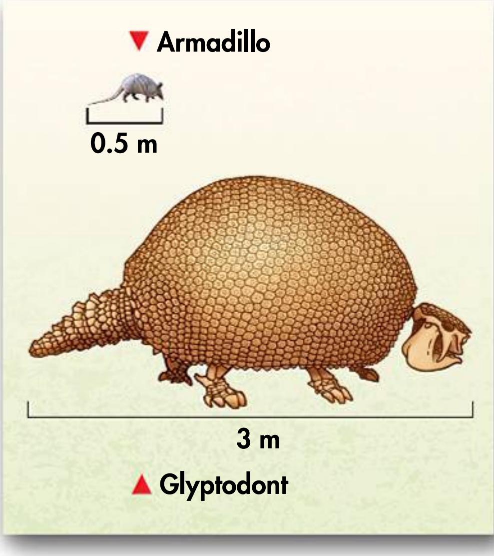
BUILD Vocabulary

fossil the preserved remains or traces of ancient organisms

WORD ORIGINS

The word *fossil* comes from the Latin word *fossilis*, meaning "dug up." Fossils are often dug out of the ground.

Related Organisms? Ancient glyptodonts were similar to armadillos that live today, but far bigger. The art shows the size of an armadillo and a glyptodont. Darwin wondered if the ancient glyptodont was related to the modern armadillo.



Key Question What did Darwin notice when he compared some fossils to living species? **Darwin noticed that some fossils of extinct animals were similar to living species.**

Solving the Puzzle On the long trip home, Darwin thought about the patterns he had seen. The little brown birds he had collected were already causing excitement back home. Experts had found that they were all finches! These finches were similar to a species of finch that lives in South America. Darwin began to wonder if different Galápagos species might have evolved from ancestors in South America. The evidence he gathered on his trip suggested that species change over time by some natural process.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. On his journey, Darwin collected ______, the preserved remains of ancient organisms.

2. The process of change over time is called ______.

Critical Thinking

3. Review What did Darwin's theory of biological evolution explain?

4. Relate Cause and Effect What ideas were changing in the scientific community at the time that Darwin traveled on the *Beagle*? How might these new ideas have influenced Darwin?

5. Review What three kinds of variations among organisms did Darwin observe during the voyage of the *Beagle*?

6. Infer Darwin found fossils of many organisms that did not resemble any living species. How might this finding have affected his understanding of life's diversity?

7. Write to Learn Answer the question in the mystery clue below. Remember that honeycreepers eat different kinds of foods. How might the sources of food differ from island to island?

MYSTERY CLUE

Like the small brown birds on the Galápagos, Hawaiian honeycreepers live on islands with different environments. How might these differences have affected honeycreeper evolution?
(Hint: **See p. 382.)**

BIOLOGY.com Search Lesson 16.1 GO • Lesson Assessment

16.2 Ideas That Shaped Darwin's Thinking

Key Questions

What did Hutton and Lyell conclude about Earth's history?

How did Lamarck propose that species evolve?

What was Malthus's view of population growth?

How is inherited variation used in artificial selection?

BUILD Understanding

Main Idea and Details Chart As you read a lesson, you can organize the information in a main idea and details chart. Write all the green headings in the Main Idea column. Then write details about each main idea in the Supporting Details column.

In Your Workbook Go to your workbook to learn more about main idea and details charts.

An Ancient, Changing Earth

Like all scientists, Darwin developed his ideas by building on the work of others. Darwin worked in an exciting time of discovery. Naturalists were finding connections between animals and their environments.

In Darwin's time, many people believed that Earth was only a few thousand years old. They also believed that Earth had not changed much in that time. But scientists were beginning to find evidence that supported different ideas about Earth's history. These ideas were part of the new science of geology. Two of the best-known geologists were James Hutton and Charles Lyell. The ideas of both these geologists influenced Darwin's thinking.

Hutton and Geological Change Hutton described how geological processes shape the land. He suggested that great forces under Earth's surface push mountains upward. These same mountains are then worn down by wind and rain. Most of the processes Hutton described are very, very slow. To make the formations he observed, Earth would have to be much older than a few thousand years. Hutton introduced a concept called *deep time* to explain his ideas. Deep time is the idea that Earth's history is so long that it is difficult to imagine.

Ancient Rocks These rock layers in the Grand Canyon were laid down over millions of years. The river then slowly carved out the canyon over many more years.

Lyell's *Principles of Geology* Lyell argued that the laws of nature do not change over time. He concluded that geological processes in the past worked like the geological processes of today. Ancient volcanoes released lava, just as volcanoes do now. Rivers in the past cut deep canyons, just as rivers do today. Over time, these processes formed the modern landscape. Such changes would take millions of years.

Key Question What did Hutton and Lyell conclude about Earth's history? **Hutton and Lyell concluded that Earth is extremely old. Also, the processes that changed Earth in the past are the same processes that operate in the present.**

Lamarck's Evolutionary Hypotheses

Darwin was not the first scientist to say that species evolve over time. But earlier scientists disagreed on *how* evolution happened. The French scientist Jean-Baptiste Lamarck was one of the first scientists to hypothesize how evolution works. Lamarck suggested two ideas.

Lamarck's Ideas Lamarck proposed that all organisms are born with a desire to become better. He hypothesized that organisms could change their bodies so that they worked better in their environment. Lamarck also thought that organisms could change their bodies by using them in new ways. For example, consider a bird that walks in water looking for food. Long legs would be very useful to that bird. According to Lamarck's ideas, the bird's legs could become longer by stretching each day. Traits that change during the life of an organism are called *acquired characteristics*.

Lamarck also thought that acquired characteristics could be passed on to offspring. This idea is called the *inheritance of acquired traits*. Thus, over a few generations, the legs of a wading bird would get longer and longer.

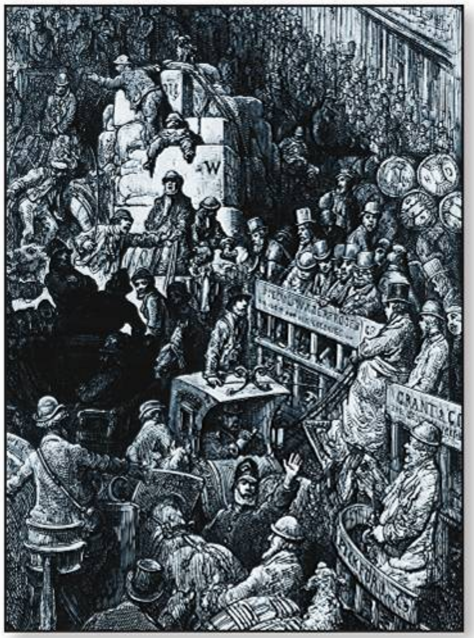
Acquired Characteristics? This long-legged water bird is a black-winged stilt. According to Lamarck, its long legs were the result of the bird's effort to stretch its legs so that it could wade in deep water.

Evaluating Lamarck's Hypotheses Today scientists know that most of Lamarck's ideas were wrong. Animals do not have a desire to become better. Evolution is not a process that makes animals more "perfect" over time. Scientists also know that there is no inheritance of acquired traits. Acquired characteristics cannot be passed on to offspring.

But Lamarck's work did help Darwin in several ways. Lamarck made a connection between an organism's body and its environment. He was one of the first scientists to suggest that organisms can change over time. He also tried to explain evolution using natural processes. Even though he was incorrect, Lamarck helped other biologists, including Darwin, form their ideas.

Key Question How did Lamarck propose that species evolve? **Lamarck suggested that individual organisms could change during their lifetimes by using or not using parts of their bodies. He also suggested that individuals could pass these changes on to their offspring.**

BIOLOGY.com Search Lesson 16.2 GO • Art in Motion



Overcrowding in London This drawing from the 1800s shows the crowded conditions in London when Darwin lived.

Population Growth

The ideas of the Thomas Malthus also helped Darwin. Malthus was an English economist who noticed that people were being born faster than people were dying. This led to overcrowding. Malthus thought that overcrowding led to conditions that would slow down population growth. These conditions included war, disease, and starvation.

Darwin saw that Malthus's ideas were true for all organisms. A maple tree can produce thousands of seeds every year. An oyster can lay millions of eggs. If all the offspring of a single species survived, that species would soon cover the world. Of course, this doesn't happen. Most offspring die. Only a few survive. Darwin thought it was important that only a few individuals survive to reproduce. It could be a key part of evolution. He wondered which individuals survive. Why did they survive?

Key Question What was Malthus's view of population growth? **Malthus reasoned that if the human population were to grow without control, then there would not be enough space and food for everyone to live.**

INQUIRY into Scientific Thinking

Variation in Peppers

As Darwin noted, most organisms produce more offspring than can survive in the environment. This may seem like a waste, but it does make evolutionary sense. Having many offspring makes it more likely that some will survive to reproduce. And more offspring means a wider variety of traits. This makes it is more likely that some traits will be helpful if the environment changes.

In this lab you will examine variations in the colors of peppers and the number of seeds produced.

1. Get a green, yellow, red, or purple bell pepper.
2. Slice open the pepper and count the number of seeds.
3. Compare your data with the data of other students who have peppers of a different color.

Pepper Color	Number of Seeds

Analyze and Conclude

1. Calculate Use the equation below to find the average number of seeds for all of the peppers.

$$\text{Average number of seeds} = \frac{\text{total number of seeds}}{\text{total number of peppers}}$$

2. Calculate Determine the difference from the average for each of the peppers in your group.

3. Infer What other traits could you measure that might affect the success of the pepper plants?

In Your Workbook Get more help for this activity in your workbook.


Artificial Selection Darwin used artificial selection in breeding fancy pigeons at his home outside London.

Artificial Selection

Darwin also studied the work of farmers who bred plants and animals. Breeders knew that some trees produced larger fruits than other trees. Some cows produced more milk than others. Breeders selected only the plants and animals with the best traits for breeding. These traits were passed on to their offspring. Over time, selective breeding could form trees with even bigger fruit, or cows that gave even more milk. Nature provided the variation. Humans selected the traits they found useful. Darwin called this process **artificial selection.**

Darwin had no idea how heredity worked. He did know that variation occurs in wild species as well as farm species. Darwin saw how important this variation was to the process of evolution. He now had all the information he needed to explain evolution. When published, his theory would change the way people understood the living world.

Key Question How is variation used in artificial selection?
In artificial selection, nature provides the variation, and humans select the traits they find useful.

BUILD Vocabulary

artificial selection
the selective breeding of plants and animals to promote desirable traits in offspring

ACADEMIC WORDS
The noun *process* means "a series of actions or changes that take place in a definite manner." Artificial selection is a process. So is evolution.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Breeders use _______ to produce better crops and livestock.

Critical Thinking

2. **Explain** How did Hutton and Lyell help to shape Darwin's thinking?
3. **Apply Concepts** What parts of Lamarck's theory of evolution were incorrect?
4. **Explain** How does artificial selection work?
5. **Write to Learn** Imagine that you are Darwin and you have just read Malthus's ideas about population. Write down Malthus's key ideas. Next to these ideas, write how they might apply to evolution.

BIOLOGY.com Search Lesson 16.2 GO • Lesson Assessment

16.3 Darwin Presents His Case

Key Questions

Under what conditions does natural selection occur?

How does Darwin's theory explain the connection between living and extinct species?

BUILD Understanding

Preview Visuals Before you read this lesson, look at the pictures of grasshoppers on page 390. Read the information in the figure. Then write three questions you have about it. As you read, answer your questions.

In Your Workbook Go to your workbook to learn more about previewing visuals.

Evolution by Natural Selection

Soon after reading Malthus and thinking about artificial selection, Darwin worked out his theory of natural selection. Most of his scientific friends thought his ideas were brilliant. But Darwin did not feel ready to publish. He did not want to be attacked for his ideas, as Lamarck had been. Darwin did not share his theory with the public for 20 years. He spent this time collecting more information to support his theory.

In 1858, Darwin read the unpublished work of another scientist, Alfred Russel Wallace. Darwin was shocked to find that Wallace's thoughts on evolution were almost the same as his own! If Darwin did not act quickly, Wallace would be given credit for describing natural selection. The next year, Darwin published his first book on evolution. It was called *On the Origin of Species*.

The Struggle for Existence In his book, Darwin combined his own thoughts with ideas from Malthus and Lamarck. Like Malthus, Darwin saw that organisms produce more offspring than can survive. Members of a population must compete for food, water, living space, and other things needed to live. Those that do not get enough will not survive to reproduce. Darwin called this *the struggle for existence*.

Variation and Adaptation Darwin knew that members of a population have variation in traits. Many of these traits, called *heritable traits*, can be passed on to offspring. Darwin hypothesized that some heritable traits make survival easier. Any heritable trait that helps an organism survive in its environment is called an **adaptation.** Adaptations can be body parts, such as sharp claws or strong wings. Adaptations can also be behaviors, such as avoiding predators.

Survival of the Fittest Like Lamarck, Darwin saw how the body of each organism works well in its environment. Darwin knew that differences in adaptations affect fitness. **Fitness** describes how well an organism can survive and reproduce in its environment.

Some individuals have adaptations that make survival and reproduction easier. These individuals have high fitness. Individuals without these adaptations are more likely to die, and have less chance to produce offspring. These individuals have low fitness. This difference in success is called *survival of the fittest*.

BUILD Connections

ADAPTATIONS

Adaptations take many forms.

A scorpionfish's coloring is an example of camouflage—an adaptation that allows an organism to blend into its background and avoid predation.

Adaptations can be forms of behavior. Here, a crane is displaying defensive behavior in an effort to scare off the fox.

Scarlet king snake

Eastern coral snake

Mimicry is an adaptation in which an organism copies a more dangerous organism. The scarlet king snake is harmless, but it looks like, or mimics, the poisonous eastern coral snake, so predators avoid it, too.

Natural Selection Darwin named his method of evolution *natural selection*. In **natural selection,** organisms with traits that are the best match to their environment survive and leave more offspring. In some ways, natural selection is like artificial selection. In both forms of selection, only some individuals reproduce. In artificial selection, the breeder selects which individuals reproduce. In natural selection, the environment determines which individuals survive and reproduce.

Natural selection happens whenever certain conditions exist. First, more individuals are born than can survive. Second, there is heritable variation in the population. Third, some individuals have traits that make them more likely to survive and reproduce.

Populations continue to evolve as they become better adapted to their environment. Populations are also likely to change if the environment changes. Traits that were well suited to the old environment may not work as well in the new environment. New adaptations may evolve.

Key Question When does natural selection occur?
Natural selection occurs when more individuals are born than can survive (the struggle for existence), there is heritable variation (variation and adaptation), and individuals have different fitness rates (survival of the fittest).

BUILD Vocabulary

adaptation a heritable characteristic that increases an organism's ability to survive and reproduce in an environment

fitness how well an organism can survive and reproduce in its environment

natural selection the process by which organisms that are most suited to their environment survive and reproduce most successfully; also called survival of the fittest

RELATED WORD FORMS

The verb *inherit* and the adjective *heritable* are related word forms. A trait that can be *inherited*, or passed on to offspring, is said to be *heritable*.

BUILD Connections

NATURAL SELECTION

This population of grasshoppers changes over time because of natural selection.

1 The Struggle for Existence

Organisms produce more offspring than can survive. Grasshoppers can lay more than 200 eggs at a time. Only a few of these offspring survive to reproduce.

2 Variation and Adaptation

There is variation in nature. Some variations that are inherited are adaptations. Adaptations increase the chance that an individual will survive and reproduce. In this population, body color is inherited—some grasshoppers are green and some are yellow. Green coloring is an adaptation that allows grasshoppers to blend into their environment.

3 Survival of the Fittest

The color green serves as a form of camouflage. It is harder for predators to see green grasshoppers than yellow grasshoppers. Therefore, green grasshoppers have higher fitness than yellow grasshoppers. In this environment, more green grasshoppers are able to survive and reproduce than yellow grasshoppers.

4 Natural Selection

Over time, green grasshoppers become more common than yellow grasshoppers. This is because
(1) more grasshoppers are born than can survive,
(2) individuals vary in color, and color is a heritable trait,
(3) green individuals have a higher fitness in this environment.

Lesson 16.3

- Data Analysis
- Tutor Tube

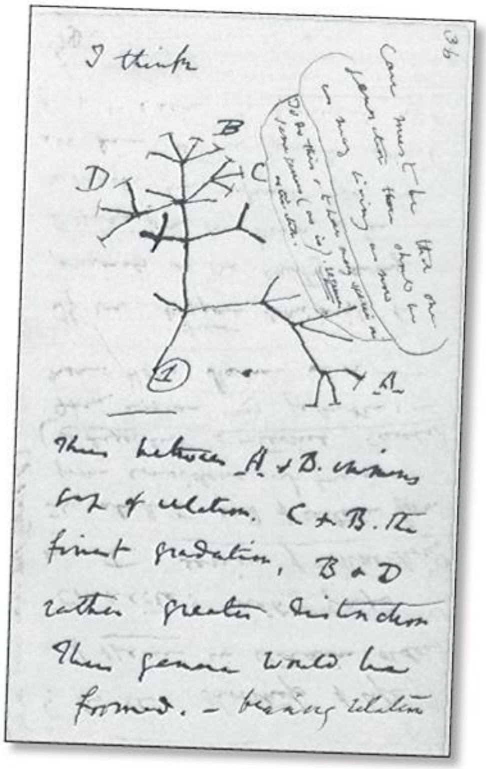
Common Descent

According to Darwin's theory, individuals that are well adapted to their environment survive and reproduce. Every organism alive today descended from parents who survived and reproduced. Those parents descended from their parents. This line of organisms continues back through time to the very earliest life forms.

In a similar way, Darwin proposed that species living today are descended from older species that survived and reproduced. Over time, those older species evolved into new species in a process he called *descent with modification*. Modification means "change." It can take thousands or even millions of years for new species to evolve. This length of time—deep time—was an idea Darwin borrowed from Hutton and Lyell. Deep time gave enough time for natural selection to work. Darwin pointed to the fossil record as evidence of descent with modification.

Darwin used the idea that species change over time to explain the great variety of life on Earth. Darwin drew the first evolutionary tree to show how organisms share ancient ancestors. This idea is called *common descent*. A single "tree of life" links all living things. If you look back in time far enough, all organisms are related.

Key Question How does common descent explain the connection between living and extinct species? **According to the principle of common descent, all species—living and extinct—are descended from ancient common ancestors.**



Descent With Modification This is a page from one of Darwin's notebooks. It shows the first evolutionary tree ever drawn. Note that Darwin wrote "I think" just above the tree.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Organisms with high ______ are more likely to survive and reproduce.

2. Sharp teeth and claws are ______ that help tigers capture their prey.

3. The traits that are most helpful for survival in an environment become more common through the process of ______.

Critical Thinking

4. Apply Concepts What do evolutionary trees show? What does a tree of life imply about all species living and extinct?

5. Relate Cause and Effect Briefly describe the process that causes a population to change by natural selection. Use the words *overproduction*, *variation*, *adaptation*, and *survival of the fittest*.

6. Write to Learn Answer the question in the mystery clue below.

MYSTERY CLUE

How might natural selection explain the history of the Hawaiian honeycreepers? **(Hint:** See p. 389.)

BIOLOGY.com Search Lesson 16.3 GO • Lesson Assessment

16.4 Evidence of Evolution

Key Questions

How does the geographic distribution of species today relate to their evolutionary history?

What do homologous structures and similarities in embryonic development suggest about the process of evolutionary change?

How do fossils help to show the descent of modern species from ancient ancestors?

How can molecular biology be used to trace the process of evolution?

What does recent research on the Galápagos finches show about natural selection?

BUILD Understanding

Concept Map Make a concept map that shows the kinds of evidence that support the theory of evolution.

In Your Workbook Go to your workbook to learn more about making a concept map. Complete the concept map for Lesson 16.4.

Biogeography

When Darwin published *On the Origin of Species* in 1859, scientists were not able to test all of his ideas. But since then, scientists have discovered a great deal of evidence. This evidence comes from many different sciences—biogeography, anatomy, geology, chemistry, genetics, and even molecular biology. Amazingly, evidence from all of these areas supports Darwin's basic ideas about evolution.

Darwin used the science of biogeography to support his theory. **Biogeography** is the study of where organisms live and where their ancestors lived in the past. Darwin noted two important patterns: (1) Closely related organisms that live in different environments often show great differences. (2) Distantly related organisms that live in similar environments are often similar.

Closely Related but Different Darwin used biogeography to explain his observations in the Galápagos. He hypothesized that birds on the islands were descended from birds in South America. Natural selection in different environments had led to differences among the closely related populations.

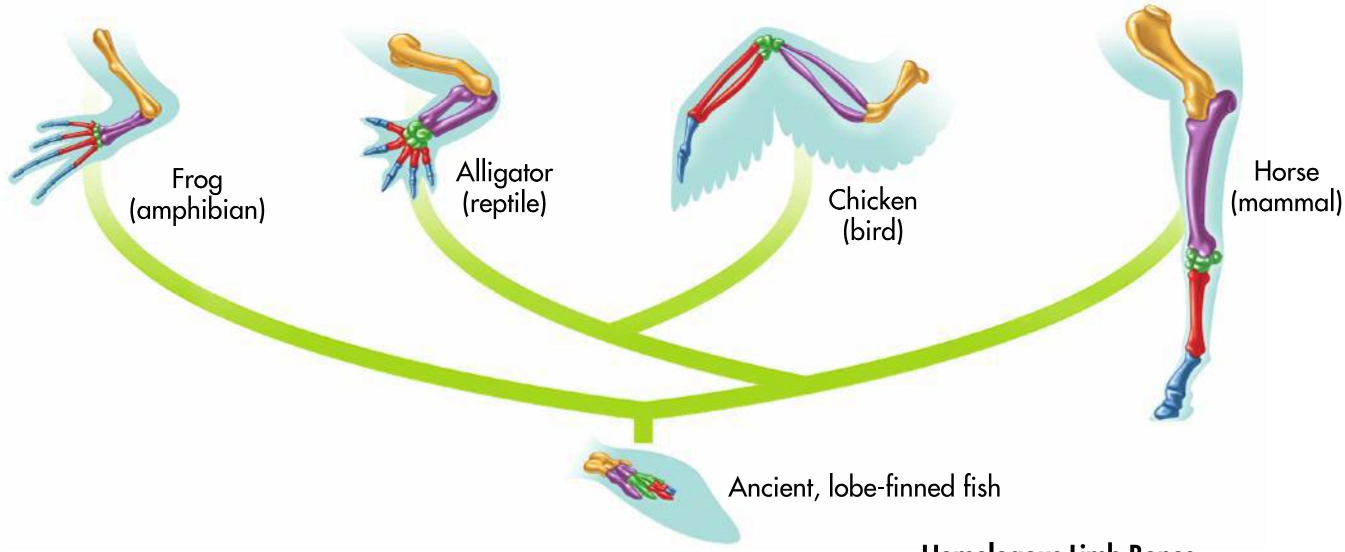
Distantly Related but Similar Darwin compared plants and animals living in similar environments around the world. For example, he found ground-dwelling birds in the grasslands of Europe, Australia, and Africa. These organisms looked alike, but were not closely related. Because they lived in similar habitats, natural selection had led to similar adaptations.

Key Question How does the geographic distribution of species today relate to their evolutionary history?

Patterns linking adaptations to environments around the world provide evidence for natural selection.

Comparing Body Structure and Embryos

In Darwin's time, researchers had discovered that many different animals have similar structures. For example, the front legs of amphibians, birds, and reptiles all have the same basic bones! Darwin suggested that animals with similar structures are related. Their structures are inherited from a common ancestor.



Homologous Limb Bones
The limb bones of seemingly unrelated animals have the same basic structures. Matching colors allow you to compare homologous structures. The limbs evolved from an ancient fish, their common ancestor.

Homologous Structures Structures that are shared by related species and that have been inherited from a common ancestor are called **homologous structures.** These structures often show modifications, or differences. The more alike homologous structures are, the more closely related the organisms. Bird limbs are more like reptile limbs than mammal limbs. This means that birds and reptiles are more closely related than birds and mammals. Homologous structures do not always work the same way. A bird's wing and horse's leg are homologous, even though they work differently.

Key Question What do homologous structures suggest about the process of evolutionary change? **Evolutionary theory explains that homologous structures adapted to different purposes are the result of descent with modification from a common ancestor.**

Analogous Structures Sometimes body parts share a common function but are not structurally related. These structures are called **analogous structures.** The wings of bees, bats, and birds are analogous. Analogous structures do not show common descent.

Vestigial Structures Some homologous structures do not have important functions. **Vestigial structures** are inherited structures that have lost much of their original function. Vestigial structures may show evolutionary relationships. For example, the hipbones of dolphins are vestigial structures. They link dolphins to ancestors that used hipbones as they walked on land.

Embryology The early stages of many animals with backbones look very similar. You may look nothing like a chicken now. But your embryonic cells grew in similar patterns. These patterns of growth produced homologous tissues and organs. These similarities are evidence of common descent.

Key Question What do similarities in embryonic development suggest about the process of evolutionary change?
Similar patterns of embryo development provide evidence that organisms have descended from a common ancestor.

BUILD Vocabulary

biogeography
the study of past and present distribution of organisms

homologous structures
structures that are similar in different species of common ancestry

analogous structures
structures that are similar in function but not structure; they do not suggest common ancestry

vestigial structure
a structure that is reduced in size and has little or no function

WORD ORIGINS
The word *homologous* comes from the Greek word *homos*, which means "same." Homologous structures may not look exactly the same, but they share certain characteristics and a common ancestor.

BIOLOGY.com Search Lesson 16.4 GO • Art Review

The Age of Earth and Fossils

Darwin knew that natural selection would take a very long time. For his theory to be true, Earth would have to be incredibly old.

The Age of Earth. Today, geologists use radioactivity to find the age of rocks and fossils. Their work supports Darwin's theory. Radioactive dating suggests that Earth is about 4.5 billion years old. That's plenty of time for evolution to take place!

Recent Fossil Finds When Darwin lived, enough fossils had been found to convince Darwin that life had changed over time. But there were not enough fossils to show clearly how modern species had descended from their ancestors. The fossil record was incomplete.

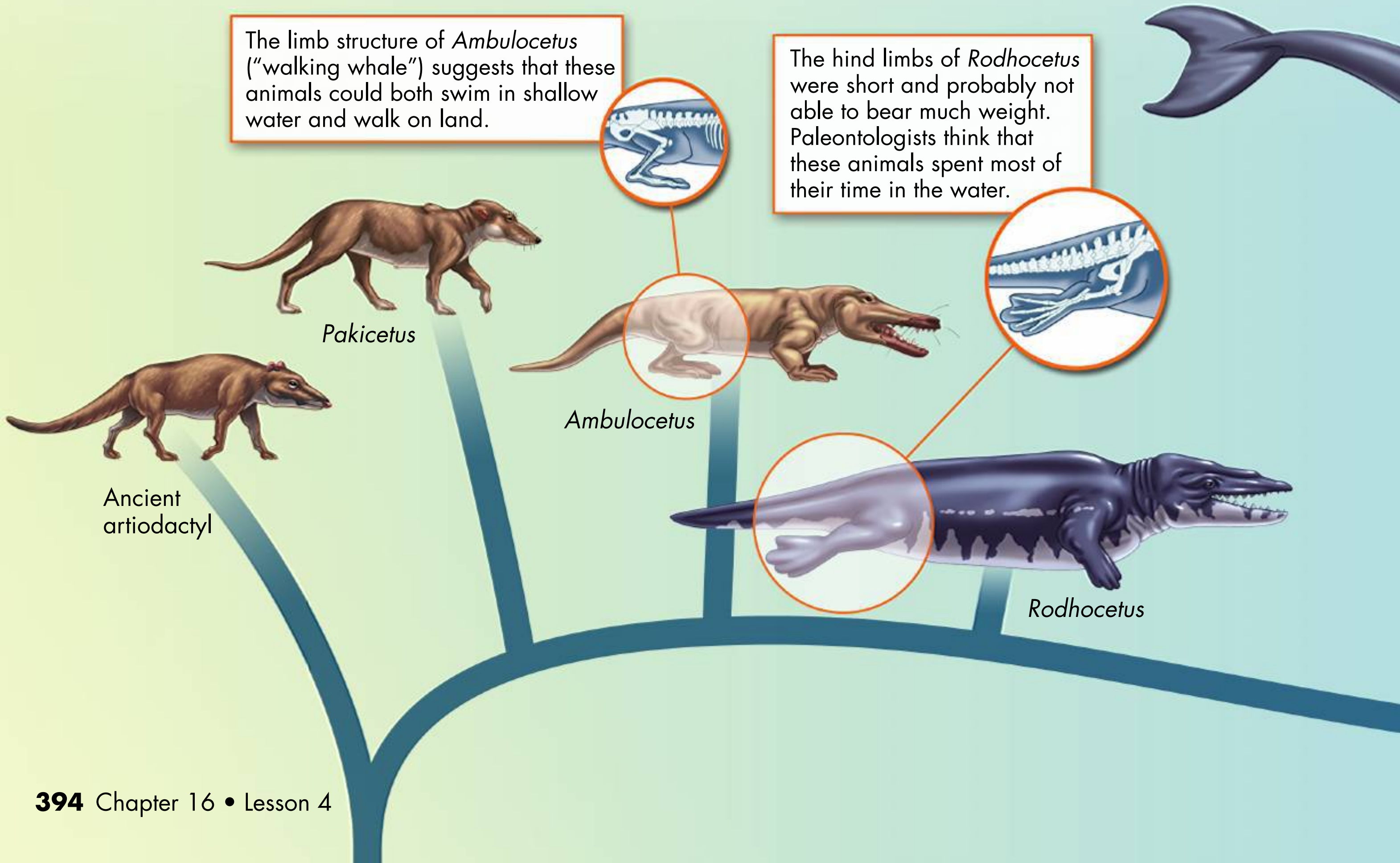
Today, hundreds of new fossil discoveries show clearly how many modern species have evolved from older species. Scientists have found fossils of animals that were "in between" dinosaurs and birds. Other fossils link fishes to land animals. New finds even connect land animals to whales. The fossil record is still incomplete. But new discoveries continue to support Darwin's theory.

Key Question How do fossils help to show the descent of modern species from ancient ancestors? **Many recently discovered fossils form series that trace the evolution of modern species from extinct ancestors.**

BUILD Connections

EVIDENCE FROM FOSSILS

Recently, scientists have discovered more than 20 fossils that show how whales evolved from ancestors that walked on land. The drawings of the ancient animals are based on fossil evidence.



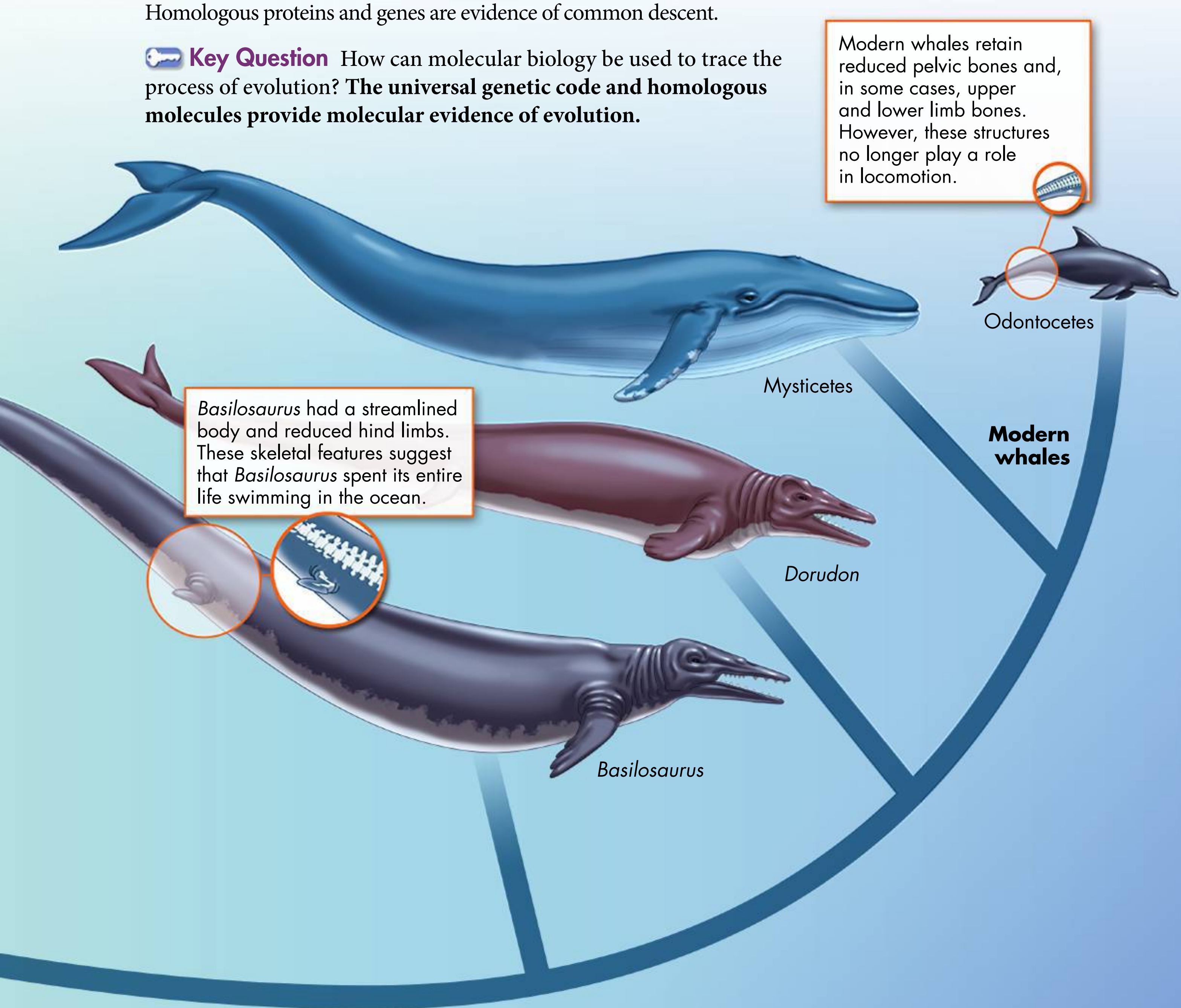
Genetics and Molecular Biology

Darwin did not understand how heredity worked. Since his time, biologists have learned a great deal about heredity. Darwin would be glad to know that modern genetics strongly supports evolution.

Common Genetic Code All living cells use DNA and RNA to make proteins and to pass on genetic information. The code is nearly the same for all living things—bacteria, yeasts, plants, fungi, and animals. The shared genetic code is powerful evidence that all organisms evolved from a common ancestor that used this code.

Homologous Molecules Biologists have found many homologous molecules. For example, the protein cytochrome *c* is important in cellular respiration. Versions of this protein are found in almost all living things. Homologous proteins and genes are evidence of common descent.

Key Question How can molecular biology be used to trace the process of evolution? **The universal genetic code and homologous molecules provide molecular evidence of evolution.**



BUILD Connections

FINCH BEAK TOOLS

Finch beaks can be compared to different tools. The different beaks allow each species of finch to pick up and eat a different kind of food.

Tree Finches

This finch strips bark from woody plants with a beak that grips and holds tightly, like a pair of pliers.

This finch feeds on small, exposed insects that it picks off plant surfaces. Its thin, straight, narrow beak works like needle-nose pliers or forceps to firmly grasp small objects at the tip.

Ground Finches

This finch feeds on insects, fruit, and nectar. Its beak works like a curved, needle-nose pliers that are good at probing and grasping at the tip.

This finch feeds on large, thick seeds with a beak that is thick, strong, and sharp. This beak works like heavy-duty wire cutters to apply strong pressure and cutting force near its base.

Testing Natural Selection

The best way to gather evidence about evolution is to observe natural selection in action. Some scientists have designed laboratory experiments using bacteria that let them test ideas about natural selection. Others have carried out experiments with guppies. These studies support Darwin's ideas. But the best way to test ideas about natural selection is to observe it in the wild. Peter and Rosemary Grant did just that. They studied finches on the Galápagos Islands.

A Testable Hypothesis Darwin hypothesized that all the Galápagos finches had descended from a common ancestor. He thought that natural selection had caused their beaks to change shape.

The Grants performed two studies to test Darwin's hypothesis. First, they carefully measured each bird's beak. They found that there was plenty of heritable variation in beak size. Second, they watched to see if differences in beak size led to differences in fitness.

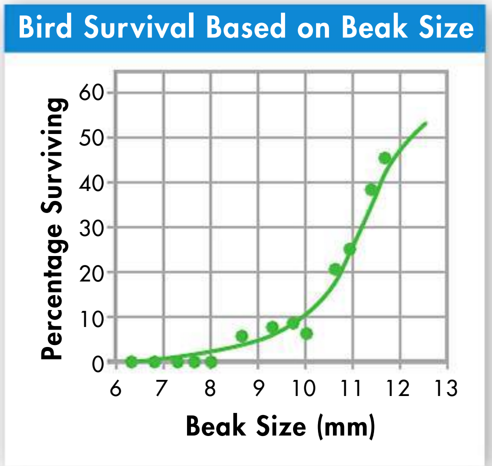
The Grants captured and released nearly every medium ground finch on one of the Galápagos Islands. They recorded which birds were alive and reproducing. They also recorded which birds had died. They carefully measured the beak of each bird. The Grants found variation in the sizes of the finches' beaks.

Natural Selection The Grants studied the finches for many years, during normal and dry seasons. When food was hard to find, the finches with the largest beaks were most likely to survive. Over a period of just decades, they observed an increase in average beak size. The Grants had observed natural selection in the wild. And it was happening much faster than expected!

The Grants also showed that variations help a species survive when the environment changes. In dry years, there were not enough small seeds for all of the finches. Competition among the finches favored birds with larger beaks. Finches with larger beaks were able to break open larger seeds. Thus, a trait that did not matter in a wet year became a helpful adaptation in a dry year.

Key Question What does research on the Galápagos finches show about natural selection? **The Grants showed that natural selection occurs in wild finch populations, sometimes quickly. They also showed that variation within a species can help the species adapt to and survive environmental changes.**

Survival of the Fittest and Beak Size
The Grants studied finches on the Galápagos Islands. This graph shows the survival of a population of ground finches. It shows that birds with larger beaks survived at a higher rate than birds with smaller beaks.



Evaluating Evolutionary Theory Like any scientific theory, evolutionary theory is constantly reviewed with each new bit of information. New studies, tools, and techniques have continued to support most of Darwin's hypotheses. Today, evolution is important in all branches of biology, from ecology to medicine.

Many important questions about evolution are still being studied: Exactly how did life begin? How do new species arise? Why do some species become extinct? Biologists often disagree about answers to these questions. But biologists agree that evolution *is* happening. To biologists, evolution is the key to understanding the natural world.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Body parts of unrelated organisms that serve the same function are examples of ______.

2. Body parts in related organisms that are structurally similar are examples of ______.

3. Inherited structures that have lost much of their original function are called ______.

Critical Thinking

4. **Explain** What is biogeography?

5. **Compare and Contrast** What is the difference between homologous and analogous structures? Which are more important to evolutionary biologists? Why?

6. **Apply Concepts** How do recent fossil finds help to support evolution?

7. **Review** How do modern genetics and molecular biology support the theory of evolution?

8. **Draw Conclusions** How do the data collected by the Grants show that variation is important to the survival of a species?

9. **Write to Learn** Answer the question in the mystery clue below. The Hawaiian islands have different environments. Some islands are very wet. Others are much drier. How might these environments affect the natural selection of honeycreepers?

MYSTERY CLUE

How can biogeography be used to explain why some species of honeycreepers are found only on the Hawaiian Islands? (**Hint:** See p. 392.)

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Skills Lab

GUIDED INQUIRY

Pre Lab: Amino Acid Sequences: Indicators of Evolution

Problem How can you use proteins to determine how closely organisms are related?

Materials light colored highlighting pen

Lab Manual Chapter 16 Lab

Skills Analyze Data, Graph, Draw Conclusions

Connect to the Big idea For years, scientists who studied evolution had to rely on only visible differences among organisms. Then a new source of evidence emerged. Biochemists were able to unravel the sequences of bases in DMA and amino acids in proteins. Scientists are able to use this data to confirm relationships based on anatomy. They also use the data to show that some species that appear very different are in fact more closely related than had been thought.

Biologists can compare the sequences of amino acids in a protein for two species. In general, when the total number of differences is small, the species are closely related. When the total number of differences is large, the species are more distantly related.

In this lab, you will compare amino acid sequences for one protein and analyze the results of a similar comparison for another protein. You will use both sets of data to predict relatedness among organisms.

Background Questions

a. **Review** What are homologous molecules?

b. **Explain** Why might scientists use molecules instead of anatomy to figure out how closely rabbits and fruit flies are related?

c. **Relate Cause and Effect** Amino acid sequences in the proteins of two species are similar. What can you conclude about the DNA in those species, and why?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Predict** Based only on their anatomy, rank gorillas, bears, chimpanzees, and mice from most recent common ancestor with humans to least recent.

2. **Use Analogies** You tell a story to a second person who tells it to a third person, and so on. As the story is retold, changes are introduced. Overtime, the number of changes increases. How is this process an analogy for what happens to DNA over time?

3. **Infer** Hemoglobin from two species is compared. On the long protein chains, there are three locations where the amino acids are different. Where would you place the common ancestor of the two species on the "tree of life," and why?

BIOLOGY.com Search Chapter 16 GO

Visit Chapter 16 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Islands are rich environments for evolution, as you will find out with the Untamed Science crew.

Art in Motion This animation shows how fossil layers accumulate and are later exposed.

Art Review Review homologus and analogous structures in vertebrates.

Visual Analogy See how different types of finch beaks function like tools.

Data Analysis Collect population data for several generations of grasshoppers and then analyze how the population changed due to natural selection.

16 CHAPTER Summary

16.1 Darwin's Voyage of Discovery

- Darwin developed a theory of evolution that explains how organisms evolved over long periods of time from common ancestors.
- Darwin noticed that (1) different places around the world that had similar habitats often had different species that were ecologically similar; (2) different, related species often lived in different habitats within a local area; and (3) some fossils of extinct animals were similar to living species.

evolution (p. 380)
fossil (p. 382)

16.2 Ideas That Shaped Darwin's Thinking

- Hutton and Lyell concluded that Earth is extremely old. Also, the processes that changed Earth in the past are the same processes that operate in the present.
- Lamarck suggested that individual organisms could change during their lifetime by using or not using different parts of their bodies. He also suggested that individuals could pass these acquired traits on to their offspring. This would cause species to change over time.
- Malthus reasoned that if the human population were to grow without control, there would not be enough space and food for everyone to live.
- In artificial selection, nature provides the variation of traits. Humans select the traits they find useful.

artificial selection (p. 387)

16.3 Darwin Presents His Case

- Natural selection occurs whenever more individuals are born than can survive, there is heritable variation, and some individuals have higher fitness than others.
- The principle of common descent says that all species are descended from ancient common ancestors. This is true of living and extinct species.

adaptation (p. 388)
fitness (p. 388)
natural selection (p. 389)

16.4 Evidence of Evolution

- Patterns linking adaptations to environments around the world provide evidence for natural selection.
- Many recently discovered fossils form series that trace the evolution of modern species from extinct ancestors.
- Homologous structures and patterns of embryo development provide evidence that species have descended, with modification, from a common ancestor.
- Many recently discovered fossils form series that trace the evolution of modern species from extinct ancestors.
- The universal genetic code and homologous molecules provide molecular evidence of common descent.
- The Grants observed natural selection occurring in a wild finch population. They also showed that variation within a species can help the species adapt to and survive environmental changes.

biogeography (p. 392)
homologous structure (p. 393)
analogous structure (p. 393)
vestigial structure (p. 393)

16 CHECK Understanding

Assess the Big idea: Evolution

Write an answer to the question below.
Q: What is natural selection?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each numbered question should be one or two paragraphs. To help you begin, read **Hints** below the questions.

1. **How was Darwin's theory of evolution influenced by the work of other scientists?**

   Hint Geologists such as Hutton and Lyell developed the concept of deep time.

   Hint Thomas Malthus described conditions that affect human populations. These conditions can also affect other organisms.

2. **How would Darwin explain the evolution of the long legs of the bird in the picture on page 385? How would his explanation differ from that of Lamarck?**

   Hint Read the caption to review some of Lamarck's ideas.

3. **Look back at the art of the natural selection of grasshoppers on page 390. Explain how conditions could change so that yellow grasshoppers are better adapted to their environment than green grasshoppers. What would happen to the relative numbers of green and yellow grasshoppers in the population?**

   Hint The word *camouflage* refers to a way of hiding in an environment. In your answer, explain how camouflage can be an adaptation.

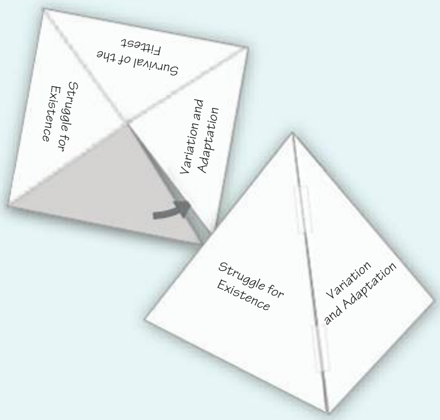
Foundations for Learning Wrap-Up

You can use the notes you took about the steps of natural selection as a tool for review. First, you will make your sheet of paper into a pyramid. To do this, cut to the center along a fold next to the colored triangle. (Do not cut all the way through.) Now you have two flaps. Tape the flap with writing over the colored flap, so the two flaps make one side. You now have a three-sided pyramid.

Activity 1 Turn each side of your pyramid into a question. For example, "What is the struggle for existence?" Write the answer on a separate sheet of paper. Then look inside your pyramid to check your answer. Make any corrections or additions that are needed on your answer sheet. Then move on to the next question.

Activity 2 Work with a partner. Quiz each other on the stages of natural selection. Begin with a population of green grasshoppers that live in a habitat with green grass. Use the sides of your pyramid as clues. For example, you could ask, "How does the struggle for existence affect the grasshoppers?" If you cannot answer a question, check inside the pyramid.

Then take turns suggesting other kinds organisms that live in other environments. For example, you might describe the process of natural selection on a population of orange and pink fish that live on a coral reef. Be creative!



16.1 Darwin's Voyage of Discovery

Understand Key Concepts

1. Who observed variations in the characteristics of plants and animals on the Galápagos Islands?
   a. James Hutton
   b. Thomas Malthus
   c. Charles Lyell
   d. Charles Darwin

Test-Taking Tip

Read Carefully! Sometimes the difference between the correct answer and an incorrect answer is a single word. In question 1, you might be tempted to answer **c,** because Charles Lyell is similar to Charles Darwin. Try to think of the answer before you read the choices, then carefully read each choice.

2. In different parts of the world, Darwin found unrelated species that looked alike because
   a. the species lived in different environments.
   b. the species lived in similar environments.
   c. the species were closely related.
   d. the species once lived in the same place.
3. What connection did Darwin make between the Galápagos tortoises and their environments?

Think Critically

4. **Relate Cause and Effect** Why was Darwin's trip on the *Beagle* so important to his development of the theory of natural selection?

16.2 Ideas That Shaped Darwin's Thinking

Understand Key Concepts

5. Which of the following ideas proposed by Lamarck was later found to be incorrect?
   a. Acquired characteristics can be inherited.
   b. All species are descended from other species.
   c. Living things change over time.
   d. There is a relationship between an organism and its environment.
6. Which of the following would an animal breeder use to increase the amount of milk given by his herd of cows?
   a. overproduction
   b. genetic isolation
   c. acquired characteristics
   d. artificial selection
7. According to Malthus, what factors limit human population growth?

Think Critically

8. **Relate Cause and Effect** Lamarck made a very significant contribution to science, even though his explanation of evolution was wrong. Explain how Lamarck helped other scientists.
9. **Infer** Could artificial selection happen without inherited variation? Explain your answer.

16.3 Darwin Presents His Case

Understand Key Concepts

10. An inherited characteristic that increases an organism's ability to survive and reproduce in its environment is called a(n)
    a. vestigial structure.
    b. adaptation.
    c. homologous structure.
    d. variation.
11. What do evolutionary trees show?
    a. all life depends on trees
    b. all life is changing due to natural selection
    c. all living species are descended from earlier ancestors.
    d. all life evolves to the point of perfection
12. What is fitness, in evolutionary terms?

Think Critically

13. **Infer** Many species of birds build nests in which they lay eggs and care for their young. How does this behavior relate to reproductive fitness?

16 CHECK Understanding

16.4 Evidence of Evolution

Understand Key Concepts

14. Series of related fossils are important evidence of evolution because they show
- **a.** how organisms changed over time.
- **b.** how animals behaved in their environments.
- **c.** how the embryos of organisms develop.
- **d.** molecular homologies.

15. The wing of a bird that cannot fly is an example of a(n)
- **a.** analogous structure.
- **b.** homologous structure.
- **c.** vestigial structure.
- **d.** molecular structure.

16. How does DNA provide evidence for common descent?

Think Critically

17. **Evaluate** Darwin hypothesized that natural selection led to the different beak shapes in the Galapagos finches. Describe how the Grants tested this hypothesis. Did their data support Darwin's hypothesis?

Connecting Concepts

Use Science Graphics

Use the illustration below to answer question 18.

18. **Infer** Based on what you can see, are the brown mice or white mice better adapted to their environment? Explain why.

solve the CHAPTER MYSTERY

SUCH DIFFERENT HONEYCREEPERS

Hawaiian honeycreepers like the i'iwi have a lot in common with the Galápagos finches. Like the finches, the honeycreepers are small birds found nowhere else on Earth. They live on islands far from the mainland. And like the finches, the 20 known species of honeycreepers are closely related to each other.

This suggests that the honeycreepers are all descended, with modification, from a recent common ancestor. Honeycreepers are recent in evolutionary terms. Biologists think the ancestor first arrived on the islands between 3 and 4 million years ago.

Many of the honeycreepers have specialized diets. Their adaptations allow them to use different food sources on the different islands. Today, habitat loss is making it harder for the honeycreepers to survive. Some species have already become extinct since humans settled on the islands.

1. **Infer** Imagine a small group of birds landed on one of the Hawaiian islands millions of years ago. This small population then reproduced. Do you think all of the descendants would have stayed on that one island? Explain your answer.

2. **Infer** Do you think that environmental conditions are the same everywhere on all of the Hawaiian Islands? How might the environment have affected the evolution of honeycreepers?

3. **Form a Hypothesis** Explain how the different species of honeycreepers in Hawaii today might have evolved from one ancestral species.

UntamedScience **Never Stop Exploring Your World.** Finding the solution to the honeycreeper mystery is only the beginning. Take a video field trip to Hawaii with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Which scientist formulated the theory of evolution through natural selection?
A Charles Darwin
B Thomas Malthus
C James Hutton
D Jean-Baptiste Lamarck

2. Lamarck's ideas about evolution were wrong because he proposed that
A species change over time.
B species descended from other species.
C acquired characteristics can be inherited.
D species are adapted to their environments.

3. Lyell's *Principles of Geology* influenced Darwin because it explained how
A organisms change over time.
B adaptations occur.
C Earth must be very old.
D the Galápagos Islands formed.

4. A farmer's use of the best livestock for breeding is an example of
A natural selection.
B artificial selection.
C extinction.
D adaptation.

5. The ability of an individual organism to survive and reproduce in its natural environment is called
A natural selection.
B evolution.
C descent with modification.
D fitness.

6. Which of the following is an important concept in Darwin's theory of evolution by natural selection?
A descent with modification
B homologous molecules
C processes that change the surface of Earth
D the tendency toward perfection

7. Which of the following provides evidence for evolution?
A fossil record
B homologous structures of living organisms
C geographical distribution of living things
D all of the above

8. DNA and RNA provide evidence of evolution because
A all organisms have nearly identical DNA and RNA.
B no two organisms have exactly the same DNA.
C each RNA codon specifies just one amino acid.
D in most organisms, the same codons specify the same amino acids.

9. A bird's wings are homologous to a(n)
A fish's tailfin.
B alligator's claws.
C dog's front legs.
D mosquito's wings.

Questions 10 and 11

The birds shown below are two of the species of finches Darwin found on the Galápagos Islands.

Woodpecker Finch

Large Ground Finch

10. What process produced the two different types of beaks shown?
A artificial selection
B natural selection
C geographical distribution
D disuse of the beak

11. The large ground finch obtains food by cracking seeds. Its short, strong beak is an example of
A the struggle for existence.
B the tendency toward perfection.
C an adaptation.
D a vestigial organ.

Open-Ended Response

12. Compare and contrast the processes of artificial selection and natural selection.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10	11	12
See Lesson	16.1	16.2	16.2	16.2	16.3	16.3	16.4	16.4	16.4	16.3	16.3	16.3

17 Evolution of Populations

Big idea **Evolution**

Q: How can populations evolve to form new species?

At first glance, these two butterflies look exactly the same. But if you look closely, you can see that the patterns on their wings are slightly different. Variations among members of a population make evolution possible. Sometimes evolution leads to new species.

BIOLOGY.com Search Chapter 17 GO • Flash Cards

INSIDE:

- 17.1 Genes and Variation
- 17.2 Evolution as Genetic Change in Populations
- 17.3 The Process of Speciation
- 17.4 Molecular Evolution

- Untamed Science Video
- Chapter Mystery

CHAPTER
MYSTERY

KILLER DISEASE

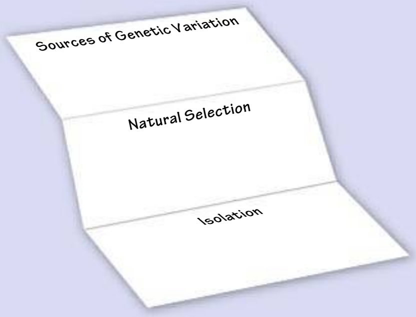
In 1918, a new disease began to kill millions of people. Around the world, more than 40 million people died. What caused this terrible disease? It was an influenza virus. This virus was a strain of "the flu" that you can catch again and again. Every year different strains of these viruses appear and cause the flu.

How did this one virus become so deadly? Could such a deadly flu ever happen again? Scientists are searching for the answers to these questions. They are still very worried about the influenza virus, and the chance of another deadly disease. That is why they are watching the "bird flu" so closely.

Read for Mystery Clues As you read this chapter, look for clues that explain how new types of influenza virus appear. How is evolution involved? Then, solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

Fold a piece of paper into three equal sections. Then lay the paper out flat. At the top of the page, write "Sources of Genetic Variation," At the top of the middle section, write "Natural Selection." At the top of the bottom section, write "Isolation." As you read, make notes or drawings that relate to each heading. These notes will help you answer the question: How can populations evolve to form new species?



17.1 Genes and Variation

Key Questions

How is evolution defined in genetic terms?

What are the sources of genetic variation?

What determines the number of phenotypes for a given trait?

BUILD Understanding

Concept Map As you read, construct a concept map to describe the sources of genetic variation.

In Your Workbook Go to your workbook to learn more about making a concept map.

BUILD Vocabulary

gene pool all the genes, including all the different alleles for each gene, that are present in a population at any one time

allele frequency the number of times that an allele occurs in a gene pool, compared to the total number of alleles in that pool for the same gene

single-gene trait a trait controlled by one gene that has two alleles

polygenic trait a trait controlled by two or more genes

PREFIXES

The prefix *poly-* means "several or many." *Polygenic* means "many genes."

Genetics Joins Evolutionary Theory

When Darwin developed his theory of evolution, he did not know how heredity worked. He did not know the source of variation in a population. Mendel's studies were published while Darwin was alive. But no one understood the importance of Mendel's work. Mendel's work was rediscovered around 1900. When scientists combined Mendel's work with Darwin's theory, they could understand how traits were inherited. Today, evolution can be described in terms of genetics.

Genotype and Phenotype in Evolution Most plants and animals have two sets of genes—one set from each parent. These genes come in different forms, called alleles. The set of alleles found in an organism is called its genotype. An organism's genotype and its environment determine its phenotype. Phenotype is an organism's appearance and other characteristics, or traits.

Natural selection acts on phenotypes. It does not act directly on genes. In any population, some individuals have phenotypes (or traits) that are a better fit for their environment. Those individuals have higher fitness. In genetic terms, higher fitness means that they have more offspring and pass on more of their genes to the next generation.

Gene Pools A population is a group of individuals that mate and produce offspring. A **gene pool** contains all the alleles of all the genes in a population. In a gene pool, some alleles are common. Others are rare. **Allele frequency** is the number of times an allele occurs in a gene pool, compared to the total number of alleles for the same gene in that pool. Allele frequency is a percentage. The diagram on the next page shows the allele frequencies for fur color in a population of mice. In this population, the frequency of the dominant allele *B* (black) is 40 percent. The frequency of the recessive allele *b* (brown) is 60 percent.

If the frequency of an allele changes over time, the population is evolving. Only populations evolve, not individuals.

Key Question How is evolution defined in genetic terms?
In genetic terms, evolution involves a change in the frequency of alleles in a population over time.

Sources of Genetic Variation

The members of a population differ from each other. Genetics explains the source of these variations.

Mutations A mutation is a genetic change. Most mutations are neutral and have little effect on fitness. Some mutations lower fitness by making survival and reproduction more difficult. Others increase fitness by making survival and reproduction easier. To play a role in evolution, a mutation must be passed from one generation to the next. The only mutations that can be passed on are those that are carried in egg or sperm cells.

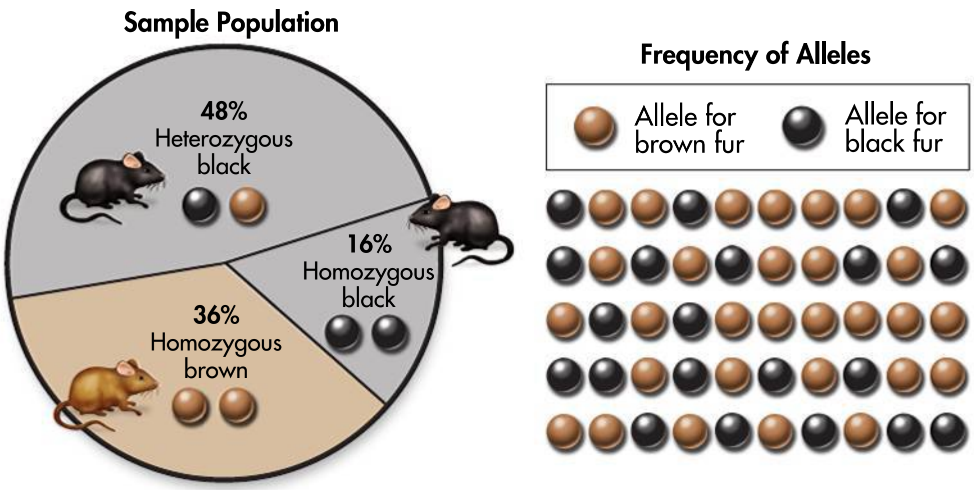
Sexual Reproduction During sexual reproduction, the genes from two parents combine in new ways. This process can produce millions of different gene combinations. Crossing-over also mixes genes. Crossing-over happens during meiosis when chromosome pairs trade pieces of DNA.

Sexual reproduction creates new genotypes. But it does not change the frequency of alleles in the whole population. Sexual reproduction is like shuffling a deck of cards. You get new combinations of cards. But the deck always has the same number of kings and queens.

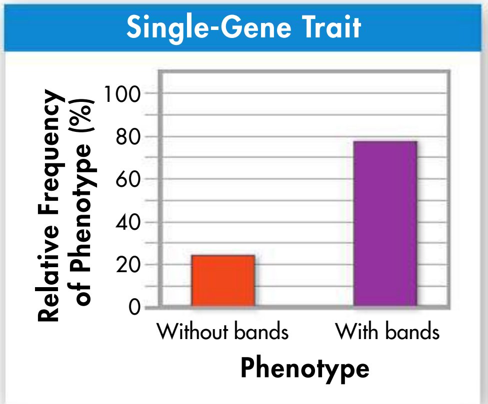
Lateral Gene Transfer Some single-celled organisms can pass genes from one individual to another. For example, many bacteria trade genes on plasmids. The passing of genes to an organism that is not an offspring is called lateral gene transfer. Lateral gene transfer is important in the evolution of single-celled organisms.

Key Question What are the sources of genetic variation?
Three sources of genetic variation are mutations, genetic recombination during sexual reproduction, and lateral gene transfer.

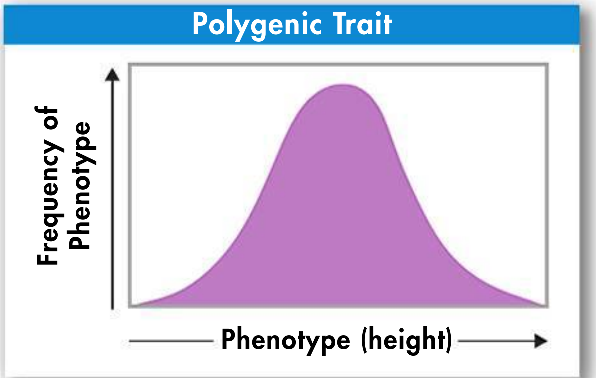
Genetic Variation Genetic variation can produce differences in appearance, such as the different colors of the kernels on these ears of corn. Other kinds of genetic variation, such as resistance to disease, cannot be seen.



Alleles in a Population To determine whether a population is evolving, scientists study its allele frequencies. This diagram shows allele frequencies for fur color in a mouse population.



Two Phenotypes A single gene controls whether or not a snail's shell has bands.



A Range of Phenotypes Human height is controlled by several genes. Most individuals are of average height, so the graph's curve is highest in the middle.

Single-Gene and Polygenic Traits

Genes control phenotype in different ways. In some cases, a single gene controls a trait. In other cases, several genes work together to control a trait.

Single Gene Traits A trait controlled by just one gene is called a **single-gene trait.** Single-gene traits may have just two or three phenotypes. For example, in one type of snail, a single gene controls stripes on the shell. The gene has two alleles, one for striped shells and one for plain shells. There are only two possible phenotypes: with or without stripes.

Polygenic Traits A trait that is controlled by two or more genes is a **polygenic trait.** Polygenic traits can have many possible genotypes and phenotypes. In other words, there is a wide range of phenotypes for polygenic traits.

One example of a polygenic trait in humans is height. Individuals can be very tall, very short, or any height in between. You can measure the height of the members of your own class. Most students will be of average height. A graph of your data might be similar to the one shown at left. The shape of this graph is like the curve of a bell. A bell curve is typical for polygenic traits.

Key Question What determines the number of phenotypes for a given trait?
The number of phenotypes for a trait depends on how many genes control the trait.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A ______ is the complete set of genes in a population.
2. The number of times that an allele occurs in a gene pool, compared to the total number of alleles in that pool for the same gene is called ______.
3. A trait that is controlled by two or more genes is called a ______ trait.

Critical Thinking

4. **Explain** What indicates that evolution is taking place in a population? Use the word *alleles* in your answer.
5. **Review** What are three sources of genetic variation?
6. **Compare and Contrast** How does the range of phenotypes for single-gene traits differ from the range for polygenic traits?
7. **Write to Learn** Answer the mystery clue below.

MYSTERY CLUE

The genes of flu viruses have very high mutation rates. How might this affect the amount of variation in the virus gene pool? (Hint: See p. 407.)

BIOLOGY.com Search Lesson 17.1 GO • Lesson Assessment

17.2 Evolution as Genetic Change in Populations

How Natural Selection Works

The word *fitness* can describe how healthy you are. But in evolution, *fitness* has a different meaning. *Fitness* describes individuals that have traits that help them survive and reproduce. Their traits are favored by natural selection. Individuals with high fitness have more offspring and pass on more of their genes. The alleles that produce these traits become more common in the population. This is the process of evolution.

Natural Selection on Single-Gene Traits In single-gene traits, natural selection can lead to changes in allele frequencies. When natural selection favors one trait over another, the allele for the favored trait becomes more common over time.

Imagine a population of brown lizards. A single gene that controls color mutates to form two new alleles: red and black. What happens to lizards with these new alleles? Red lizards are easier to see. They often get eaten before they can reproduce. For that reason, the red allele will probably not become common. Black lizards can warm up in the sun more quickly than brown lizards. The warmer black lizards can run from predators more quickly than brown lizards. Therefore, the frequency of the black allele is likely to increase. Over time, black lizards will become more common.

Key Question How does natural selection affect single-gene traits? **Natural selection on single-gene traits can lead to changes in allele frequencies. This leads to changes in phenotype frequencies.**

Key Questions

How does natural selection affect single-gene and polygenic traits?

What is genetic drift?

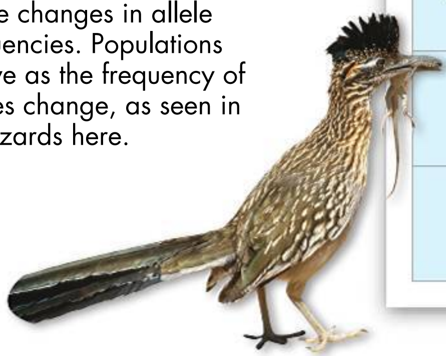
What five conditions maintain genetic equilibrium?

BUILD Understanding

Preview Visuals Before you read, look at the chart below. What trend does the chart seem to show? How is it related to evolution?

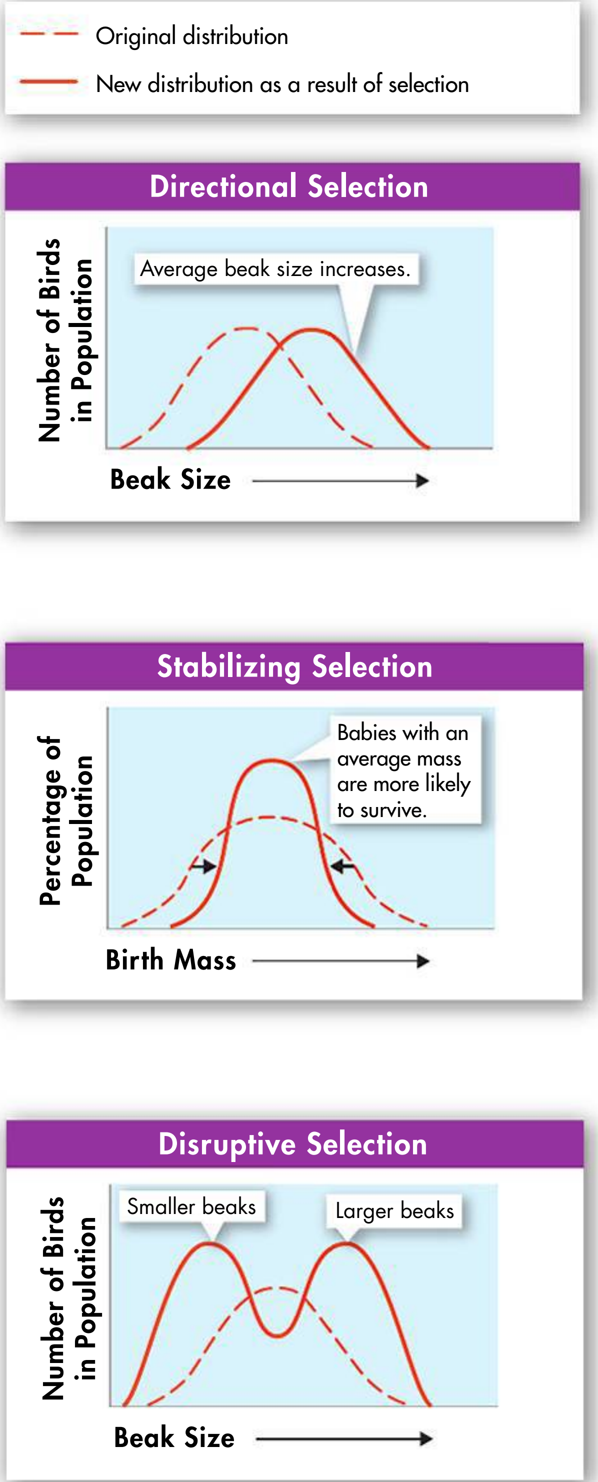
In Your Workbook Go to your workbook to learn more about previewing visuals. Complete the previewing visuals chart for Lesson 17.2.

Selection on a Single-Gene Trait Natural selection on a single-gene trait can cause changes in allele frequencies. Populations evolve as the frequency of alleles change, as seen in the lizards here.



Effect of Color Mutations on Lizard Survival

Initial Population	Generation 10	Generation 20	Generation 30
80%	80%	70%	40%
10%	0%	0%	0%
10%	20%	30%	60%



Selection on Polygenic Traits Natural selection on polygenic traits has one of three patterns. These patterns are directional selection, stabilizing selection, or disruptive selection.

Natural Selection on Polygenic Traits

Traits that are controlled by more than one gene produce a range of phenotypes. This range can often be shown by a bell curve. Natural selection can act on polygenic traits in one of three ways: directional selection, stabilizing selection, or disruptive selection.

▶ ***Directional Selection*** Sometimes natural selection favors organisms at one end of the bell curve. When individuals at one end of the curve have higher fitness than the others, **directional selection** takes place.

Imagine a population of birds that live on an island. The island has many large seeds with thick shells, but few small seeds. Birds with bigger beaks would have more to eat than birds with smaller beaks. Birds with bigger beaks would live longer and have more offspring. Over time, the average size of beaks would get bigger. Natural selection would move in one direction—toward larger beaks.

▶ ***Stabilizing Selection*** Sometimes natural selection favors the average individuals. When individuals near the center of the bell curve have the highest fitness, **stabilizing selection** takes place. Stabilizing selection shifts the ends of the curve closer to the middle.

Human babies are affected by stabilizing selection. Very small babies are usually less healthy and less likely to survive. Very large babies may have trouble being born. In this example, the fitness of the extremes is lower than that of the average.

▶ ***Disruptive Selection*** Sometimes the most extreme traits are most likely to survive and reproduce. The average types have a harder time surviving and reproducing. This situation is called **disruptive selection.** Disruptive selection can eventually create two distinct phenotypes. These phenotypes are shown by a curve with two peaks.

Suppose a population of birds lives on an island where medium-size seeds are rare. Most seeds are either large or small. Birds with very small or very large beaks would be more likely to survive. The population might split into two groups: one with smaller beaks and one with larger beaks.

Key Question How does natural selection affect polygenic traits? **Natural selection on polygenic traits can affect the relative fitness of phenotypes. Natural selection produces one of three types of selection: directional selection, stabilizing selection, or disruptive selection.**

Genetic Drift

Natural selection is not the only cause of evolutionary change. In small populations, chance events can cause evolution. A random change in the frequency of the alleles in a gene pool is called **genetic drift.** Genetic drift may be caused by the bottleneck effect or the founder effect.

Genetic Bottlenecks Sometimes, a disaster can kill off most of a population. For example, a flood or disease may leave only a few individuals alive. The small group of survivors might have a set of alleles that is very different from the lost population. When this small population grows, its gene pool will be different from the original population. A change in allele frequency following a dramatic loss of population is called the **bottleneck effect.** The bottleneck effect can greatly reduce the genetic diversity in a population.

The Founder Effect Genetic drift can also happen when a few individuals move into a new habitat. The small group may have a set of alleles that is different from the main population. The **founder effect** is a change in allele frequency that results from a small group starting a new population.

The hundreds of species of fruit flies on the different Hawaiian islands demonstrate the founder effect. All of these species came from a single species of fruit fly in South America. Each Hawaiian species has allele frequencies that differ from the original species.

Key Question What is genetic drift? **Genetic drift is the change in allele frequency that happens in small populations due to random events.**

BUILD Vocabulary

directional selection a form of natural selection in which individuals at one end of a distribution curve have higher fitness than individuals in the middle or at the other end of the curve

stabilizing selection a form of natural selection in which individuals near the center of a distribution curve have higher fitness than individuals at either end of the curve

disruptive selection a form of natural selection in which individuals at the upper and lower ends of a distribution curve have higher fitness than individuals near the middle of the curve

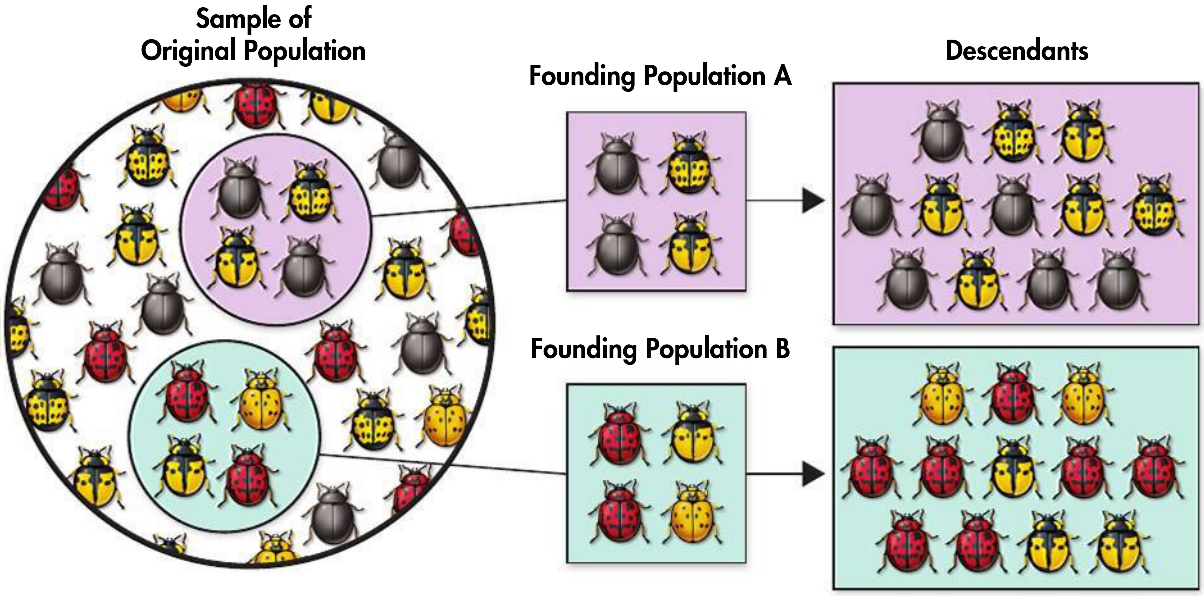
genetic drift a random change in allele frequency caused by a series of chance occurrences that cause an allele to become more or less common

bottleneck effect a change in allele frequency following a dramatic reduction in the size of a population

founder effect a change in allele frequencies as a result of the migration of a small group of a population

ACADEMIC WORDS

The adjective *random* means "lacking a pattern" or "happening by chance." A random change happens by chance.



Founder Effect When a small group starts a new population, the descendants can differ from the original population. In the art, a diverse population gives rise to two very different populations.

BUILD Vocabulary

genetic equilibrium
a situation in which the allele frequencies in a population remain the same

Hardy-Weinberg principle
the principle that states that allele frequencies in a population remain constant unless one or more factors cause those frequencies to change

sexual selection
the process by which individuals select mates on the basis of heritable traits

WORD ORIGINS

The word *equilibrium* comes from two Latin words: *aequus*, which means "level," and *libra*, which means"a balance." Equilibrium is a state in which all the forces are balanced by each other, so the condition is stable.

Evolution Versus Genetic Equilibrium

To understand how populations evolve, it helps to imagine a population that does *not* evolve. If a population is not evolving, the allele frequencies in the gene pool do not change. This condition is called **genetic equilibrium.**

Sexual Reproduction and Allele Frequency In sexual reproduction, genes are shuffled. This produces many new gene combinations. But meiosis and fertilization do not change the allele frequencies in the total population. Therefore, sexual reproduction alone does not affect genetic equilibrium.

The Hardy-Weinberg Principle The **Hardy-Weinberg principle** states that allele frequencies in a population will stay in genetic equilibrium unless something causes them to change. This principle predicts that five conditions can upset genetic equilibrium and cause a population to evolve.

▶ ***Nonrandom Mating*** In genetic equilibrium, individuals must mate with other individuals at random. But in many species, individuals choose mates that have particular traits, such as size or color. When individuals pick mates with certain heritable traits, the process is called **sexual selection.** If mates are selected for a particular trait, the frequency of that trait will increase.

▶ ***Small Population*** Genetic drift usually does not affect a large population. But it can affect small populations greatly. Therefore, evolution takes place more easily in a small population.

▶ ***Movement Into or Out of the Population*** Individuals that join a population may add new alleles to the gene pool. Individuals that leave can lower the frequency of certain alleles. Either direction of movement will affect the genetic equilibrium.

▶ ***Mutations*** Mutations can create new alleles. These new alleles can change the allele frequencies of the population.

▶ ***Natural Selection*** If different genotypes have different fitness, individuals with those genotypes will be more likely to survive. Genetic equilibrium will be upset. The population will evolve.

In real populations, one or more of these conditions is usually true. Therefore, most of the time, most species are evolving.

Key Question What five conditions can disturb genetic equilibrium? **The Hardy-Weinberg principle predicts that five conditions can disturb genetic equilibrium and cause evolution to occur. These conditions are (1) nonrandom mating, (2) small population size, (3) movement into or out of a population, (4) mutations, and (5) natural selection.**

Choosing a Mate In many species, mating is not random. For example, female peacocks prefer mates with big, colorful tail feathers. This is an example of sexual selection.

INQUIRY into Scientific Thinking

Allele Frequency

The Hardy-Weinberg principle can be used to predict the frequencies of genotypes in a population that is not evolving. This equation can be used to predict the percentages of the possible genotypes in a population:

$$\boldsymbol{p^2 + 2pq + q^2 = 1}, \text{ where}$$

p and ***q*** stand for two alleles of the same gene;
$\boldsymbol{p^2}$ and $\boldsymbol{q^2}$ stand for the homozygous genotypes;
pq stands for the heterozygous genotype.

Sample Problem

A population has two alleles for a gene: ***A*** (dominant) and ***a*** (recessive). In one generation, the frequency of allele ***A*** is 60% and the frequency of allele ***a*** is 40%. What will be the frequencies of each genotype in the next generation?

1. From genetics, you know that a cross of these two alleles can produce three genotypes: ***AA, Aa,*** and ***aa.*** In the equation, allele ***A*** will be ***p,*** and allele ***a*** will be ***q.***

$$p^2 \quad + \quad 2pq \quad + \; q^2 \quad = \quad 1$$

$$AA \quad + \quad 2Aa \quad + \; aa \quad = \quad 1, \text{ or } 100\%$$

2. Substitute the known frequencies for alleles *A* and *a*.

$\boldsymbol{A = 60\%}$, or **0.60** $\qquad$ $\boldsymbol{a = 40\%}$, or **0.40**

$\boldsymbol{A^2 = 36\%}$, or **0.36** $\qquad$ $\boldsymbol{a^2 = 16\%}$, or **0.16**

$\boldsymbol{2Aa = 2\,(0.60 \times 0.40) = 2\,(0.24) = 0.48}$, or **48%**

The next generation will have these frequencies: 36% ***AA;*** 48% ***Aa;*** 16% ***aa.*** If the population does not show these frequencies, evolution is taking place.

Practice Problems

Some members of a human population have a genetic condition. The condition is controlled by two alleles, *S* (dominant) and *s* (recessive). The condition affects only individuals that are homozygous for the recessive allele (*ss*). Heterozygous individuals (*Ss*) do not have the condition. The *s* allele is found in 6% of the population.

1. Calculate What percentage of the population carries the *S* allele? (**Hint:** $p + q = 100\%$)

2. Calculate What are the frequencies of the *SS*, *Ss*, and *ss* genotypes?

3. Calculate In a population of 10,000 people, how many people would have the condition?

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The change in allele frequency after a dramatic drop in the size of a population is called the ________.

2. The change in allele frequency caused by the migration of a small group is called the ________.

3. The ________ identifies conditions necessary for gene frequencies in a population to remain constant.

Critical Thinking

4. Relate Cause and Effect How does natural selection affect a single-gene trait?

5. Compare and Contrast Compare directional selection and disruptive selection.

6. Relate Cause and Effect What is genetic equilibrium? What five conditions are necessary to maintain genetic equilibrium?

7. Write to Learn Answer the mystery clue below.

MYSTERY CLUE

Normally, your immune system can kill invading viruses. What would happen if a flu virus had a mutation that your immune system could not fight? (Hint: See p. 409.)

17.3 The Process of Speciation

Key Questions

What types of isolation lead to the formation of new species?

What is the current hypothesis about Galápagos finch speciation?

BUILD Understanding

Compare/Contrast Table In a compare/contrast table, describe the three mechanisms of reproductive isolation.

In Your Workbook Go to your workbook to learn more about using compare/contrast tables. Complete the compare/contrast table for Lesson 17.3.

BUILD Vocabulary

species
a population whose members can breed and produce fertile offspring

speciation
the formation of a new species

reproductive isolation
the separation of a species or population so that members can no longer interbreed

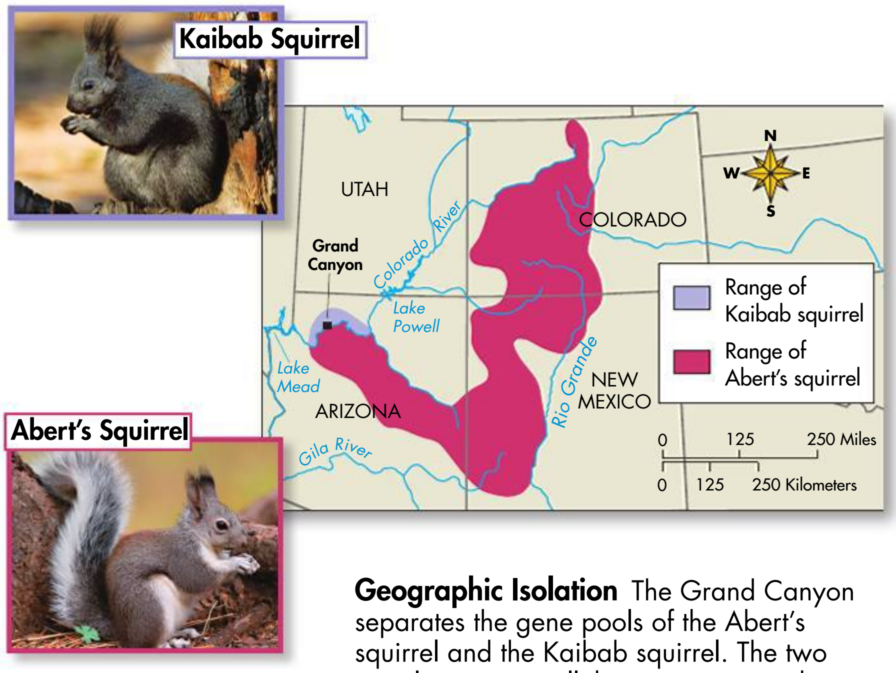
geographic isolation
a form of reproductive isolation in which two populations are separated by geographic barriers such as rivers, mountains, or bodies of water

Isolating Mechanisms

Biologists define a **species** as a population whose members can breed and produce fertile offspring. How does one species become two? If members of a population can no longer mate, a new species may evolve. The formation of a new species is called **speciation.**

Breeding connects the gene pool of a species. If a species is split into two parts, genetic changes in one part of the gene pool cannot spread to the other. When two populations can no longer mate and produce offspring, **reproductive isolation** has occurred. Geography, behavior, and time can separate populations from each other.

Geographic Isolation When populations are separated by a barrier, such as a river, mountain, or ocean, **geographic isolation** can occur. For example, the Abert's and Kaibab squirrels once belonged to the same population. About 10,000 years ago, a small population became isolated north of the Grand Canyon. Since then, genetic drift and natural selection have led to two different-looking populations.



Geographic Isolation The Grand Canyon separates the gene pools of the Abert's squirrel and the Kaibab squirrel. The two populations are still the same species, but they have evolved striking differences.

Behavioral Isolation If two interbreeding populations develop different behaviors, such as different mating dances, then **behavioral isolation** can happen. Two nearly identical species of birds—eastern meadowlarks and western meadowlarks—share the same habitat. These two species do not interbreed because their mating songs are different.

Temporal Isolation A third isolating mechanism is temporal isolation. **Temporal isolation** happens when populations that live in the same habitat reproduce at different times.

Key Question What types of isolation lead to new species? **New species can arise from behavioral isolation, geographic isolation, and temporal isolation.**

BUILD Vocabulary

behavioral isolation a form of reproductive isolation in which two populations develop differences in courtship rituals or other behaviors that prevent them from breeding

temporal isolation a form of reproductive isolation in which two or more species reproduce at different times

WORD ORIGINS

Temporal comes from the Latin *tempus*, meaning "time." In temporal isolation, the time of reproduction separates populations.

Speciation in Darwin's Finches

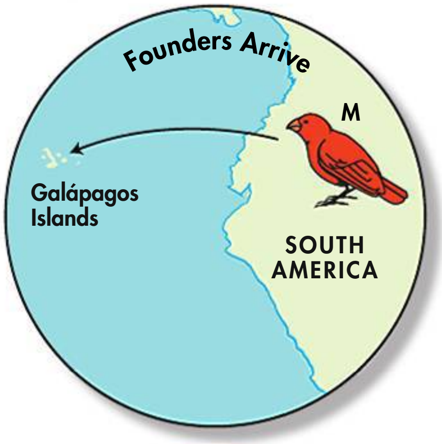
Since Darwin, many scientists have studied the Galápagos finches. The Grants showed that under the right conditions, natural selection can happen quickly. This knowledge makes the Galápagos finches a good choice for describing how speciation might work in real life.

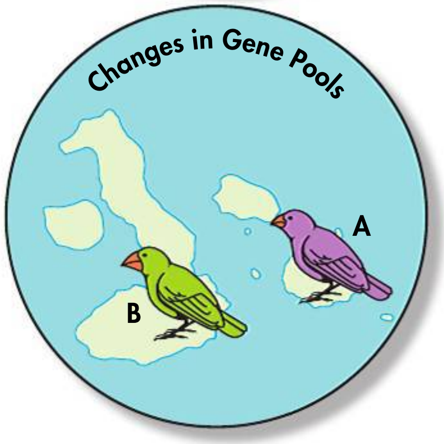
Speciation probably began when a small number of finches founded a new population. This population was geographically isolated from the main population. Over time, the gene pool changed. According to the currently accepted hypothesis, isolation, competition, and natural selection formed new species that could no longer interbreed.

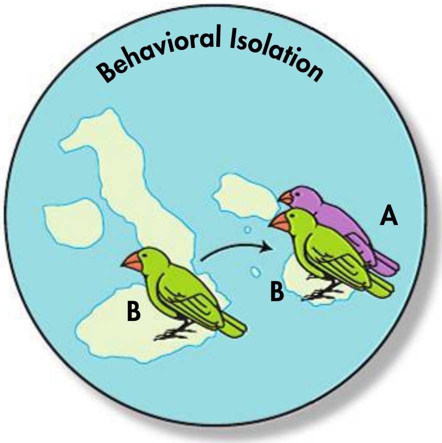
Founders Arrive Many years ago, a few finches from South America arrived on one of the islands. Maybe they were blown there by a storm. The small group survived and reproduced. Because of the founder effect, the allele frequencies of this new population were different from the original population.

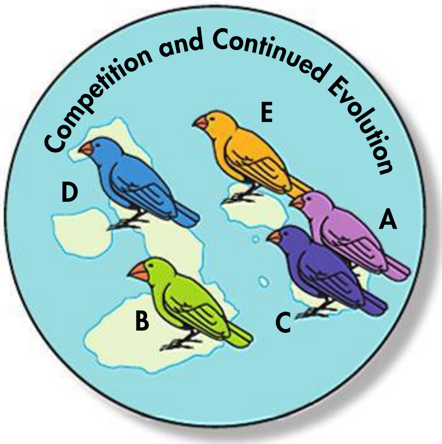
Geographic Isolation These finches do not usually fly over open water, so the population was geographically isolated. The founder effect, geographic isolation, and natural selection led to the evolution of a new species of finch. Eventually some of these finches moved to a new island, where the process was repeated.

Changes in Gene Pools The environment on the second island may have had different plants with larger seeds. Directional selection would have favored birds with larger beaks. Over time, a population with larger beaks evolved.









Behavioral Isolation Imagine that a few birds from the second island cross back to the first island. Will the two populations interbreed? Probably not. Finches choose mates carefully. They like mates that look like themselves. A small-beaked bird will not breed with a large-beaked bird. Even though they share the same habitat, the two populations are now isolated by behavior. They have become two different species.

Competition and More Evolution The two new species live together and compete for seeds. During the dry season, it is difficult to find enough seeds to eat. Individuals with very small beaks have greater success than birds with average-size beaks. Small-beaked birds can specialize in eating very small seeds that birds with average-size beaks cannot eat. Over time the differences lead to reproductive isolation. A third species evolves.

Over many years, this process could have repeated itself again and again on the different islands. The combination of geographic isolation, behavioral isolation, and natural selection could have produced the 13 different finch species found in the Galápagos today.

Key Question What is the current hypothesis about Galápagos finch speciation?
According to this hypothesis, speciation in Galápagos finches happened by the founding of a new population, geographic isolation, changes in the new population's gene pool, behavioral isolation, and ecological competition.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The formation of a new species is called _____.

2. The form of reproductive isolation in which populations are separated by rivers, mountains, or oceans is called ________.

3. The form of reproductive isolation in which species reproduce at different times is called ________.

Critical Thinking

4. Explain How can differences in behavior lead to reproductive isolation?

5. Sequence Scientists hypothesize that a series of events lead to the evolution of different species of finches on the Galápagos islands. List the following events in the correct order: behaviors prevent the birds from interbreeding; changes in gene pool; geographic isolation; a small group of birds arrives from South America.

6. Write to Learn Answer the question in the mystery clue below. Use the word *gene pool* in your answer.

MYSTERY CLUE

A population of viruses inside an animal is isolated from other virus populations. How might this isolation affect virus evolution? (Hint: See p. 414.)

17.4 Molecular Evolution

Molecular Clocks

A genome is the complete set of genes found in an organism. Each genome has many genes. For example, your body has about 25,000 working genes! Scientists often study genomes to learn how organisms have evolved. By comparing the genes of different organisms, scientists can test different hypotheses. Some hypotheses suggest how closely organisms are related. Other hypotheses suggest how long ago evolutionary lines split apart. One way to test these hypotheses is by using DNA as a molecular clock. A **molecular clock** uses mutation rates in DNA to estimate how long ago two organisms shared a common ancestor.

Ticking Mutations Some kinds of mutations happen at a steady rate, like seconds ticking on a clock. As time passes, more and more mutations happen. Some mutations help or hurt the survival of an organism. Because these mutations are affected by natural selection, they cannot be used as "molecular ticks." But many mutations do not affect an organisms's fitness. Such mutations are said to be *neutral*. Neutral mutations change DNA without affecting an organism's fitness.

Neutral mutations can collect in the DNA of different species at about the same rate. Scientists can compare the number of neutral mutations in specific sequences of DNA from different organisms. The more differences there are, the more mutations have happened. By counting mutations, researchers can estimate how long it has been since the two organisms shared a common ancestor.

Key Questions

What are molecular clocks?

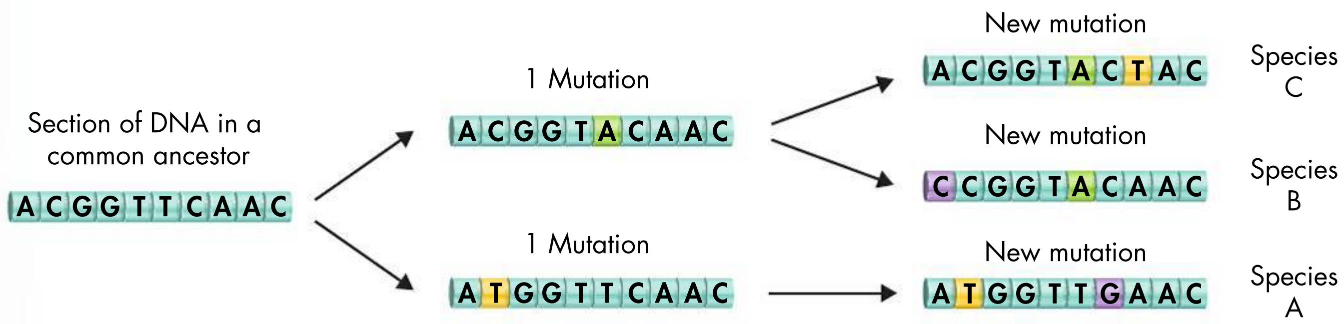
Where do new genes come from?

How may Hox genes be involved in evolutionary change?

BUILD Understanding

Flowchart A flowchart is a way to show the steps in a process. As you read about gene duplication, make a flowchart that shows how duplicate genes evolve.

In Your Workbook Go to your workbook to learn more about making a flowchart. Complete the flowchart for Lesson 17.4.



Molecular Clock By comparing DNA sequences, biologists can estimate how closely related species are. Two species that have only a few different mutations shared an ancestor recently. Species that have many different mutations shared an ancestor long ago.

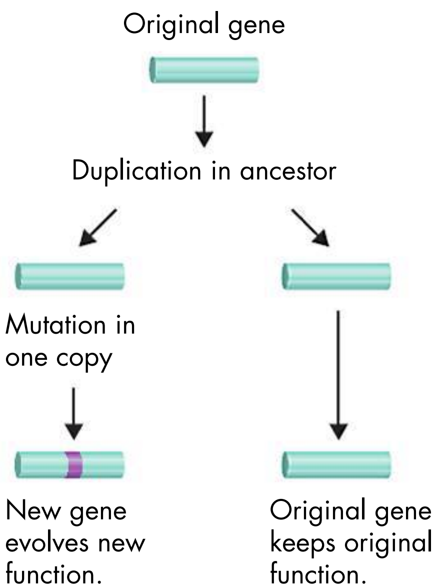
BUILD Vocabulary

molecular clock
a method that uses mutation rates in DNA to estimate the length of time that two species have been evolving independently

RELATED WORDS FORMS

The adjective *molecular* comes from the noun *molecule*. A molecular clock uses DNA molecules to measure the speed of evolution.

Gene Duplication
In this diagram, a gene is first duplicated. Then one of the two genes mutates.



Rate of Mutation Not all genes mutate at the same rate. You can think of a gene that mutates quickly as the second hand on a clock. These genes are useful for measuring evolution that happens over a short time. Other genes mutate more slowly. Such genes are used to measure evolution that takes place over a much longer time.

Key Question What are molecular clocks?
Molecular clocks are pieces of DNA that mutate at a known rate. Scientists use molecular clocks to estimate how much time has passed since two species shared a common ancestor.

Gene Duplication

Humans have about 25,000 working genes. Where did all these genes come from? Modern genes probably evolved from a much smaller number of genes in the earliest forms of life.

Copying Genes One way that the number of genes grew so large was by the duplication, or copying, of existing genes. Duplication can happen during meiosis as chromosome pairs exchange DNA. Sometimes one chromosome ends up with extra DNA during the exchange.

Duplicate Genes Evolve Sometimes a duplicated gene mutates. The mutation changes the way the gene works. The mutated copy of the gene performs a new role. The original gene continues to perform its old role.

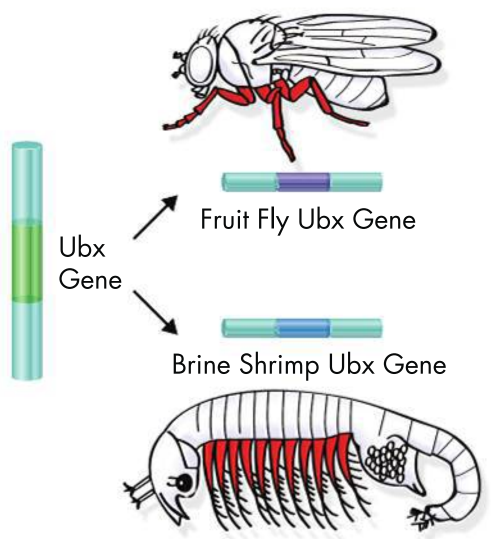
Gene Families Several copies of a gene can form a group of related genes that is called a gene family. Genes in a family usually make slightly different proteins that carry out similar roles. For example, one gene family makes several kinds of oxygen-carrying proteins. This gene family evolved from just one original gene.

Key Question Where do new genes come from?
One way that new genes evolve is through the duplication, and then modification, of existing genes.

Developmental Genes and Body Plans

An exciting new way of studying evolution looks at gene activity during development. Small changes in the way genes work in an embryo can lead to big changes in the adult body.

Hox Genes and Evolution Hox genes are a group of genes that play an important role in animal development. Hox genes determine which parts of the embryo develop arms, legs, or wings. Hox genes also control the size and shape of the adult body parts.



Changes in a Hox Gene
Fruits flies and brine shrimp share a common ancestor. The Hox gene called Ubx directs the development of legs in both animals. Millions of years ago, mutations on Ubx caused fruit flies to have six legs and brine shrimp to have many legs.

Shrimp and insects share an ancient common ancestor. This ancestor had dozens of legs. Shrimp still have many legs, but insects have only six. What happened to those other legs? A single mutation in a Hox gene turns off the growth of some pairs of legs. Thus, a change in one Hox gene can cause a major difference between two groups of animals.

Timing Is Everything The growth of an embryo is carefully controlled by genes. Growth starts and stops at exact times. Small changes in starting and stopping times can make a big difference in the final organism. For example, small changes in timing can make the difference between long, slender fingers and short, stubby toes.

Key Question How may Hox genes be involved in evolutionary change? **Even small changes in Hox genes can produce large changes in adult animals.**

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. When scientists use the rates of mutation in DNA to estimate how long two species have been evolving separately, they are using a _______.

Critical Thinking

2. Relate Cause and Effect How can crossing-over result in gene duplication?

3. Relate Cause and Effect How can a duplicate gene become a new gene with a different function?

4. Review What is the function of Hox genes?

5. Relate Cause and Effect Why have small changes in Hox genes had such a great effect on the evolution of animal diversity?

6. Write to Learn How does time affect the number of differences in the genes of two species with a common ancestor?

BIOLOGY.com Search Lesson 17.4 GO • Lesson Assessment

Pre-Lab: Competing for Resources

Problem How can competition lead to speciation?

Materials assorted tools, large and small seeds, large and small paper plates, timer or clock with second hand

Lab Manual Chapter 17 Lab

Skills Focus Use Models, Predict, Apply Concepts

Connect to the Big idea Speciation is not easy to see in nature. Usually, new phenotypes take years to emerge or become common enough to be noticed. Also, new phenotypes can be difficult to track in a complex environment. For scientists who want to study speciation, islands can provide an ideal environment.

Peter and Rosemary Grant spent years studying finches on the Galápagos Islands. They measured and recorded the traits and diets of hundreds of birds. During a year with a severe drought, the Grants were able to observe natural selection in action as food became scarce. In this lab you will model variation in bird beaks and diet to demonstrate the impact of competition on survival and speciation.

Background Questions

a. **Review** What is speciation?

b. **Relate Cause and Effect** How did geographic isolation lead to speciation among the Galápagos finches?

c. **Compare and Contrast** How does an adaptation differ from other inherited traits?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Use Models** In this lab, what do the different types of tools represent?
2. **Predict** Which tools do you think will work best for picking up small seeds? Which will work best for picking up large seeds?
3. **Design an Experiment** Why will the time you have to collect seeds be limited?

BIOLOGY.com Search Chapter 17 GO

Visit Chapter 17 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Climb the cliffs of Hawaii with the Untamed Science crew to discover how geographic isolation can result in a new species.

Art Review Review your understanding of alleles and allele frequencies in a population.

Art in Motion Watch how different types of selection change the types of individuals that comprise a population.

Tutor Tube Learn more about the mechanisms of speciation from the tutor.

17 CHAPTER Summary

17.1 Genes and Variation

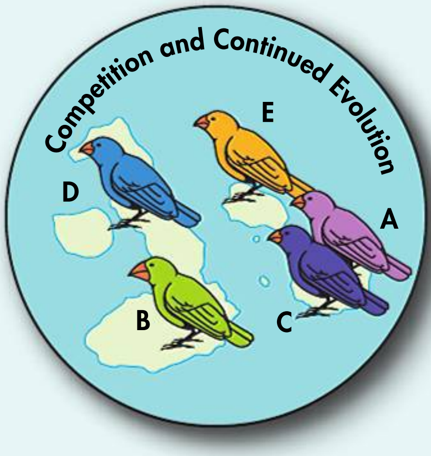
- Evolution is change in the frequency of alleles in a population over time.
- Three sources of genetic variation are mutations, genetic recombination during sexual reproduction, and lateral gene transfer.
- The number of phenotypes produced for a trait depends on how many genes control the trait.

gene pool (p. 406)
allele frequency (p. 406)
single-gene trait (p. 408)
polygenic trait (p. 408)

17.2 Evolution as Genetic Change in Populations

- Natural selection on single-gene traits can lead to changes in allele frequencies. This can lead to changes in phenotype frequencies.
- Natural selection on polygenic traits can affect the relative fitness of phenotypes. This selective pressure can cause one of three types of selection: directional selection, stabilizing selection, and disruptive selection.
- Genetic drift may occur in small populations. By chance, individuals that carry one allele may leave more offspring than other individuals leave. Over time, a series of chance events can cause an allele to become more or less common in a population.
- The Hardy-Weinberg principle predicts that five conditions can cause evolution to take place: (1) nonrandom mating, (2) small population size, (3) movement into or out of the population, (4) mutations, and (5) natural selection.

directional selection (p. 410)
stabilizing selection (p. 410)
disruptive selection (p. 410)
genetic drift (p. 411)
bottleneck effect (p. 411)
founder effect (p. 411)
genetic equilibrium (p. 412)
Hardy-Weinberg principle (p. 412)
sexual selection (p. 412)



17.3 The Process of Speciation

- When populations become reproductively isolated, they can evolve into separate species. Reproductive isolation can develop in a variety of ways. These include behavioral isolation, geographic isolation, and temporal isolation.
- Speciation in Galápagos finches most likely occurred by: founding of a new population, geographic isolation, changes in the population's gene pool, behavioral isolation, and ecological competition.

species (p. 414)
speciation (p. 414)
reproductive isolation (p. 414)
geographic isolation (p. 414)
behavioral isolation (p. 415)
temporal isolation (p. 415)

17.4 Molecular Evolution

- A molecular clock uses mutation rates in DNA to estimate the time that two species have been evolving separately.
- One way that new genes evolve is through the duplication, and then modification, of existing genes.
- Small changes in Hox gene activity during development can produce large changes in adult animals.

molecular clock (p. 417)

17 CHECK Understanding

Assess the Big idea Evolution

Write an answer to the question below.

Q: How can populations evolve to form new species?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each numbered question should be one or two paragraphs long. To help get ideas, read the **Hints** below the questions.

1. **Why is genetic variation in a population necessary for natural selection to take place? Use the words *fitness* and *phenotype* in your answer.**

   Hint The fitness of an organism depends upon the conditions of its environment.

2. **How does population size affect evolution?**

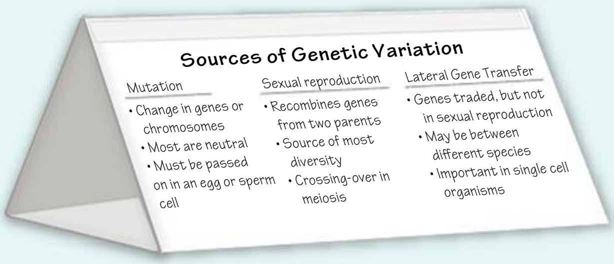
   Hint The Hardy-Weinberg principle describes the conditions under which a population will *not* evolve.

3. **On the Galápagos Islands, there is a species of finch that eats only fruit. Describe a process by which this species may have evolved from a species that eats many kinds of foods.**

   Hint Refer to the art on pages 415 and 416.

Foundations for Learning Wrap-Up

When you have finished taking notes, fold the paper into a triangle with the notes on the outside. Tape the ends together to make a table tent, as shown below.



Activity 1 Work with a partner to review each of the main topics. Ask a partner to pick a side of your table tent—Sources of Genetic Variation, Natural Selection, or Isolation. Have your partner form a question or two about each topic, such as "What are three sources of genetic diversity?" While you answer, your partner will watch your table tent to be sure you have answered correctly and completely. When you have answered all three sides, change roles.

Activity 2 Use your table tent to explain how a new species of birds may have arisen on an island. Begin with the side labeled Sources of Genetic Variation. You may also refer to the art about the speciation in Darwin's finches in Lesson 17.3.

17.1 Genes and Variation

Understand Key Concepts

1. The combined genetic information of a population forms a
   a. genotype. **c.** phenotype.
   b. gene pool. **d.** bottleneck.

Test-Taking Tip

Read Before You Choose Read all the choices before you pick your answer. Sometimes a choice can be partly correct, but there is a better choice later in the list. In question 1, you might be tempted to answer **a**, because a genotype is a set of genes. But genotypes refer to individuals, not populations. So **b**, gene pool, is the best choice.

2. Mutations that improve an individual's ability to survive and reproduce are
   a. harmful. **c.** helpful.
   b. neutral. **d.** chromosomal.
3. Identify two ways that sexual reproduction is a source of genetic variation.

Think Critically

4. **Compare and Contrast** Compare the effects of two mutations: a mutation in a body cell and a mutation in an egg cell. Which mutation could affect evolution? Why?

17.2 Evolution as Genetic Change in Populations

Understand Key Concepts

5. In a population, short individuals have a greater fitness than average-size or tall individuals. This difference in fitness could lead to
   a. directional selection.
   b. stabilizing selection.
   c. disruptive selection.
   d. artificial selection.
6. A change in the allele frequency of a small population that is caused by chance is known as
   a. a gene pool.
   b. the Hardy-Weinberg principle.
   c. variation.
   d. genetic drift.
7. What is *fitness* in genetic terms?
8. How does meiosis in sexual reproduction affect the frequency of alleles in a population?

Think Critically

9. **Apply Concepts** Why is genetic drift most common in small populations?
10. **Infer** Genetic equilibrium is rare in most populations. Why do you think this is the case?

17.3 The Process of Speciation

Understand Key Concepts

11. When two populations no longer interbreed, what is the result?
    a. genetic equilibrium
    b. reproductive isolation
    c. stabilizing selection
    d. artificial selection
12. Two populations of turtles nest on an island. One of the species nests in June. The other species nests in August. These two species are separated by
    a. temporal isolation.
    b. geographical isolation.
    c. genetic isolation.
    d. behavioral isolation.
13. Why is variation important to the survival of a species when the environment changes?

Think Critically

14. **Relate Cause and Effect** Before a population splits into two different species, there must usually be reproductive isolation. Explain why this is so.

17 CHECK Understanding

17.4 Molecular Evolution

Understand Key Concepts

15. Hox genes are important to evolution because
- **a.** they mutate often.
- **b.** they are only found in egg and sperm cells.
- **c.** they are immune to natural selection.
- **d.** they have a large effect on the traits of an organism.

16. What are scientists counting when using a molecular clock?
- **a.** mutations
- **b.** genes
- **c.** gene families
- **d.** chromosomes

17. What are neutral mutations?

18. Why do molecular clocks use mutations that have no effect on phenotype?

Think Critically

19. **Sequence** Describe how duplicate genes can lead to the creation of new genes.

Connecting Concepts

Use Science Graphics

Use the data table to answer questions 20 and 21.

Frequency of Alleles

Year	Frequency of Allele *B*	Frequency of Allele *b*
1910	0.81	0.19
1930	0.49	0.51
1950	0.25	0.75
1970	0.10	0.90

20. **Interpret Tables** Describe the trend shown by the data in the table.

21. **Form a Hypothesis** What might account for the trend shown by the data?

solve the CHAPTER MYSTERY

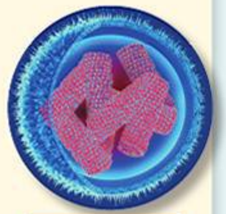
KILLER DISEASE

The genes of flu viruses mutate often. Also, different strains of flu can swap genes. These mutations and the ability to gene swap gives the viruses plenty of genetic diversity.

Natural selection acts on viruses in the environment of your own body! Viruses have proteins on their surfaces that make them targets for your immune system. Viruses with proteins that your body recognizes will be destroyed. These viruses have low fitness. Viruses that your body can't recognize have a higher fitness.

Viruses evolve new proteins often. This makes them harder for your immune system to recognize. That's when you get sick. That's also why you can have the flu one winter, and then get another strain the next winter.

Rarely, flu virus evolution produces a very new protein. Your immune system is unable to recognize or fight these new proteins. Such flu viruses can be deadly, as was the influenza virus of 1918. If a strain like that appeared today, it would kill many people.



Influenza Virus

1. **Infer** Vaccines help prepare your body for an infection. Doctors recommend that people receive a new vaccine for the flu every year. People do not need to receive a new vaccine for measles every year. What does this suggest about a difference between the measles virus and flu viruses?

2. **Apply Concepts** Can you think of other issues in public health that relate directly to evolution?

UntamedScience™ **Never Stop Exploring Your World.** Finding the solution to the epidemic mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Which of the following conditions is MOST likely to result in changes in allele frequencies in a population?
A random mating
B small population size
C no migrations into or out of a population
D absence of natural selection

2. Mutations and the genetic recombination that occurs during sexual reproduction are both sources of
A genetic variation.
B stabilizing selection.
C genetic equilibrium.
D genetic drift.

3. In a population of lizards, the smallest and largest lizards are more easily preyed upon than medium-size lizards. What kind of natural selection is MOST likely to occur in this situation?
A genetic drift
B sexual selection
C stabilizing selection
D directional selection

4. Populations of antibiotic-resistant bacteria are the result of the process of
A natural selection.
B temporal isolation.
C genetic drift.
D artificial selection.

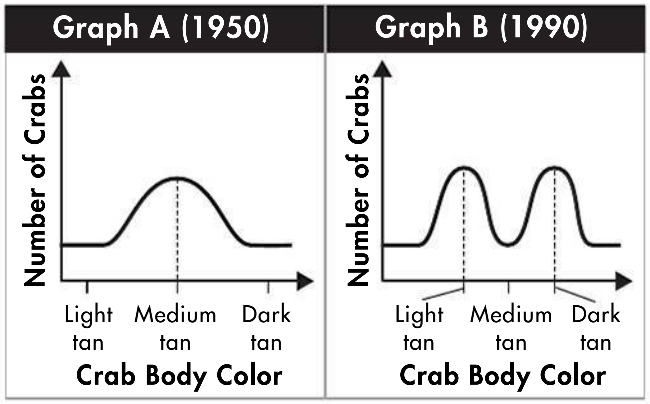
5. If species A and B have very similar genes and proteins, what is probably true?
A Species A and B share a relatively recent common ancestor.
B Species A evolved independently of species B for a long period.
C Species A is younger than species B.
D Species A is older than species B.

6. When two species reproduce at different times, the situation is called
A genetic drift.
B temporal selection.
C temporal isolation.
D lateral gene transfer.

7. The length of time that two taxa have been evolving separately can be estimated using
A genetic drift.
B gene duplication.
C a molecular clock.
D Hox genes.

Questions 8–9

The graphs below show the changes in crab color at one beach.



8. What process occurred over the 40-year period?
A artificial selection
B directional selection
C stabilizing selection
D disruptive selection

9. Which of the following is MOST likely to have caused the change in the distribution?
A A new predator arrived that preferred dark-tan crabs.
B A new predator arrived that preferred light-tan crabs.
C A change in beach color made medium-tan crabs the least visible to predators.
D A change in beach color made medium-tan crabs the most visible to predators.

Open-Ended Response

10. How does evolution change the relative frequency of alleles in a gene pool? Why does this happen?

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	17.3	17.1	17.2	17.2	17.4	17.3	17.4	17.2	17.2	17.1

18 Classification

Big idea: Unity and Diversity of Life

Q: What is the goal of biologists who classify living things?

The National Museum of Natural History has one of the largest collections of bird species in the world. Nearly 80 percent of all the world's species are found here.

BIOLOGY.com Search Chapter 18 GO • Flash Cards

INSIDE:

- 18.1 Finding Order in Diversity
- 18.2 Modern Evolutionary Classification
- 18.3 Building the Tree of Life

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

GRIN AND BEAR IT

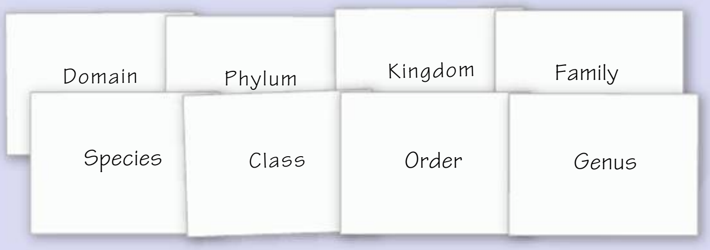
If you just looked at polar bears and brown bears, you would probably think that they were different species. Polar bears are much larger than brown bears. Their paws let them swim and walk on snow and ice. Their white fur hides them in the snow. In contrast, brown bears are brown. And their paws are not as big.

Polar bears and brown bears look very different. They also act differently. Do those differences mean that they are different species? Remember the definition of a species: "a group of similar organisms that can breed and produce fertile offspring." Polar bears and brown bears *can* interbreed and produce fertile offspring. This should make them the same species. Are they?

Read for Mystery Clues As you read this chapter, look for clues to help you decide if polar bears and brown bears are separate species. Then, solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

To understand biological classification, you will need to learn a few new words. Write the following words on index cards: *Domain, Kingdom, Phylum, Class, Order, Family, Genus,* and *Species*.



As you read the chapter, write the definition for each word on the back of the card. Also, write down examples of the terms. You will use these cards for two activities at the end of the chapter. They will help you answer the question: What is the goal of biologists who classify living things?

18.1 Finding Order in Diversity

Key Questions

What are the goals of binomial nomenclature and systematics?

How did Linnaeus group species into larger taxa?

BUILD Understanding

Preview Visuals Before you read, look at the diagram From Species to Kingdom on p. 431. Notice all the levels of classification. As you read about each level, look at the diagram again.

In Your Workbook Go to your workbook to learn more about previewing visuals.

Assigning Scientific Names

The first step in studying the diversity of life is to describe and name each species. For names to be useful, everyone must use the same name for each species.

People in different places often use different words to describe the same organism. Using common names can cause problems. For example, the words *cougar*, *puma*, *panther*, and *mountain lion* are all common names for the same animal. Sometimes, people use the same name for different organisms. For example, in the United Kingdom, a *buzzard* is a kind of hawk. In the United States, a *buzzard* is a vulture. And of course, a person who does not speak English would not use any of these names!

By the 1700s, scientists knew that it was too confusing to call organisms by their common names. They agreed to use a Latin or Greek name for each species. At first, this did not help much. The early names were very long and complicated. The name for a tree might be "Oak with deeply divided leaves that have no hairs on their undersides and no teeth around their edges." Also, scientists used different characteristics to describe species.

Binomial Nomenclature In the 1730s, a Swedish scientist named Carolus Linnaeus developed a two-word naming system called **binomial nomenclature.** In binomial nomenclature, each species is assigned a scientific name that has two words. Scientific names are written in italics. The first word begins with a capital letter. The second word is lowercase.

The scientific name for the polar bear is *Ursus maritimus*. The first part of the name—*Ursus*—is the genus to which the organism belongs. A **genus** (plural: genera, JEHN er uh) is a group of closely related species. The genus *Ursus* contains five other species of bears, including *Ursus arctos*, the brown bear.

The second part of a scientific name is unique to each species. This part of the name often describes an important trait or the organism's habitat. The word *maritimus* comes from the Latin word for "sea." Polar bears live on ice that floats in the sea.

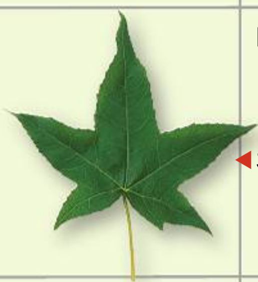
Key Question What is the goal of binomial nomenclature?
In binomial nomenclature, each species is given a two-part scientific name.

Binomial Nomenclature The scientific name of the polar bear is *Ursus maritimus*, which means "marine bear."

BUILD Connections

USING A DICHOTOMOUS KEY

A dichotomous key is used to identify organisms. The key is made up of a series of statements about visible traits. Each statement can be considered a question that can be answered yes or no. The answers lead you to new statements until you have identified your organism. Use the key to identify the leaf shown here. Note the clues to help you at each step.

Step	Leaf Characteristics	Tree
1a	Compound leaf (leaves divided into leaflets) . . . go to Step 2	
1b	Simple leaf (leaf not divided into leaflets) . . . go to Step 4	
2a	Leaflets all attached at a central point	Buckeye 
2b	Leaflets attached at several points . . . go to Step 3	
3a	Leaflets tapered with pointed tips	 Pecan
3b	Leaflets oval with rounded tips	Locust 
4a	Veins branched out from one central point . . . go to Step 5	
4b	Veins branched off main vein in middle of the leaf . . . go to Step 6	
5a	Heart-shaped leaf	Redbud 
5b	Star-shaped leaf 	Sweet gum
6a	Leaf with jagged edges	Birch
6b	Leaf with smooth edges	Magnolia 

Because your leaf is a simple leaf, you skip ahead to Step 4.

Continue reading the statements until you determine the identity of your leaf.

Because your leaf has jagged edges, you determine that it's from a birch tree.

Carolus Linnaeus

Classifying Species Into Larger Groups In addition to naming organisms, biologists organize, or classify, species into larger groups. The science of naming and grouping organisms is called **systematics** (sis tuh MAT iks). In systematics, biologists try to place organisms into groups that have biological meaning. Organisms in a group should be more similar to one another than they are to organisms in other groups. Biologists call these groups *taxa* (singular: taxon).

You may not know it, but you use classification systems all the time. For example, you may talk about "teachers" or "pets." You also refer to smaller groups, such as "biology teachers" or "dogs." When you do this, you are using names for groups that many people understand.

Key Question What is the goal of systematics?
The goal of systematics is to organize living things into groups that have biological meaning.

The Linnaean Classification System

Linnaeus developed the system of binomial nomenclature. He also developed a classification system for organizing species into larger groups. Linnaeus classified species according to physical similarities and differences.

Linnaeus's original classification system had four levels, or ranks. Over time, his system grew to include seven levels: species, genus, family, order, class, phylum, and kingdom. As you read about these levels, look at the diagram of the classification of the Bactrian camel shown on the next page. The scientific name of the camel that has two humps is *Camelus bactrianus*. (Bactria was an ancient country in Asia.)

▶ ***Species*** A species is a group of individuals that can interbreed and produce fertile offspring.

▶ ***Genus*** As its name tells you, the Bactrian camel belongs to the genus *Camelus*. The genus *Camelus* also includes the dromedary camel, *Camelus dromedaries*, which has only one hump.

▶ ***Family*** Llamas belong to the genus *Lama*. Because camels and llamas share many traits, they are classified in the same family. A **family** is a group that includes genera that share similar traits. The family that includes *Camelus* and *Lama* is Camelidae.

▶ ***Order*** Closely related families are grouped together in the next larger rank—an **order.** Camels and llamas (Camelidae) are grouped with several other families, including the deer family and the cattle family. Together they form the order Artiodactyla. This order includes hoofed animals that have an even number of toes.

▶ ***Class*** Similar orders are grouped together into the next larger rank, called a **class.** The order Artiodactyla is placed with other mammals in the class Mammalia.

BUILD Vocabulary

binomial nomenclature
a classification system in which each species is assigned a two-part scientific name

genus a group of closely related species; the first part of the scientific name in binomial nomenclature

systematics the science of naming and grouping organisms

family in classification, a group of similar genera

order in classification, a group of closely related families

class in classification, a group of closely related orders

phylum in classification, a group of closely related classes

kingdom the largest and most inclusive group in the Linnaean classification system

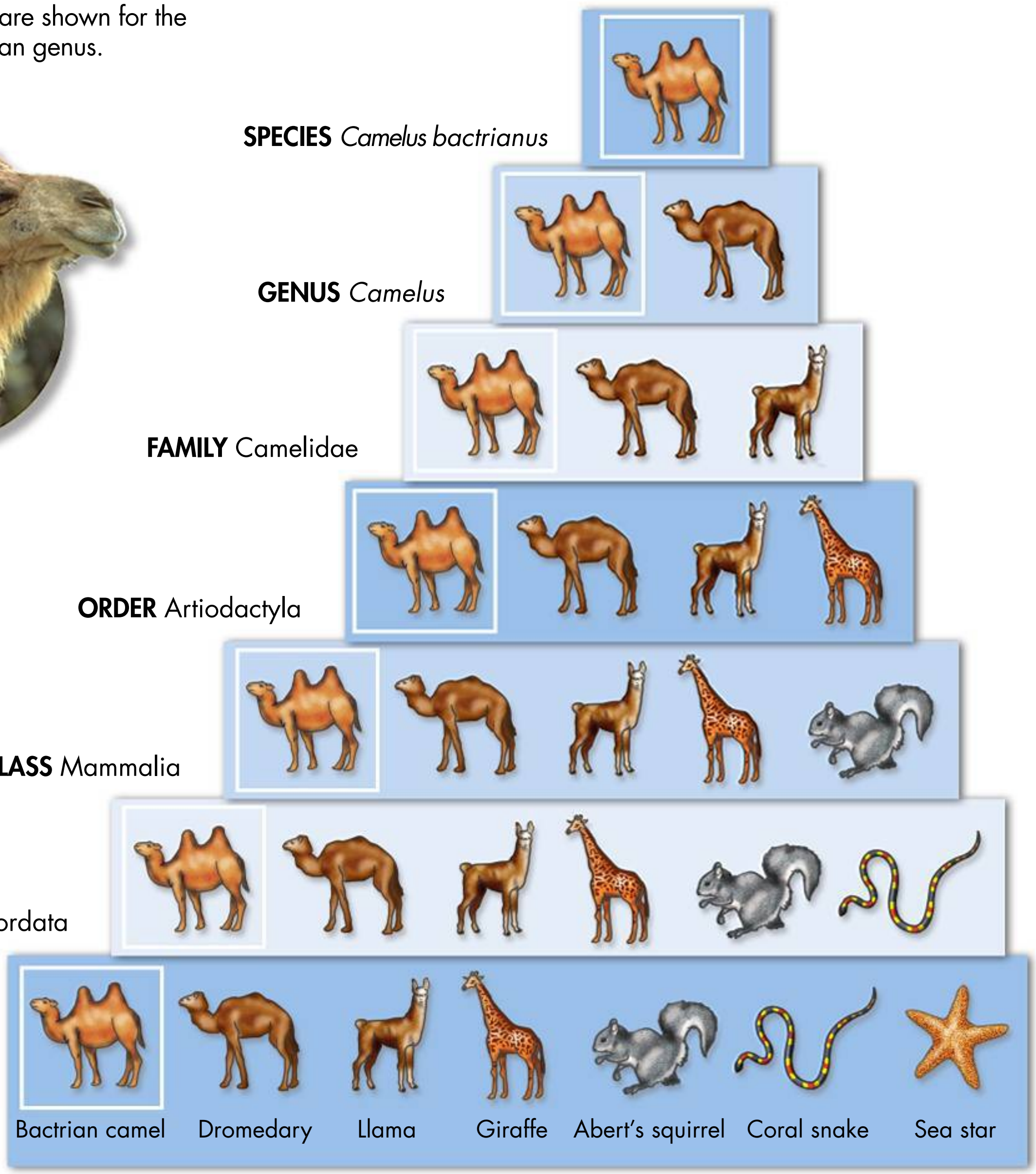
PREFIXES
The prefix *bi-* means "two." In binomial nomenclature, the names of species have two parts.

▶ ***Phylum*** Classes are grouped into a **phylum.** The class Mammalia is grouped with birds, reptiles, amphibians, and fishes into the phylum Chordata. All of the members of this phylum have a nerve cord along their back.

▶ ***Kingdom*** The largest of Linnaeus's taxonomic groups is called the **kingdom.** The Bactrian camel is placed in the kingdom Animalia. Kingdom Animalia includes all animals.

Key Question How did Linnaeus group species into larger taxa? **Over time, Linnaeus's original classification system grew to include seven levels: species, genus, family, order, class, phylum, and kingdom.**

From Species to Kingdom The diagram shows how a Bactrian camel, *Camelus bactrianus*, is grouped within each level of classification. Only a few organisms are shown for the levels that are larger than genus.



Looks Can Be Deceiving
Classifying organisms based on traits that are easy to see can lead to problems. Barnacles and limpets look very similar, yet they are not closely related. Barnacles and crabs do not look alike, yet they *are* closely related.

Barnacles

Limpets

Problems With Traditional Classification

Individual species tend to define themselves by choosing with whom to mate. Thus, there is a "natural" definition of a species. But higher ranks, such as genus and family, are defined by biologists.

Linnaeus grouped organisms into larger taxa based on similarities and differences that could be seen. Linneaus chose his characteristics carefully. For this reason, many of his groups are still used in modern classification. But it is not always obvious which traits should be used to define a group. For example, would you call a dolphin a fish, because it looks like a fish? Or would you call it a mammal, because it is warmblooded and produces milk? Scientists have changed the way they name and group organisms to solve such problems.

When modern scientists classify organisms, they are interested in more than similarities and differences. They apply Darwin's ideas, and look for evolutionary relationships. Scientists today try to place species into groups that show how closely members are related to each other.

Crab

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The largest group in Linnaeus's seven-level classification system is the _______.

2. The two-part naming system that gives each species a unique name is _______.

3. The science of naming and classifying organisms is called _______.

Critical Thinking

4. Explain Why do biologists classify organisms?

5. Apply Concepts The scientific name of a red maple is *Acer rubrum*. Which part of this name identifies the genus? Which part describes the species?

6. Sequence List the seven ranks in the Linnaean classification system, beginning with the smallest.

7. Compare and Contrast In which level of classification are the members more closely related—a kingdom or an order?

8. Write to Learn Answer the question in the mystery clue below. Use the word *species* in your answer.

MYSTERY CLUE

Polar bears and brown bears can interbreed and produce fertile offspring in zoos. In nature this rarely happens. What do you think this means about the relationship between them? (Hint: See p. 430.)

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18.2 Modern Evolutionary Classification

Evolutionary Classification

Linnaeus began classifying organisms more than one hundred years before Darwin published his ideas about a "tree of life." Darwin's ideas suggested a new way to classify organisms. Biologists today use evolutionary relationships to place species into larger groups, or taxons.

Common Ancestors Evolutionary classification groups species into larger taxa, in which all members are descended from a common ancestor. All members of any group should be more closely related to each other than to members of any other group. The larger the taxon, the farther back in time all of its members shared a common ancestor. The study of how living and extinct organisms are related is called phylogeny (fy LAHJ uh nee).

Clades Evolutionary classification puts organisms into groups called clades. A **clade** is a group of species that includes a single common ancestor and all of its descendants. A clade includes both living and extinct organisms. Clades must be monophyletic (mahn oh fy LET ik). A **monophyletic group** includes a single common ancestor and *all* of its descendants. Monophyletic groups cannot include any organisms that are *not* descended from the common ancestor.

Some taxa that were defined before evolutionary classification are monophyletic. But others are not. These groups have a common ancestor but do not include all of its descendants. Class Reptilia (reptiles) is not monophyletic. So in evolutionary classification, reptiles are not a true group.

Key Question What is the goal of evolutionary classification? **The goal of evolutionary classification is to group species into larger categories that show lines of evolutionary descent, rather than overall similarities and differences.**

Cladograms

In evolutionary classification, biologists compare carefully selected traits. They use these traits to determine the order in which groups of organisms branched off from a common ancestor. This information is used to link clades together in a cladogram. A **cladogram** is a drawing that shows relationships among species and larger taxa by showing how evolutionary lines branched off a common ancestor.

Key Questions

What is the goal of evolutionary classification?

What is a cladogram?

How are DNA sequences used in classification?

BUILD Understanding

T-Chart As you read a lesson, you can organize the information in a T-chart. Write all the key questions on the left side of the chart. Answer each question on the right side of the chart.

In Your Workbook Go to your workbook to learn more about T-charts.

BUILD Vocabulary

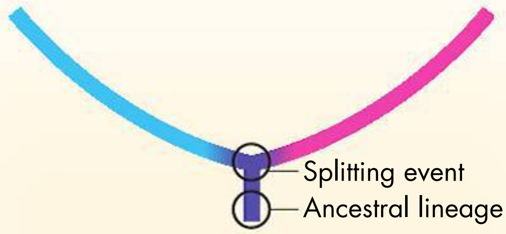
clade an evolutionary branch of a cladogram that includes a single ancestor and all its descendants

monophyletic group a group that consists of a single ancestral species and all its descendants and excludes any organisms that are not descended from that common ancestor

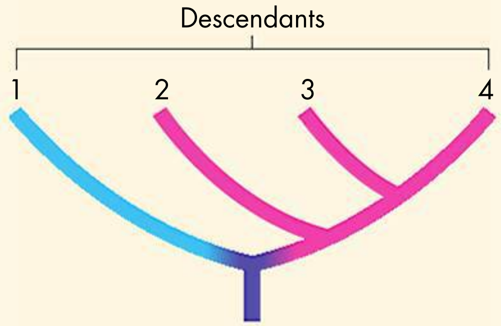
cladogram a diagram showing patterns of shared characteristics among species

derived character a trait that arose in the most recent common ancestor of an evolutionary line and was passed on to its descendants

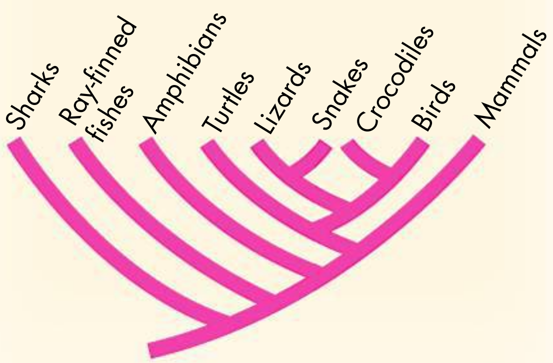
Building a Cladogram A cladogram shows the relationships among different evolutionary lines.



1 Cladograms are diagrams showing how evolutionary lines, or lineages, split from each other over time. This diagram shows a single ancestral lineage splitting into two. The point of splitting is called a "node" in the cladogram.



2 How recently lineages share a common ancestor reflects how closely the lineages are related to one another. Here, lineages 3 and 4 are each more closely related to each other than either of them is to any other lineage.



3 This cladogram shows the evolutionary relationships among vertebrates, animals with backbones.

Building Cladograms

Look at the cladograms on the left. Each cladogram looks like a tree with branches. The bottom, or "root," shows the common ancestor of all the organisms in the cladogram. The point where each branch splits off is called a *node*. Each node represents a speciation event. In speciation, one species splits into two new species. A node shows the last point at which the two new lines shared a common ancestor.

In a cladogram, the pattern of the branches shows how closely organisms are related. Look at cladogram 2. Notice that lines 3 and 4 share a common ancestor more recently than either does with line 2. Therefore, lines 3 and 4 are more closely related to each other than either is to line 2.

Key Question What is a cladogram?
A cladogram links groups of organisms by showing how evolutionary lines branched off from common ancestors.

Derived Characters

Biologists focus on particular characteristics, or traits, to put organisms into clades. A **derived character** is a trait that arose in the most recent common ancestor of a group and was passed on to its descendants. For example, having four limbs is a derived character in clade Tetrapoda. The common ancestor of all tetrapods had four limbs. Hair is a derived character for the clade Mammalia. All mammals have hair. But having four limbs is not a derived character for mammals. If it were, only mammals would have that trait.

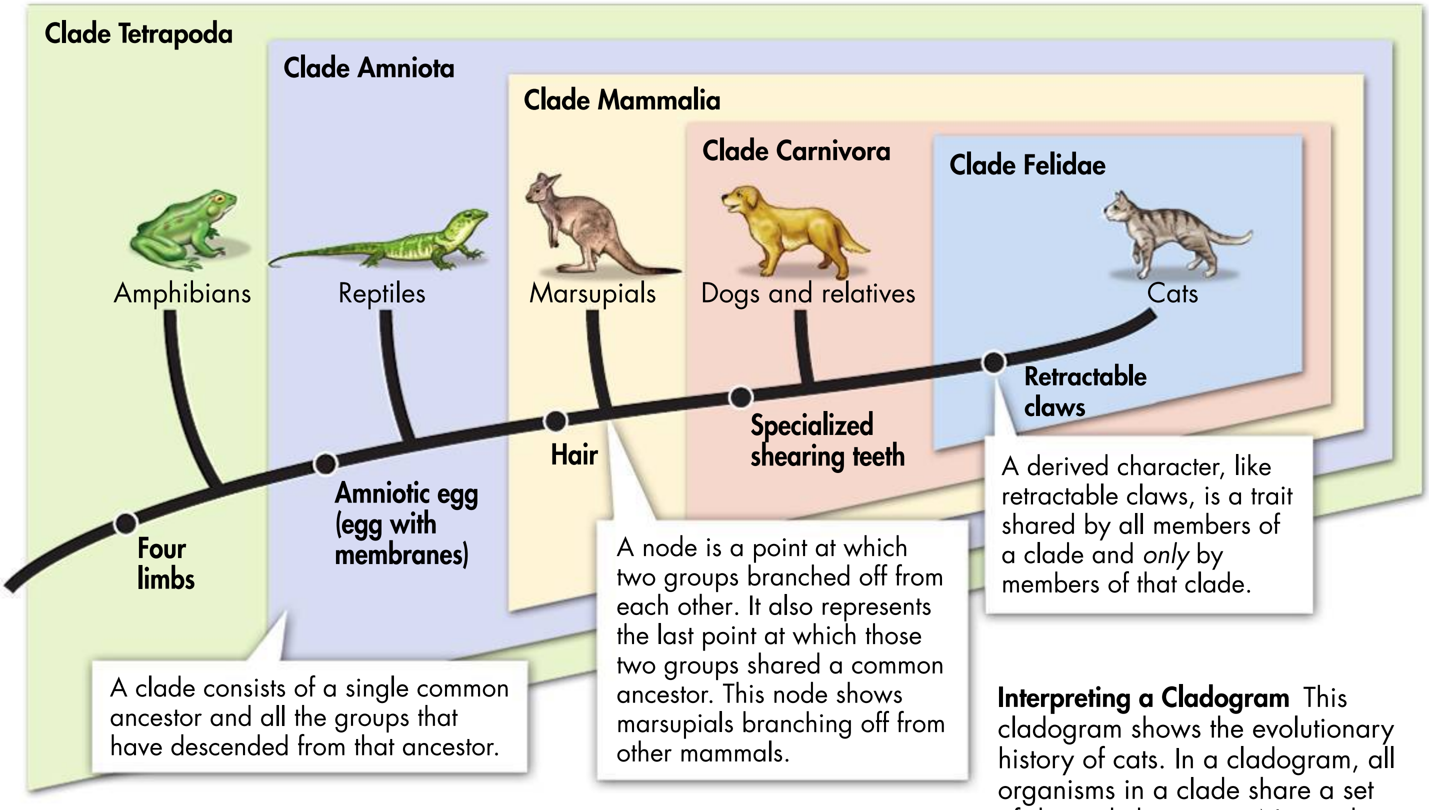
Lost Traits

Sometimes descendents lose a derived character. For example, snakes are reptiles, members of the clade Tetrapoda. But snakes do not have four limbs. During the process of evolution, snakes lost their legs.

Biologists must be careful about using the *absence* of a trait in classification. Distantly related groups can sometimes lose the same trait. For example, both whales and snakes have lost their legs. But whales and snakes are not very closely related. Snakes are more closely related to other reptiles than to whales.

Interpreting Cladograms

The cladogram on the next page shows the evolutionary line of the cat family. At the lower left is the common ancestor of all animals with four legs. The position of the nodes shows the order in which different groups branched off. First, amphibians branched off from the line leading to clade Amniota. (Amniota includes reptiles and mammals.) Next, reptiles branched off from the line leading to the clade Mammalia, and so on. Notice that smaller clades fit within larger clades. For example, clade Amniota is part of clade Tetrapoda.



Interpreting a Cladogram This cladogram shows the evolutionary history of cats. In a cladogram, all organisms in a clade share a set of derived characters. Notice that smaller clades are nested within larger clades.

Derived characters are listed along the main trunk. Each trait is a derived character for all the organisms to the right. For example, marsupials, dogs, and cats all have hair. On the cladogram, they are to the right of the common ancestor that had hair. The last derived character on the cladogram is retractable claws. Members of the cat family can retract, or pull back, their claws. Members of the dog family do not have this trait.

INQUIRY into Scientific Thinking

Constructing a Cladogram

1. Find the list of organisms in the table at right. Then look at the list of derived characters. The more characters that two organisms share, the more closely related they are.
2. Find the organism in the table that is *least* closely related to the others. That organism will be the first organism on your cladogram.
3. Use the information in the table to complete your cladogram. Put each organism on a separate branch.
4. Write the derived characters along the main trunk.

In Your Workbook Go to your workbook for more help with cladograms.

Derived Characters in Organisms

Organism	Derived Character		
	Backbone	**Legs**	**Hair**
Earthworm	Absent	Absent	Absent
Trout	Present	Absent	Absent
Lizard	Present	Present	Absent
Human	Present	Present	Present

Analyze and Conclude

1. **Interpret Tables** What trait separates the earthworm from the other animals?
2. **Classify** Do you have enough information to decide where to put a frog on your cladogram? Explain your answer.
3. **Draw Conclusions** Does your cladogram indicate that lizards and humans share a more recent common ancestor than either does with an earthworm? Explain your answer.

Hooded vulture from Africa

American vulture

Stork

DNA and Classification Scientists today compare DNA to help classify organisms. Vultures from Africa and American vultures were once grouped together in the falcon family. DNA analysis has shown that American vultures are more closely related to storks than to African vultures.

Clades and Traditional Taxonomic Groups How does the modern way of classifying organisms compare with the traditional system of classification? Biologists have found that many traditional groups are also true clades. For example, class Mammalia is the same as clade Mammalia. This clade includes all vertebrates with hair and several other derived traits.

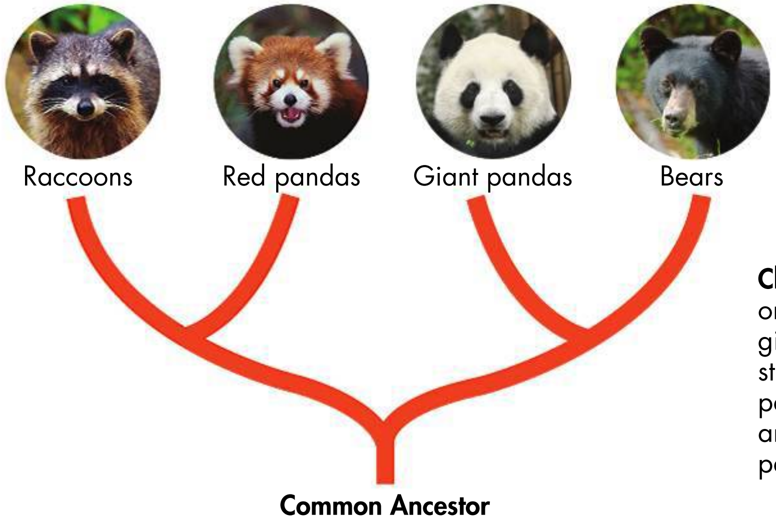
In other cases, traditional groups are not true clades. For example, birds and reptiles were traditionally put in two separate classes—Aves and Reptilia. Research has shown that all reptiles are descended from a common ancestor. Birds are also descended from this ancestor. So without birds, class Reptilia is not a clade. (Remember that a clade contains an ancestor and *all* of its descendants.) In modern classification, birds belong to three clades: Aves (birds themselves), Dinosauria, and Reptilia. Is it correct to call birds reptiles? An evolutionary biologist would say yes!

DNA in Classification

Most of the examples of evolutionary classification you have read about are based on physical traits such as fur, bones, and teeth. The goal of modern systematics is to understand the relationships of *all* life on Earth. If two organisms do not share any obvious features, how can you tell if they are related?

Genes as Derived Characters Remember that all species inherit genes on strands of DNA. Very different organisms often share a number of homologous genes. The similarities and differences in these homologous genes can tell how closely related organisms are. Because genes mutate at a steady rate, they can be used as molecular clocks. The more similar the genes in two organisms are, the more recently they shared a common ancestor. In these comparisons, genes and mutations are used as derived characters.

New Techniques Redraw Old Trees Information from DNA is helping to make evolutionary trees more accurate. For example, look at the three birds on the left. The hooded vulture from Africa looks like the American vulture in the middle. Both vultures were once classified in the same clade. But by studying their DNA, researchers have learned that American vultures are more closely related to storks than to African vultures.



Classification of Pandas Biologists once classified the red panda and giant panda together. Recently, DNA studies have shown that the giant panda shares a more recent common ancestor with bears than with red pandas or raccoons.

Evidence from DNA has also helped biologists classify pandas. Giant pandas and red pandas share many traits. For example, both pandas have bones in the wrist that work like a human thumb. But studies of DNA show that giant pandas share more recent ancestors with bears than with raccoons. So giant pandas are now classified with bears in the family Ursidae. Red pandas are placed in a clade that also includes raccoons, seals, and weasels.

Key Question How are DNA sequences used in classification? **In general, the more derived genetic characters that two species share, the more recently they shared a common ancestor. This information also tells how closely they are related.**

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. _______ are groups of species that include a single common ancestor and all descendants of that ancestor.

2. A _______ is a diagram that shows the evolutionary relationships among clades.

3. A trait that evolved in a recent common ancestor and was passed on to the descendants of that ancestor is called a _______.

Critical Thinking

4. Explain How does evolutionary classification differ from traditional classification?

5. Apply Concepts What do the locations of derived characters on a cladogram show?

6. Relate Cause and Effect Explain how DNA analysis changed the classification of giant pandas.

7. Write to Learn Answer the question in the mystery clue below.

MYSTERY CLUE

When DNA is compared, some brown bears are more closely related to polar bears than they are to other brown bears. What do you think this means for the classification of polar bears? (Hint: See p. 436.)

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18.3 Building the Tree of Life

Key Questions

What are the six kingdoms of life as they are now identified?

What does the tree of life show?

BUILD Understanding

Concept Map As you read, construct a concept map describing the characteristics of the three domains.

In Your Workbook Go to your workbook to learn about making a concept map.

BUILD Vocabulary

domain a larger, more inclusive taxonomic category than a kingdom

Bacteria the domain of unicellular prokaryotes that have cell walls containing peptidoglycan

Archaea the domain of unicellular prokaryotes that have cell walls that do not contain peptidoglycan

WORD ORIGINS

The domain Archaea and kingdom Archaebacteria come from the Greek word *arkhaios*, which means "ancient or primitive." Archaea live in harsh environments that may resemble early, or primitive, conditions on Earth.

Changing Ideas About Kingdoms

Since the time of Linnaeus, biologists have worked to improve the system of classification. Classification today is based on the most recent discoveries and reflects evolutionary relationships. As scientists learn more and more about living and extinct organisms, the classification system will continue to change.

Linnaeus's original system had only two kingdoms: plants and animals. Animals were organisms that moved and used food for energy. Plants included everything that was not an animal. Over the years, classification at the level of the kingdom has changed greatly.

Five Kingdoms In the late 1800s, researchers discovered that single-celled organisms were very different from plants and animals. A third kingdom, called Protista, was created to contain all microorganisms. Later, biologists gave yeasts, molds, and mushrooms their own kingdom: Fungi. When biologists realized how different bacteria were from other organisms, they added a fifth kingdom: Monera. (Bacteria are prokaryotes, or organisms that lack a nucleus and other organelles.) The research and discoveries that expanded the classification system from two to five kingdoms took more than 200 years.

Six Kingdoms More recently, biologists studying bacteria reached a surprising conclusion. Kingdom Monera contained two very different kinds of bacteria. So the bacteria were divided into two new kingdoms: Eubacteria and Archaebacteria. These two new kingdoms give us the six kingdoms used in modern classification.

Key Question What are the six kingdoms of life as they are now identified?
The six-kingdom classification system includes the kingdoms Eubacteria, Archaebacteria, Protista, Fungi, Plantae, and Animalia.

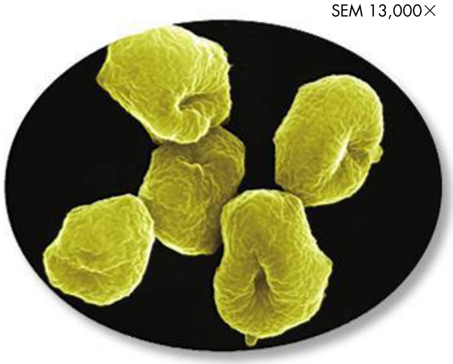
Three Domains Genetic studies show that the two groups of bacteria are very different from each other. The bacteria are also very different from all the other organisms, or eukaryotes. To reflect these differences, biologists have added a new level of classification—the domain. A **domain** is larger and includes more than a kingdom.

Classification of Living Things

DOMAIN	Bacteria	Archaea	Eukarya			
KINGDOM	**Eubacteria**	**Archaebacteria**	**"Protista"**	**Fungi**	**Plantae**	**Animalia**
CELL TYPE	Prokaryote	Prokaryote	Eukaryote	Eukaryote	Eukaryote	Eukaryote
CELL STRUCTURES	Cell walls with peptidoglycan	Cell walls without peptidoglycan	Cell walls of cellulose in some; some have chloroplasts	Cell walls of chitin	Cell walls of cellulose; chloroplasts	No cell walls or chloroplasts
NUMBER OF CELLS	Unicellular	Unicellular	Most unicellular; some colonial; some multicellular	Most multicellular; some unicellular	Most multicellular: some green algae unicellular	Multicellular
MODE OF NUTRITION	Autotroph or heterotroph	Autotroph or heterotroph	Autotroph or heterotroph	Heterotroph	Autotroph	Heterotroph
EXAMPLES	*Streptococcus, Escherichia coli*	Methanogens, halophiles	*Amoeba, Paramecium,* slime molds, giant kelp	Mushrooms, yeasts	Mosses, ferns, flowering plants	Sponges, worms, insects, fishes, mammals

Three Domains Today organisms are grouped into three domains and six kingdoms. This table shows the key characteristics used to classify organisms into these major taxonomic groups.

There are three domains. Domain **Bacteria** contains the organisms in kingdom Eubacteria. Domain **Archaea** contains the organisms in kingdom Archaebacteria. Domain Eukarya contains the kingdoms Fungi, Plantae, and Animalia, and "Protista." Why are there quotation marks around the word "Protista"? Scientists have found that the members of the old kingdom Protista do not form a monophyletic group. The many kinds of unicellular eukaryotes do not have a single common ancestor. Therefore, "Protista" is not a true clade.

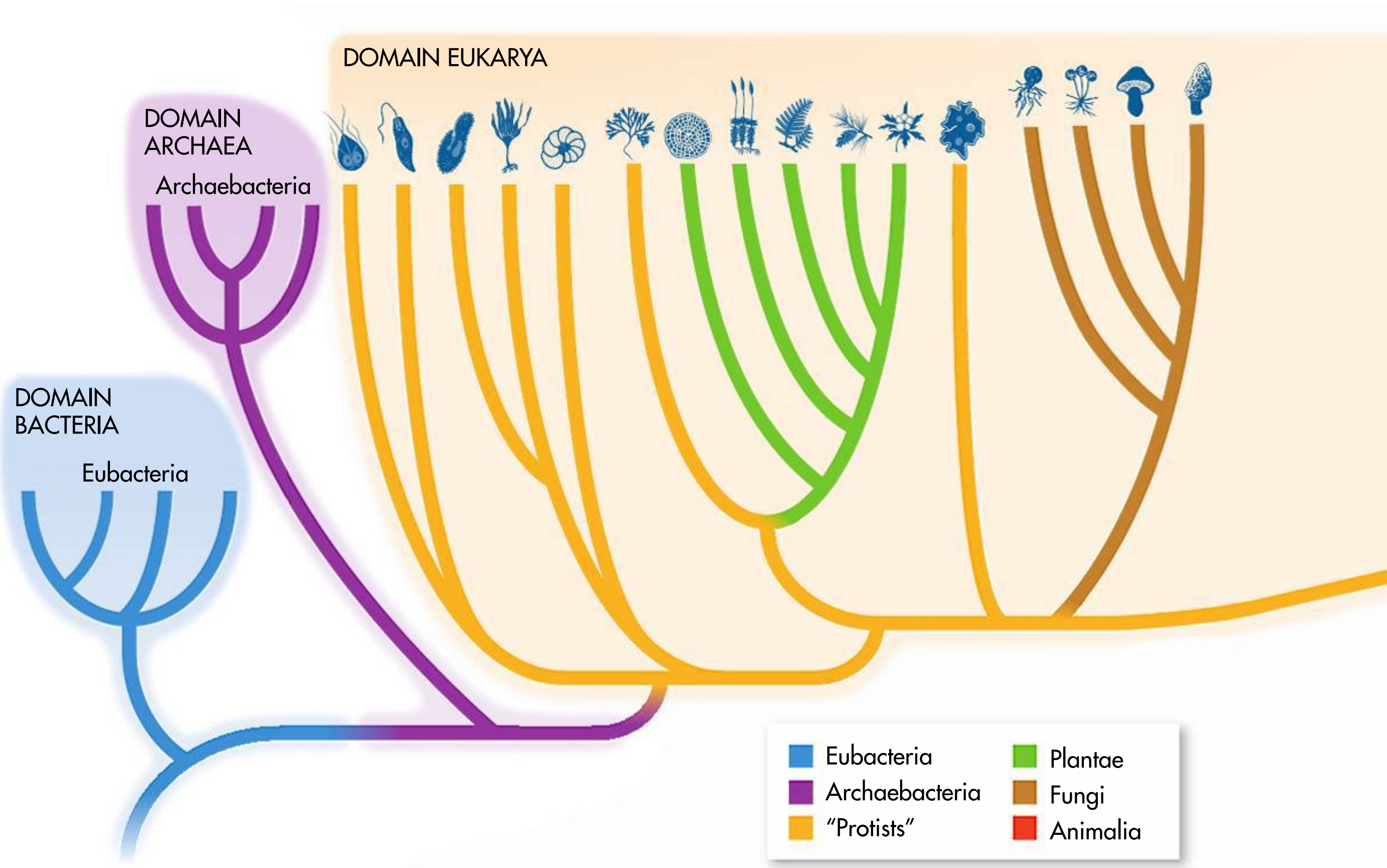


Sulfolobus This member of the domain Archaea lives in hot springs. It thrives in acidic environments that have large amounts of sulfur.

The Tree of All Life

Evolutionary classification is a rapidly changing science. It has a difficult goal—to show all life on a single evolutionary tree. Evolutionary biologists often change the way that organisms are grouped. They also change the names of groups. Cladograms show hypotheses about the relationships among groups. These hypotheses change as more evidence becomes available.

Domain Bacteria Members of the domain Bacteria are single-celled prokaryotes. They do not have a nucleus. They have thick cell walls that contain a substance called peptidoglycan. Bacteria are a very diverse group. Some live in the soil. Some make their own food by photosynthesis. And some are parasites that cause deadly diseases.



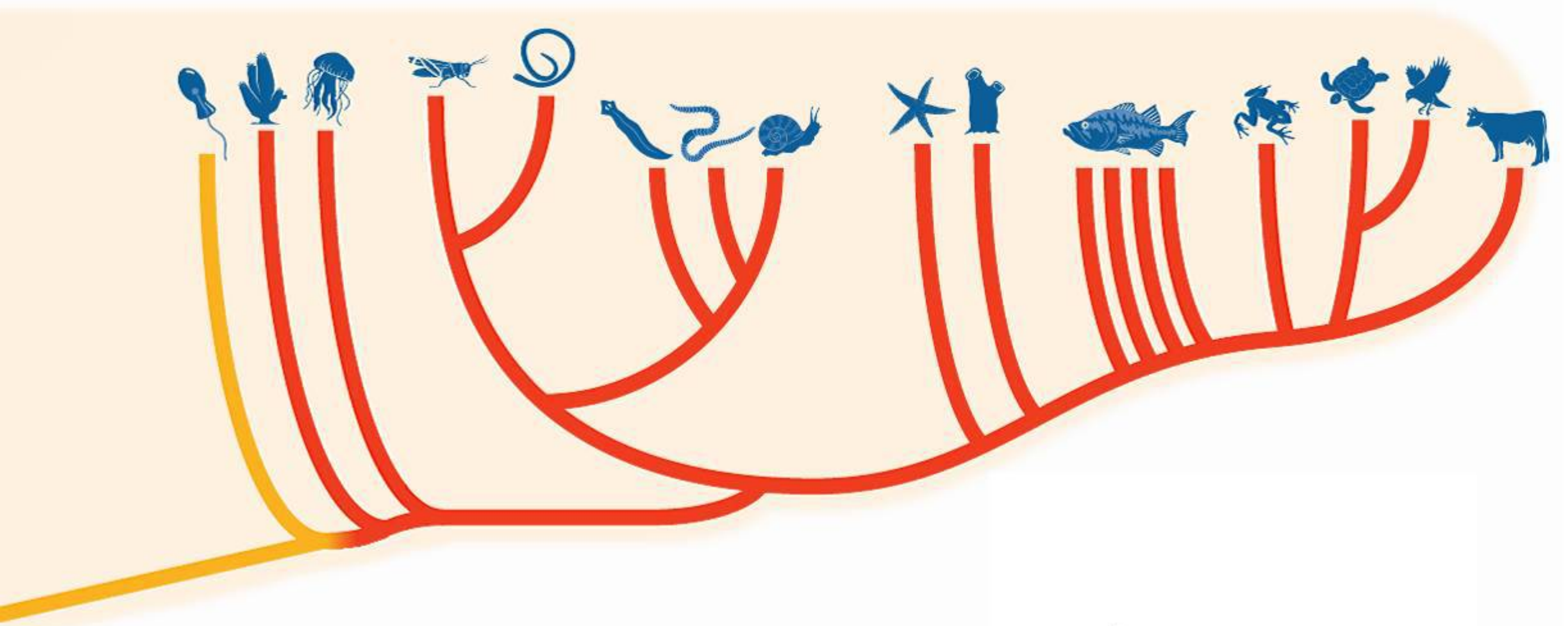
Tree of Life The tree of life shows the most recent hypothesis about how the major groups of organisms are related to one another.

Domain Archaea Members of the domain Archaea are also single-celled prokaryotes. They have unusual cell membranes. Their cell walls do not have peptidoglycan. These bacteria live in some of the most extreme environments on Earth. Some live in hot springs. Others live in very salty water. Still others live only in places that have no oxygen.

Domain Eukarya The domain **Eukarya** contains all of the organisms that have a nucleus. It includes four major groups from the six-kingdom system: "Protista," Fungi, Plantae, and Animalia.

▶ ***"Protists"*** In the cladogram above, notice that kingdom "Protista" is spread out over several different branches. This kingdom is not monophyletic, so many members are not closely related. Recent studies of these organisms have divided them into at least five clades. Each of these clades is more closely related to other groups than to other "protists." Most "protists" are single-celled organisms, but the brown algae are multicellular. Some "protists" are photosynthetic. Others are heterotrophic.

▶ ***Fungi*** Members of the kingdom Fungi are heterotrophs that have cell walls containing chitin. Most fungi feed on dead organisms. Fungi release enzymes that digest food outside of their body. The body of the fungus then absorbs the digested food. Most fungi, such as mushrooms, are multicellular. Some, such as yeasts, are single-celled.



▶ ***Plantae*** Members of the kingdom Plantae make their own food by photosynthesis. They also have cell walls that contain cellulose. Most are multicellular. Green algae, once considered to be protists, are now classified as plants. Many green algae are single-celled organisms.

▶ ***Animalia*** Members of kingdom Animalia are multicellular and do not have cell walls. Animals are heterotrophic. To get energy, they feed on other organisms or the remains of other organisms. Most animals can move from place to place, at least in part of their life cycle.

Key Question What does the tree of life show?
The tree of life shows current hypotheses about the evolutionary relationships among the groups within the three domains of life.

BUILD Vocabulary

Eukarya the domain consisting of all organisms that have a nucleus

WORD ORIGINS

Members of domain Eukarya are called eukaryotes. *Eukaryote* comes from two Greek roots. *Eu* means "good" and *kary* means "nucleus." So, a eukaryote is an organism with a good, or true, nucleus.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The three _______ are very large groups that help to organize the six kingdoms.

2. The domain _______ includes protists, fungi, plants, and animals.

3. The domain _______ includes bacteria that live in very harsh environments.

Critical Thinking

4. Review What are the six kingdoms of life as they are now identified?

5. Classify Which kingdoms include prokaryotes? Which kingdoms include eukaryotes?

6. Relate Cause and Effect Why did biologists add the level of "domain"?

7. Write to Learn Do you think the tree of life cladogram will always stay the same as it appears in your book? Explain your answer.

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Real-World Lab

OPEN-ENDED INQUIRY

Pre-Lab: Dichotomous Keys

Problem Can you construct a dichotomous key that can be used to identify organisms?

Materials reference materials

Lab Manual Chapter 18 Lab

Skills Focus Observe, Classify, Compare and Contrast, Sequence

Connect to the Big idea Given the enormous variety of life on Earth, not even experts can identify every organism they observe. Experts and amateurs use dichotomous keys to identify organisms. These keys are based on the appearance of organisms. A key is a series of paired statements. Readers select the statement that best describes an organism at each step until the organism is identified and named. In this lab, you will practice using a dichotomous key. Then you will construct your own key for a group of organisms.

Background Questions

a. **Review** Why do biologists prefer to identify an organism by its scientific name?

b. **Compare and Contrast** How is the way modern biologists group species into larger categories different from the system that Linnaeus used?

c. **Review** How many choices does a dichotomous key provide at each step?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Observe** Name three different physical traits that are used in the shark dichotomous key.
2. **Classify** Do all the sharks you will try to identify belong to the same genus? Explain your answer.
3. **Apply Concepts** After you make a list of physical traits that you can use in your dichotomous key, how will you decide which trait to pick for the first step?

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Visit Chapter 18 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Hop on board with the Untamed Science crew to find out how organisms are classified.

Art in Motion View a short animation that explains how to use a dichotomous key.

Art Review How well do you know the characteristics of the three domains? Test yourself in this activity.

InterActive Art Build your understanding of cladograms with this animation.

18 CHAPTER Summary

18.1 Finding Order in Diversity

- In binomial nomenclature, each species is given a two-part scientific name.
- The goal of systematics is to organize living things into groups that have biological meaning.
- Over time, Linnaeus's original classification system was expanded to include seven levels: species, genus, family, order, class, phylum, and kingdom.

binomial nomenclature (p. 428)
genus (p. 428)
systematics (p. 430)
family (p. 430)
order (p. 430)
class (p. 430)
phylum (p. 431)
kingdom (p. 431)

18.2 Modern Evolutionary Classification

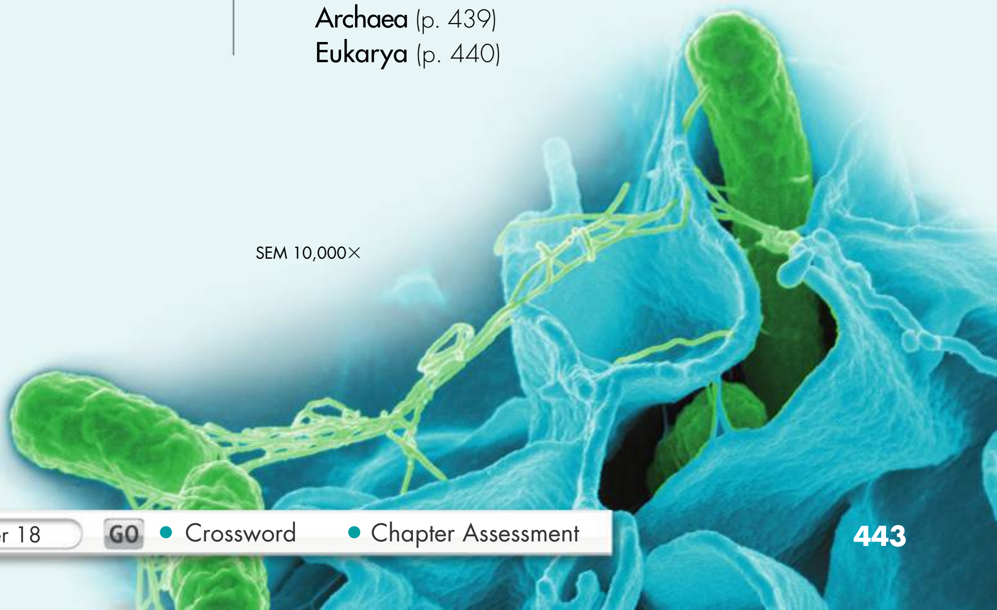
- The goal of evolutionary classification is to group species into larger categories that reflect lines of evolutionary descent, rather than overall similarities and differences.
- A cladogram links groups of organisms by showing how evolutionary lines branched off from common ancestors over time.
- In general, the more derived genetic characters that two species share, the more recently they shared a common ancestor. This information also tells how closely two species are related.

clade (p. 433)
monophyletic group (p. 433)
cladogram (p. 433)
derived character (p. 434)

18.3 Building the Tree of Life

- The six-kingdom system of classification includes the kingdoms Eubacteria, Archaebacteria, Protista, Fungi, Plantae, and Animalia.
- The tree of life shows current hypotheses about evolutionary relationships among the groups within the three domains of life.

domain (p. 438)
Bacteria (p. 439)
Archaea (p. 439)
Eukarya (p. 440)



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18 CHECK Understanding

Assess the Big idea Unity and Diversity of Life

Write an answer to the question below.

Q: What is the goal of biologists who classify living things?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each numbered question should be one or two paragraphs long. To help you begin, read the **Hints** below the questions.

1. **Why do biologists give each species its own two-part name?**

   Hint The two-part naming system is called binomial nomenclature. The first part of the name is the genus name. The second part is unique to each species.

2. **How are derived characters used to show evolutionary relationships?**

   Hint A cladogram is a visual way of organizing and presenting evolutionary relationships among a group of organisms.

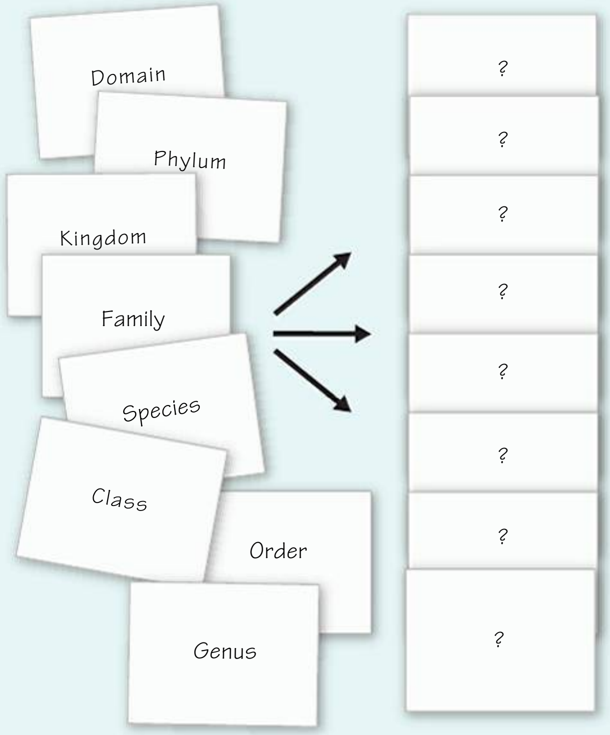
3. **Is the kingdom Protista a true clade? Explain your answer.**

   Hint Look at the tree of life. Where are the protists located?

Foundations for Learning Wrap-Up

Use the index cards that you made at the beginning of the chapter as a tool for review.

Activity 1 Shuffle the cards until they are no longer in order. Then lay the cards on your desk and arrange them in order, from the largest group to the smallest. Repeat this activity until it becomes easy.



Activity 2 Work with a partner. Lay your cards on your desk to help you with the following activity. Your partner will use examples in the textbook, such as the camel chart on page 431. He or she will name two organisms, such as *camel* and *squirrel*. Name the smallest taxon that both animals belong to, such as *family* or *kingdom*. Check your answers in the textbook. Then, switch roles with your partner.

18.1 Finding Order in Diversity

Understand Key Concepts

1. By looking at its name, you know that *Rhizopus nigricans* must be
   a. a plant.
   b. an animal.
   c. in the genus *nigricans*.
   d. in the genus *Rhizopus*.

2. A useful classification system does NOT
   a. show relationships.
   b. reveal evolutionary trends.
   c. use different names for the same organism.
   d. change the taxon of an organism based on new data.

Test-Taking Tip

Watch for Qualifiers When reading a question, watch out for the words NOT, EXCEPT, ALL, and ONLY. These words can change a correct answer into an incorrect answer. For example, the word NOT appears in question 2 above. Without this word, choices **a, b,** and **d** could all be correct, since they all describe a useful classification system. The word NOT is a signal to look for the one exception. The correct answer is **c,** because a useful classification system does NOT use different names for the same organism.

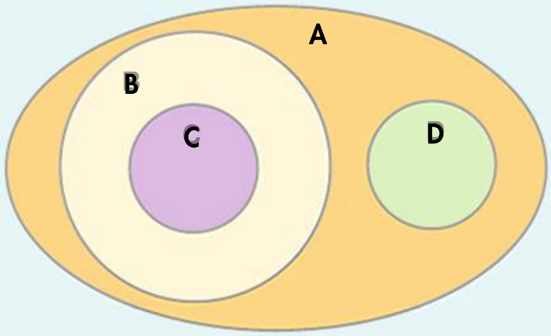
3. In Linnaeus's system of classification, orders are grouped together into
   a. genera. **c.** families.
   b. species. **d.** classes.

4. The largest and most inclusive rank in the Linnaean classification system is the
   a. kingdom. **c.** phylum.
   b. order. **d.** domain.

5. What features of binomial nomenclature make it useful for scientists around the world?

Think Critically

6. **Classify** Venn diagrams can be used to show groups within groups. The Venn diagram below shows four groups as circles—A, B, C, and D. Each shape is a taxonomic level. Shapes that overlap share common members. Shapes that do not overlap do not share members. Use these levels to label the shapes in the diagram: *kingdom Animalia*, *phylum Chordata*, *class Insecta*, and *class Mammalia*. Give reasons for your labels. (**Hint:** See the diagram on p. 431.)



18.2 Modern Evolutionary Classification

Understand Key Concepts

7. A specific trait that is used to construct a cladogram is called a
   a. taxon. **c.** clade.
   b. structural feature. **d.** derived character.

8. A branch of a cladogram that consists of a single common ancestor and all its descendants is called
   a. cladistics. **c.** a clade.
   b. a kingdom. **d.** a class.

9. What does each node in a cladogram represent?

Think Critically

10. **Apply Concepts** Hair is a derived character for clade Mammalia. Having four limbs is not a derived character for this clade. Explain why this is so. For which clade is four limbs a derived character?

18 CHECK Understanding

18.3 Building the Tree of Life

Understand Key Concepts

11. Which of the following kingdoms contains ONLY heterotrophs?

a. Protista **c.** Plantae

b. Fungi **d.** Eubacteria

12. What characteristics are used to place an organism in the domain Bacteria?

Think Critically

13. Classify Study the descriptions of the following organisms and place them in the correct kingdoms.

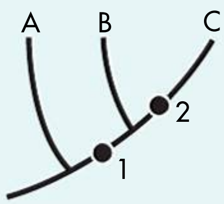
Organism A: Multicellular eukaryote without cell walls.

Organism B: Unicellular eukaryote with cell walls of chitin.

Connecting Concepts

Use Science Graphs

The cladogram below shows the relationships among three imaginary groups of organisms—groups A, B, and C. Use the cladogram to answer questions 14–16.



14. Interpret Visuals Which groups share derived character 1?

15. Apply Concepts What does the node, or fork, between characters 1 and 2 represent?

16. Infer Which group split off from the other groups first?

solve the CHAPTER MYSTERY

GRIN AND BEAR IT

Most biologists classify the polar bear, *Ursus maritimus*, as a separate species from the brown bear, *Ursus arctos*. The teeth, body shape, metabolism, and behavior of polar bears are very different from those of brown bears. But some researchers now wonder if the two are the same species.

Polar bears and brown bears can mate and produce fertile offspring. That ability is the definition of a species. But, in the wild, polar bears and brown bears almost never mate.

DNA analysis makes the question harder to answer, not easier. Different populations of brown bears have different genetic makeups. Some populations of brown bears have DNA that is different from that of polar bears. Other brown bears have DNA that is more similar to polar bears than to other brown bears. It may be that polar bears are not a separate species after all. It may also be that brown bears by themselves do not form a single clade.

1. Classify List the evidence that supports classifying polar bears and brown bears as two separate species. Then list the evidence that shows that polar bears and brown bears belong to the same species.

2. Infer What evidence exists that different populations of brown bears belong to different clades?

UntamedScience **Never Stop Exploring Your World.** Solving the mystery of scientific classification is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Which of the following is NOT a characteristic of Linnaeus's system for naming organisms?
A two-part name
B multipart name describing several traits
C name that identifies the organism's genus
D name that includes the organism's species identifier

2. In which of the following are the taxa in correct order?
A phylum, kingdom, species
B genus, order, family
C kingdom, phylum, class
D order, class, family

3. In the six-kingdom system of classification, which kingdoms contain unicellular organisms?
A Eubacteria only
B Eubacteria and "Protista" only
C Archaebacteria only
D Eubacteria, Archaebacteria, Plantae, and "Protista"

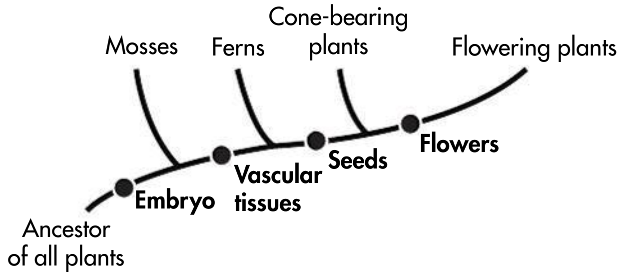
4. If species A and B have very similar genes, which of the following statements is probably true?
A Species A and B shared a relatively recent common ancestor.
B Species A evolved independently of species B for a long period.
C Species B is older than species A.
D Species A is older than species B.

5. The taxon called Eukarya is a(n)
A order.
B phylum.
C kingdom.
D domain.

6. Bacteria are classified into
A two domains.
B three domains.
C three species.
D three kingdoms.

Questions 7–9

The cladogram below shows the evolutionary relationships among four groups of plants. Use the cladogram to answer questions 7–9.



7. Which of the following groups, by themselves, do NOT form a clade?
A cone-bearing plants and flowering plants
B ferns, cone-bearing plants, and flowering plants
C mosses and ferns
D mosses, ferns, cone-bearing plants, and flowering plants

8. Which of the following groups share the most recent common ancestor?
A cone-bearing plants and flowering plants
B mosses and ferns
C mosses and cone-bearing plants
D ferns and flowering plants

9. Which derived character appeared first during the course of the plants' evolution?
A seeds
B flowers
C embryo
D vascular tissues

Open-Ended Response

10. Why have biologists changed many of Linnaeus's original classifications of organisms?

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	18.1	18.1	18.3	18.2	18.3	18.3	18.2	18.2	18.2	18.2

19 History of Life

Big idea **Evolution**

Q: How do fossils help biologists understand the history of life on Earth?

Ichthyosaurs were reptiles that looked like dolphins. They lived in the seas during the Mesozoic Era. This ichthyosaur died around the time of giving birth.

BIOLOGY.com Search Chapter 19 GO • Flash Cards

INSIDE:

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

MURDER IN THE PERMIAN

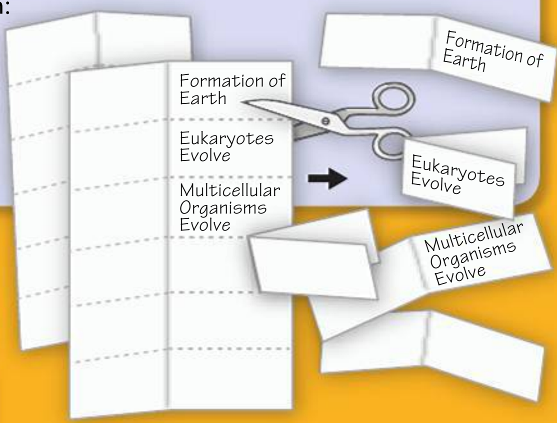
About 250 million years ago, life on Earth nearly came to an end. This time is known as the Permian extinction, because it happened at the end of the Permian Period. The Permian extinction may be the greatest murder mystery in the history of the world. Whatever happened back then killed about 96 percent of marine species and 70 percent of terrestrial vertebrate species.

Scientists once thought that this extinction happened over a long period. But new fossils suggest that it took no more than 200,000 years. In geology, that is a short amount of time.

Read for Mystery Clues As you read this chapter, look for clues to help you decide what could have killed so much of life on Earth. Then, solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

As you read the chapter, you will learn about key events in the history of life. To help remember these events, you will make folded tabs for 12 key events. Start with two sheets of notebook paper. Fold the sheets in half lengthwise. Cut each sheet into six pieces to make 12 folded tabs, as shown below. As you read, make notes about the key events on the inside of each tab. Be sure to include the time when each event took place. At the end of the chapter are two activities that use the folded tabs to help answer the question: How do fossils help biologists understand the history of life on Earth?



19.1 The Fossil Record

Key Questions

What do fossils reveal about ancient life?

How do we date events in Earth's history?

How was the geologic time scale established, and what are its major divisions?

How have our planet's environment and living things interacted to shape the history of life on Earth?

BUILD Understanding

Main Ideas and Details Chart One way to take notes is to make a main ideas and details chart. In the left column, write down the main idea. In the right column, write down details that support the main idea.

In Your Workbook Go to your workbook to learn more about making a main idea and details chart. Complete the chart for Lesson 19.1.

Fossils and Ancient Life

Fossils are one of the most important sources of information about ancient life. All fossils together make up the history of life on Earth called the *fossil record*. The scientists who study fossils are called **paleontologists** (pay lee un TAHL uh jists).

Types of Fossils Many fossils are the preserved remains of organisms. Usually, only hard parts of organisms, such as shell, teeth, bone, or wood, are preserved. (Soft body parts usually rot or are eaten before they can be preserved.) Fossils can be as large as a whole animal. Others are as tiny as bacteria or pollen grains. Many fossils are just pieces of an organism—a few teeth or bits of bone. Some fossils are called *trace* fossils. Trace fossils are signs of activity, such as footprints, burrows, or even droppings.

What Fossils Show Only a tiny percentage of ancient organisms became fossils. Although incomplete, the fossil record holds enough information to teach us a great deal about ancient life. Without fossils, we would know almost nothing about extinct species. An **extinct** species has no living members.

Fossils can show how an organism lived or what it ate. By comparing fossils to living organisms, paleontologists can trace the evolution of a body part or a whole species. Bone structure and footprints can show how an animal moved. Fossils from plants, such as leaves and pollen, can tell whether an area was a swamp or a forest. When plant and animal fossils are found together, paleontologists can learn about ancient ecosystems.

Key Question What do fossils reveal about ancient life?
The fossil record shows the structure of ancient organisms, their environment, and the way in which they lived.

Fossil Fish Like this 50-million-year-old fossil of a fish, most fossils form from the hard parts of organisms.

Dating Earth's History

To understand the fossil record, we need a time scale to tell what happened when. To find the age of rocks and fossils, scientists use relative dating and radiometric dating.

Sedimentary Rocks Fossils are usually found in sedimentary rock. Most sedimentary rocks form when sediments settle to the bottom of a body of water. Sediments are tiny particles, such as sand and clay. Over time, more and more layers of sediment build up. The weight of the many layers and chemical reactions turn the sediments into rock. As sediments build up, they bury dead organisms that have settled to the bottom. The remains of these organisms may become fossils.

Relative Dating When sedimentary rocks form, new layers are laid on top of older rocks. The layers on the bottom are usually older than the layers above them. Therefore, fossils in lower layers are usually older than fossils in upper layers. Scientists use the position of the layers to find the relative age of fossils. **Relative dating** places rock layers and their fossils in order according to time. Relative dating does not tell the age of a fossil in years.

To find the relative age of rock layers and their fossils, scientists use **index fossils.** Index fossils help scientists identify rocks and fossils of the same age that are found in different places. An index fossil must be easy to recognize. It should be found in only a few rock layers. (That would mean that it lived for only a short time.) But the layers that hold the index fossil must be found in many places.

BUILD Vocabulary

paleontologist a scientist who studies fossils

extinct the word used to describe a species that has died out and has no living members

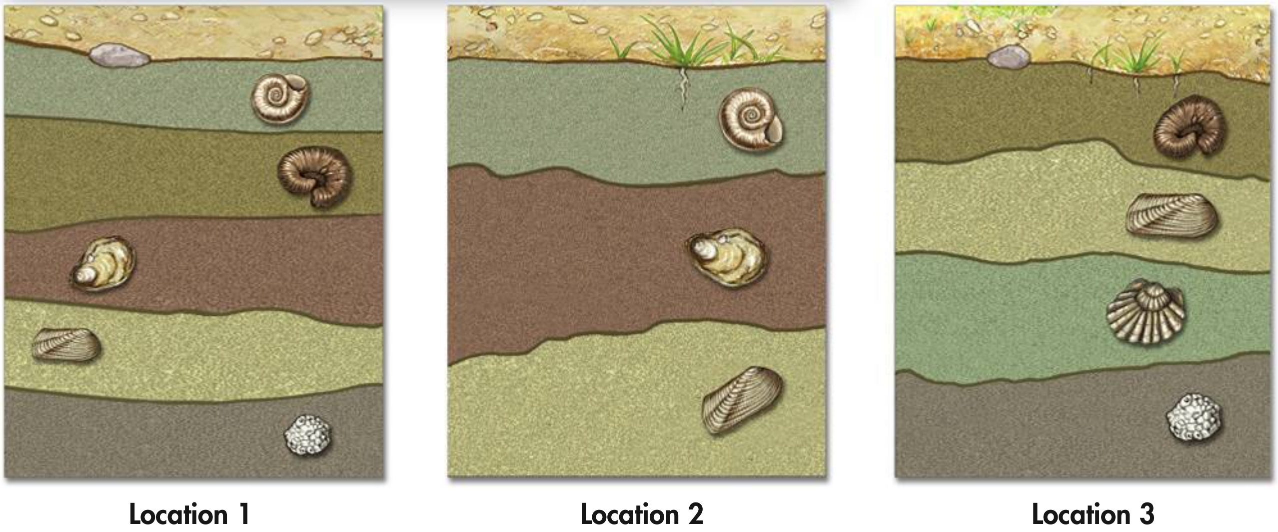
relative dating a method of determining the age of a fossil by comparing its placement with that of fossils in other rock layers

index fossil a distinctive fossil that is used to establish and compare the relative ages of rock layers and the fossils they contain

WORD ORIGINS

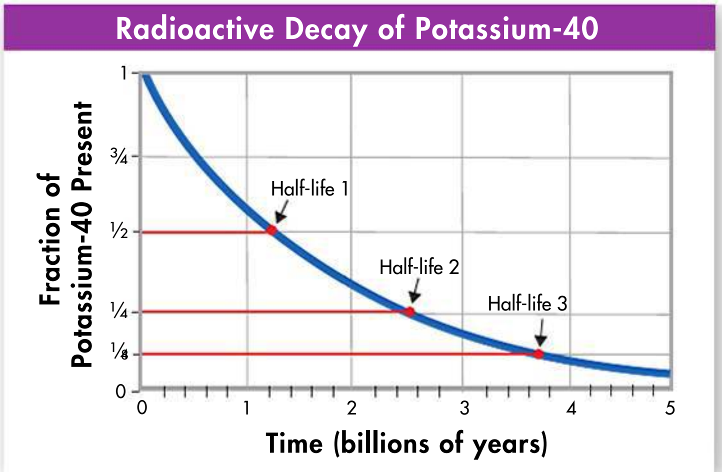
The word *paleontologist* comes from the Greek word *palaios*, meaning "ancient." A paleontologist studies the remains of ancient life.

Index Fossils Each of these fossils is an index fossil. If the same index fossil is found in two different rock layers, the rock layers are probably about the same age. Use the index fossils to find which layers are missing from each location. Layers may be missing because they were never laid down or because they were worn away.



Radiometric Dating In **radiometric dating,** scientists use radioactive isotopes to find the age of rocks and fossils. These isotopes decay, or break down, into nonradioactive isotopes at a steady rate. A **half-life** is the time it takes for half of the radioactive atoms in a sample to decay. After one half-life, half of the radioactive atoms have decayed. Radiometric dating gives the *absolute age*, or age in years.

Different radioactive isotopes decay at different rates, so they have different half-lives. Carbon-14 has a half-life of 5730 years. It is useful for finding the age of organisms that lived in the recent past—the last 60,000 years. Because carbon-14 is found in living organisms, it can be used to date fossils directly.



Radioactive Decay A half-life is the time it takes for half of the radioactive atoms in a sample to decay. The half-life of postassium-40 is 1.26 billion years.

Isotopes with longer half-lives are used to date older fossils. Isotopes used for dating very old fossils include potassium-40 (half-life: 1.26 billion years), uranium-238 (half-life: 4.5 billion years), and rubidium-87 (half-life: 48.8 billion years). These isotopes are found in rocks, but not in fossils. To date an older fossil, researchers first find the age of the rocks in which the fossil is found. They then use this information to infer the age of the fossil itself.

Key Question How do we date events in Earth's history? **Relative dating can be used to determine whether a fossil is older or younger than other fossils. Radiometric dating uses the proportion of radioactive to nonradioactive isotopes to find the absolute age of a sample.**

INQUIRY into Scientific Thinking

Modeling Half-Life

1. Make a data table like the one to the right.
2. Take a sheet of paper, and cut out 100 1-cm squares. Write an *X* on one side of each square. Put all the squares in a cup.
3. Mix the squares in the cup. Then spill them out.
4. Remove all the squares that have the *X* showing. These represent radioactive isotopes that have decayed into different isotopes.
5. Repeat steps 3 and 4 until there are five or fewer squares left.
6. Make a graph of your results. Put the number of spills on the *x*-axis. Put the number of squares left after each spill on the *y*-axis.

Spill Number	Number of Squares Left
1	
2	
3	
4	
5	

Analyze and Conclude

1. Analyze Data How many spills did you need to remove half the squares? To remove three fourths?

2. Calculate If each spill represents 100 years, what is the half-life of the squares?

In Your Workbook Get more help for this activity in your workbook.

Geologic Time Scale

Eon	Era	Period	Time (millions of years ago)
Phanerozoic	Cenozoic	Quaternary	2–present
		Neogene	23–2
		Paleogene	66–23
	Mesozoic	Cretaceous	146–66
		Jurassic	200–146
		Triassic	251–200
	Paleozoic	Permian	299–251
		Carboniferous	359–299
		Devonian	416–359
		Silurian	444–416
		Ordovician	488–444
		Cambrian	542–488
Pre-cambrian Time	Protero-zoic		2500–542
	Archean		4000–2500
	Hadean		About 4600–4000

Geologic Time Scale The basic divisions of the geologic time scale are eons, eras, and periods. About 90 percent of Earth's history took place before the Cambrian Period.

Geologic Time Scale

Geologists and paleontologists have made a time line of Earth's history called the **geologic time scale.** The most recent version is shown above.

Establishing the Time Scale At first, scientists studied rock layers and index fossils to place them in order according to their relative ages. Then scientists noticed major changes in the fossil record between certain rock layers. Geologists used the boundaries between these layers to mark the end of one time division and the beginning of another. Years later, radiometric dating was used to find the ages of each of the layers. The geologic time scale is always being tested and corrected.

Key Question How was the geologic time scale established, and what are its major divisions? **The geologic time scale is based on both relative and absolute dating. The major divisions of the time scale are eons, eras, and periods.**

BUILD Vocabulary

radiometric dating a method for determining the age of a sample by comparing the amount of radioactive atoms to the nonradioactive atoms of the same element

half-life the length of time required for half of the radioactive atoms in a sample to decay

geologic time scale the time line used to represent Earth's history

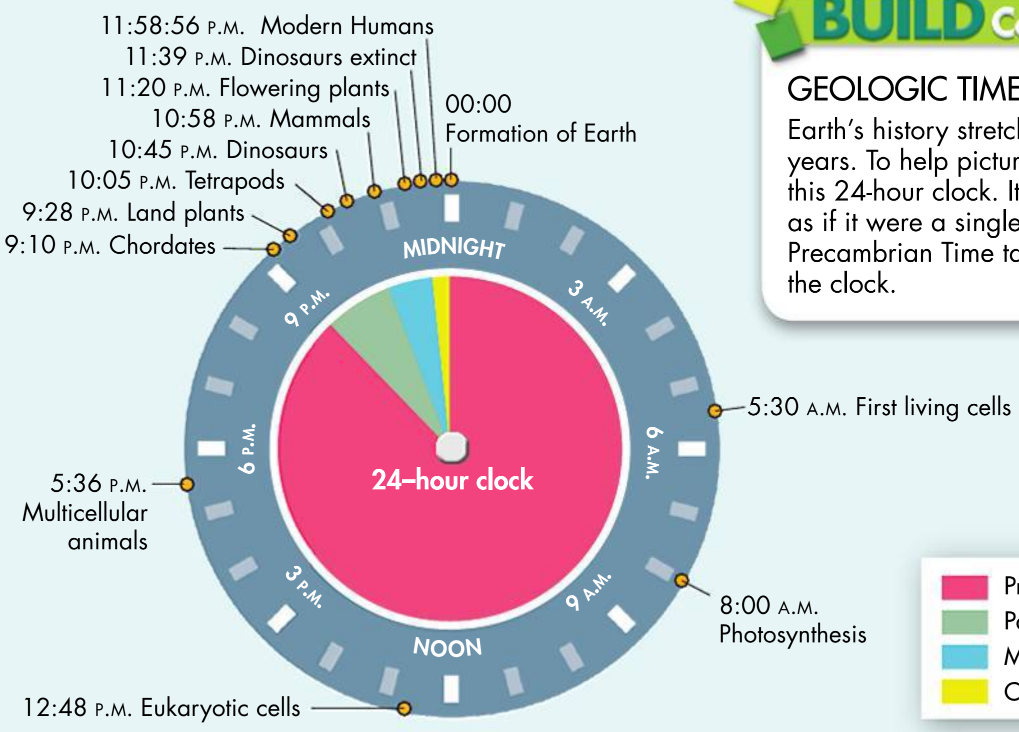
PREFIXES

The prefix *radio-* means "radiation" or "radiant energy." In radiometric dating, scientists measure the amount of radiation given off by a sample.

BUILD Connections

GEOLOGIC TIME AS A CLOCK

Earth's history stretches back for billions of years. To help picture such deep time, look at this 24-hour clock. It shows the history of Earth as if it were a single 24-hour day. Notice that Precambrian Time takes up almost 22 hours on the clock.



- Precambrian 00:00–9:07 P.M.
- Paleozoic Era 9:07–10:40 P.M.
- Mesozoic Era 10:40–11:39 P.M.
- Cenozoic Era 11:39–00:00 P.M.

Divisions of the Geologic Time Scale Divisions of geologic time have different lengths. For example, the Cambrian Period lasted 54 million years. The Cretaceous Period lasted 80 million years. Eons are the largest divisions of time. Eons are divided into **eras.** Eras are further divided into **periods.** Periods range in length from hundreds of millions of years to just 2 million years.

Life on a Changing Planet

In our planet's long history, its physical environment has undergone many changes. These changes have greatly affected life on Earth.

The Physical Environment Some of the factors that have changed the physical environment are plate tectonics, changing climates, and collisions with objects from space.

▶ ***Geological Forces*** Geologic forces can form mountain ranges and move continents. The theory of **plate tectonics** states that Earth's surface is divided into huge plates. These plates move very slowly. Over long periods of time, their movement has pushed continents together, then pulled them apart again. The movement of the plates causes earthquakes and volcanoes.

The movement of the continents has affected the distribution of organisms. For example, Africa and South America are now separated by the Atlantic Ocean. But fossils of a reptile called *Mesosaurus* have been found on both Africa and South America. These fossils are evidence that these two continents were once joined together.

BUILD Vocabulary

era a major division of geologic time; usually divided into two or more periods

period a division of geologic time into which eras are subdivided

plate tectonics the theory that explains the slow movement of solid continental plates over Earth's mantle

WORD ORIGINS

The word *tectonics* from the Greek *tekton*, which means "builder." Plate tectonics is the theory that explains the movement of continents, formation of volcanoes, and mountain building.

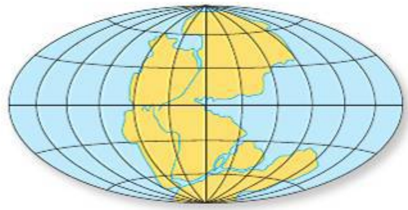
▶ *Changing Climate* Earth's climate has changed greatly over the history of life. Many of these changes were caused by small shifts in temperature. For example, during the great ice ages, temperatures were only about 5°C cooler than they are now. These small changes had a big effect on living things.

▶ *Comets and Asteroids* Evidence shows that large objects from space have crashed into Earth several times. These collisions threw large amounts of dust into the air. This dust would have blocked enough sunlight to cause global cooling and other kinds of climate change. Such events could have caused organisms around the world to go extinct.

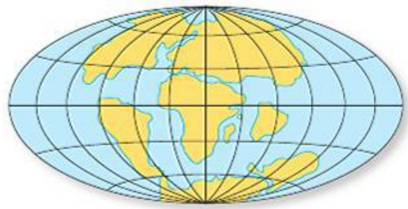
Biological Forces Living organisms also play a major role in shaping the environment. Earth's early oceans held very little oxygen. The first photosynthetic organisms began using carbon dioxide and giving off oxygen. Since then, our planet has never been the same! As levels of carbon dioxide dropped, the climate cooled.

Even today, organisms shape the landscape as they build soil from rock and sand. Plants, animals, fungi, and microorganisms are part of the cycles of carbon, nitrogen, and oxygen. Earth is indeed a living planet!

Key Question How have our planet's environment and living things interacted to shape the history of life on Earth? **Geological forces, changing climates, and collisions with comets and asteroids have changed the habitats of living organisms. The actions of living organisms have also changed conditions in the land, water, and atmosphere of Earth.**



End of Permian Period At the end of the Permian Period, Earth's continents collided to form one giant landmass called Pangaea.



End of Cretaceous Period By the end of the Cretaceous Period, the continents as we know them began to drift apart.

Present Day

The Changing Face of Earth Over the last 225 million years, the movement of the continents has changed Earth dramatically.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. In ________, rock layers and their fossils are placed in order according to time.

2. Fossils that are used to determine the relative ages of rock layers are called ________.

3. The ________ of a radioactive element is the amount of time it takes for one half of the atoms in a sample to decay.

Critical Thinking

4. Explain What can a paleontologist learn from fossils?

5. Review What are the two ways in which geologists determine the age of fossils?

6. Explain How are eras and periods related?

7. Relate Cause and Effect Describe two ways that plate tectonics has affected life on Earth.

8. Write to Learn Answer the first clue in the mystery.

MYSTERY CLUE

Paleontologists discovered dramatic changes in the fossil record at the end of the Permian Period. What methods do you think they used to date that change at 251 million years ago? (Hint: See p. 452.)

BIOLOGY.com Search Lesson 19.1 GO • Lesson Assessment

19.2 Patterns and Processes of Evolution

Key Questions

- ***What processes influence whether species and clades survive or become extinct?***
- ***How fast does evolution take place?***
- ***What are two patterns of macroevolution?***
- ***What is coevolution?***

BUILD Understanding

Concept Map Make a concept map that includes the patterns of macroevolution shown in this lesson.

In Your Workbook Go to your workbook to learn more about making concept maps. Complete the concept map for Lesson 19.2.

Speciation and Extinction

The fossil record shows a parade of organisms that evolved, survived for a time, and then disappeared. More than 99 percent of all the species that ever lived are now extinct. How have so many different groups evolved? Why are so many extinct?

The study of Earth's history leaves no doubt that life has changed over time. Many changes took place within species. Others took place in larger groups and over longer periods of time. Major changes in structure, behavior, and ecology are **macroevolutionary patterns.** The ways that new species form and others become extinct are marcroevolutionary patterns. The extinction of the dinosaurs is a macroevolutionary pattern. So is the increase in the number of flowering plants.

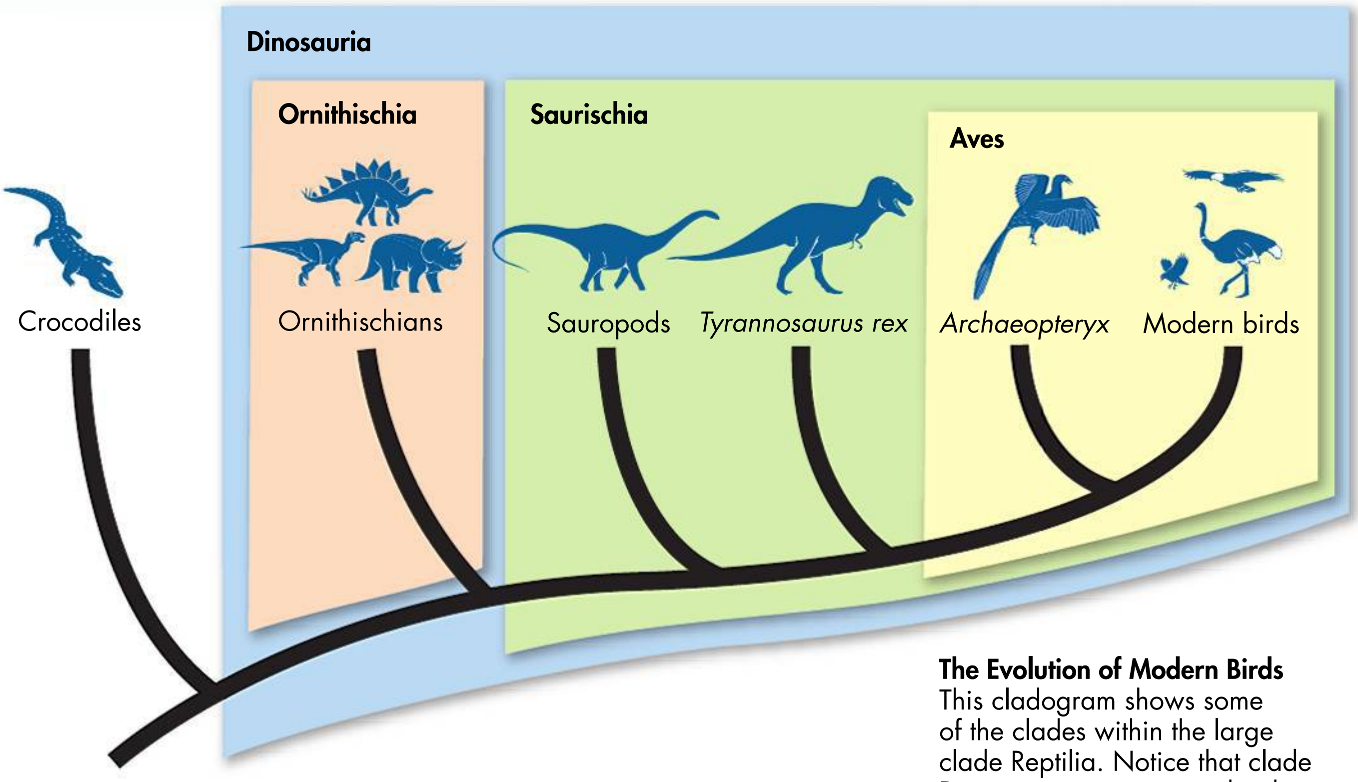
Macroevolution and Cladistics Paleontologists study fossils to learn about the history of life. Part of their work is classifying fossils. As with living species, cladistics is used to classify fossil species. Paleontologists use shared derived characteristics to place fossils in clades. Paleontologists put some fossils into clades that contain only extinct organisms. They classify others in clades with organisms that are alive today.

Cladograms often show that a fossil species is related to a living species. Usually this does not mean that the fossil was the direct ancestor of the living species. For example, the cladogram on the facing page shows many dinosaurs that descended from a line of common ancestors. These dinosaurs were not the direct ancestors of modern birds.

Adaptation and Extinction Throughout the history of life, organisms have lived in changing environments. When conditions change, the process of evolution allows some species to adapt. These species thrive in the new environment. Other species do not adapt. Eventually, those species become extinct.

The rate of speciation and extinction varies from clade to clade. Some clades contain many species that have survived for long periods of time. Other clades have only a few species, which soon become extinct.

Why are some clades more successful than others? Part of the answer to this question is species diversity. Variation among species in a clade is like the variation among individuals in a species. Both are "raw material" for evolution.



The Evolution of Modern Birds
This cladogram shows some of the clades within the large clade Reptilia. Notice that clade Dinosauria is represented today by modern birds.

Genetic variation increases the chance that a species will survive in a changing environment. In the same way, the diversity of species in a clade increases the chance that a clade will survive. If new species evolve more quickly than species become extinct, a clade will survive. If extinctions happen faster than speciation, a clade will die out.

Clade Reptilia is a highly successful clade. It includes living organisms such as snakes, lizards, and turtles. It also includes dinosaurs, which lived for tens of millions of years. Most species in clade Dinosauria are now extinct. But clade Dinosauria also included some species that adapted to new conditions. Descendents of those species are still alive today. We call them birds.

Patterns of Extinction Some species become extinct because of the slow and steady process of natural selection. This "everyday" extinction is called **background extinction.** Other species go extinct in a relatively short period. This process is called **mass extinction.** In a mass extinction, entire ecosystems vanish. Some mass extinctions may have been caused by a single event, such as the large asteroid that hit Earth at the end of the Cretaceous period. Other mass extinctions were probably due to several causes working together, such as volcanic eruptions, changing climates, and changing sea levels.

Key Question What processes influence whether species and clades survive or become extinct? **If the rate of speciation in a clade is equal to or greater than the rate of extinction, the clade will survive. If the rate of extinction is greater than the rate of speciation, the clade will become extinct.**

BUILD Vocabulary

macroevolutionary patterns the changes in anatomy, phylogeny, behavior, and ecology, which take place in clades that are larger than a single species

background extinction extinction caused by the slow and steady process of natural selection

mass extinction an event during which many species become extinct during a relatively short time

PREFIXES

The prefix *macro-* comes from the Greek *makro-*, meaning "large." Macroevolutionary patterns are large patterns of evolution.

Rate of Evolution

How long does it take for a species to evolve? Do all species evolve at the same speed? Evidence shows that evolution does not always move at the same speed. Two models for describing the rate of evolution are gradualism and punctuated equilibrium.

Gradualism Darwin was impressed by the slow, steady pace of geologic change. He thought that evolution was also slow and steady. This idea is known as **gradualism.** The fossil record shows that many organisms have changed gradually over time.

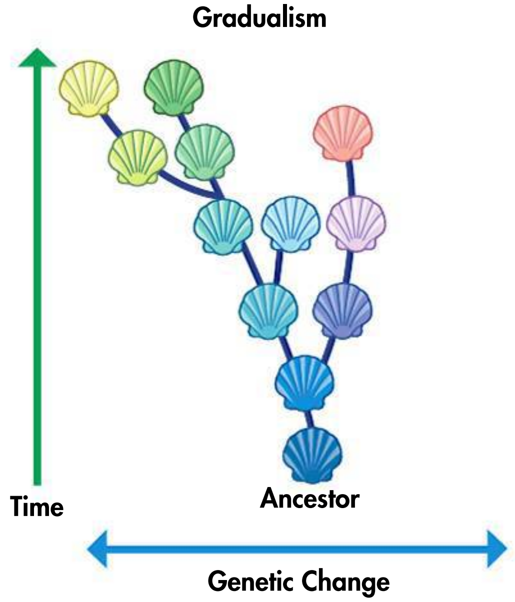
Punctuated Equilibrium The fossil record also shows that evolution has not always been slow and steady. Some species do not seem to evolve at all. For example, fossils of horseshoe crabs show that their major body structures have changed very little over millions of years. Such species are said to be in *equilibrium*. They may be evolving genetically, but their structures do not change much.

Fossils of other organisms show periods of stability and rapid change. Equilibrium that is interrupted by periods of rapid change is **punctuated equilibrium.** Some biologists suggest that most new species are produced during these periods of rapid change. (But remember that evolution takes place according to the geologic time scale. To a geologist, "rapid change" may mean thousands of years!)

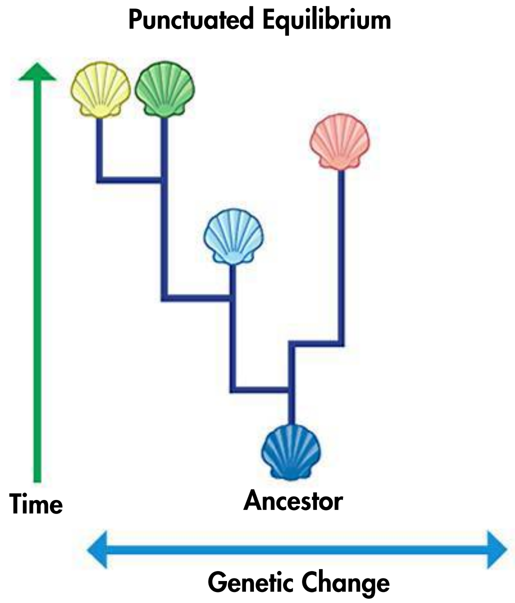
Rapid Change After Equilibrium Small, isolated populations can evolve rapidly. This rapid evolution is possible because genetic changes spread more quickly among fewer individuals. Rapid evolution may also happen when a small group moves to a new environment. That is what happened with the Galápagos finches.

Mass extinctions can lead to rapid evolution. After a mass extinction, there are fewer competing species. As a result, more "jobs" are available for new species. The fossil record shows that after a mass extinction, the groups that survive evolve rapidly. Biodiversity is eventually restored.

Key Question How fast does evolution take place? **Evidence shows that evolution has moved at different rates for different organisms at different times over the long history of life on Earth.**



Gradualism involves a slow, steady change in a particular line of descent.



Punctuated equilibrium involves stable periods interrupted by rapid changes involving many different lines of descent.

Models of Evolution Biologists have two different ways of looking at and thinking about the rate of evolution: gradualism and punctuated equilibrium. These simplified drawings compare the two patterns.

Adaptive Radiation and Convergent Evolution

Two important patterns of macroevolution are adaptive radiation and convergent evolution. Darwin noticed both of these patterns as he traveled on the *Beagle*.

Adaptive Radiation Fossils show that a single species can evolve into a clade with many species. All of these species have variations on the original ancestor's body plan. The new species may fill different ecological niches. **Adaptive radiation** is the process by which a single species or small group of species evolves into several different forms that live in different ways. Sometimes, this process can happen relatively quickly. Adaptive radiation can happen when species move to a new environment or after a mass extinction. It can also happen when a new adaptation lets a species live in an environment that had not been used before.

▶ ***Adaptive Radiations in the Fossil Record*** Dinosaurs lived for about 150 million years during the Mesozoic. They arose from several adaptive radiations of reptiles. Fossils show that when dinosaurs were at their greatest diversity, mammals were small and not very diverse. After most of the dinosaurs became extinct, an adaptive radiation of mammals began. That radiation led to the great diversity of mammals of the Cenozoic Era.

▶ ***Modern Adaptive Radiation*** Two examples of adaptive radiation are the Galápagos finches and Hawaiian honeycreepers. Their stories are similar: A single species evolved into many different species. Both finches and honeycreepers evolved different beaks and behaviors that let them eat different kinds of food.

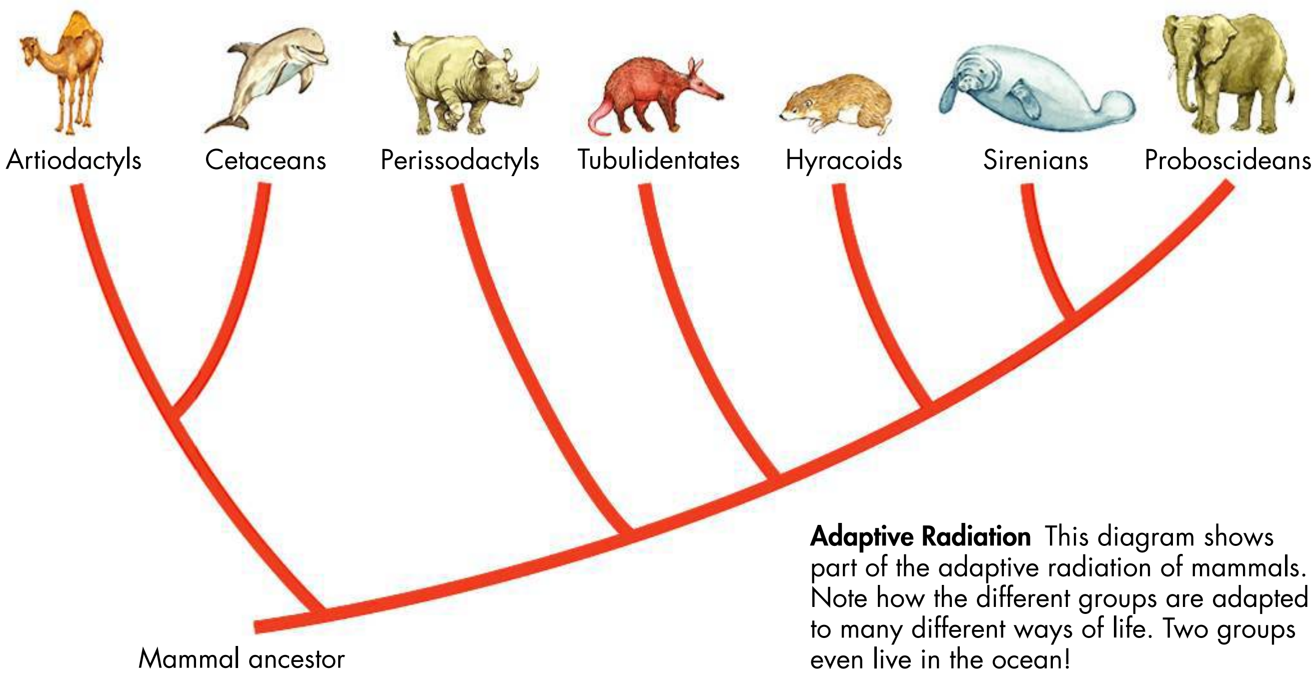
BUILD Vocabulary

gradualism
the evolution of a species by the gradual addition of small genetic changes over long periods of time

punctuated equilibrium
the pattern of evolution in which long stable periods are interrupted by brief periods of more rapid change

adaptive radiation
the process by which a single species or a small group of species evolves into several different forms that live in different ways

WORD ORIGINS
The word *radiation* means "to spread out in all directions." It comes from the Greek *radi-*, which means "ray," as in a ray of the sun. In adaptive radiation, species evolve in many directions.



Adaptive Radiation This diagram shows part of the adaptive radiation of mammals. Note how the different groups are adapted to many different ways of life. Two groups even live in the ocean!

Convergent Evolution Mammals that feed on ants and termites are found in five different parts of the world. These species are unrelated. But they all have powerful front claws, a long hairless snout, and a tongue covered with sticky saliva. These adaptations are very useful for hunting and eating insects.

Convergent Evolution Sometimes, organisms in different places evolve in similar environments. These organisms start out with different structures. But they face similar selection pressures. In such cases, natural selection may cause different body structures to evolve in ways that let them carry out similar functions. Over time, the different organisms become more and more alike. This process is called convergent evolution. In **convergent evolution,** natural selection forms similar structures and characteristics in organisms that are not closely related.

During the voyage of the *Beagle*, Darwin noticed similarities among large grassland birds on different continents. Although they look alike, emus, rheas, and ostriches are not closely related. All three of these birds have long, strong legs let them run swiftly through tall grasses. These three flightless birds are an example of convergent evolution.

The different kinds of anteaters also show convergent evolution. Most continents have mammals that specialize in eating ants and termites. South America has giant anteaters, North America has armadillos, and Africa has aardvarks. All of these animals have long tongues. They also have strong front legs with claws that can pull apart termite mounds and ant nests. The similar adaptations of these distantly related animals let them eat the same kinds of food.

Key Question What are two forms of macroevolution?
Two important patterns of macroevolution are adaptive radiation and convergent evolution.

BUILD Vocabulary

convergent evolution the process by which unrelated organisms independently evolve similarities when adapting to similar environments

coevolution the process by which two species evolve in response to changes in each other over time

ACADEMIC WORDS

The word *convergent* is the adjective form of the verb *converge*, which means "to come together from different directions."

Coevolution

Sometimes the lives of two species are so closely connected that they evolve together. For example, many flowering plants can reproduce only if they are pollinated by a certain species of insect. The insect, in turn, depends on the nectar or pollen from those flowers for food. The process by which two species evolve in response to changes in each other is called **coevolution.**

Flowers and Pollinators Coevolution of flowers and pollinators is common and can lead to unusual results. For example, Darwin discovered a flower with a long structure called a spur. The spur was 40 centimeters long. At the bottom of the spur was a supply of nectar. Nectar in flowers usually attracts pollinators. But what pollinator could reach down such a long tube? Darwin predicted that the plant must be pollinated by an insect with mouth parts that could reach to the bottom of the spur. About 40 years later, scientists discovered a moth with a 40-centimeter-long feeding tube. This moth matched Darwin's prediction!

Plants and Herbivorous Insects Coevolution also takes place between plants and the insects that eat them. Insects have been eating flowering plants ever since both groups evolved. In some cases, plants have evolved poisons to protect themselves from being eaten. But insects have evolved in response to the poisons. Natural selection has favored any individuals that are resistant to the poisons.

Milkweed plants are poisonous to many insects. But the caterpillars of monarch butterflies are able to eat their leaves. In fact, the monarch caterpillars store the milkweed poisons in their bodies. The poisons help protect the monarchs from predators!

Key Question What is coevolution? **The relationship between two organisms may become so specific that neither organism can survive without the other. Thus, an evolutionary change in one organism is usually followed by a change in the other organism.**

Coevolution Milkweed plants produce poisons that protect them from being eaten. But monarch butterflies have coevolved with the milkweed plants. Their caterpillars can eat milkweed leaves without harm. In fact, monarchs store the milkweed poisons in their own bodies. This poison protects the monarchs against *their* predators!

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. An event during which many species become extinct over a short period of time is a ______.

2. The slow, steady "everyday" rate of extinction that has happened throughout the history of life is called ______.

3. The process by which two species evolve in response to changes in each other over time is called ______.

Critical Thinking

4. **Review** How does variation within a clade affect the clade's chance of surviving environmental change?

5. **Compare and Contrast** Explain how punctuated equilibrium is different from gradualism.

6. **Review** What is adaptive radiation?

7. **Apply Concepts** Describe an example of coevolution.

8. **Write to Learn** Answer the second clue of the mystery. Use the words *cellular respiration* in your answer.

MYSTERY CLUE

Evidence indicates that before the Permian extinction, the oceans lost most of their oxygen. What effect do you think the loss of oxygen had on most organisms? (Hint: See p. 457.)

19.3 Earth's Early History

Key Questions

What do scientists hypothesize about early Earth and the origin of life?

What do scientists hypothesize about the origins of DNA and RNA?

What theory explains the origin of eukaryotic cells?

What is the evolutionary significance of sexual reproduction?

BUILD Understanding

Flowchart Construct a flowchart that shows what scientists hypothesize about early Earth. Show the major steps from the origin of Earth to the appearance of eukaryotic cells.

In Your Workbook Go to your workbook to learn about making a flowchart. Complete the flowchart for lesson 19.3.

Early Earth Violent volcanic eruptions helped shape Earth's early history.

The Mysteries of Life's Origins

How did life on Earth begin? What were the earliest forms of life? Scientists are working hard to answer these questions. As new evidence comes to light, hypotheses about early life are likely to change.

Evidence suggests that Earth formed from pieces of rock and dust. One or more huge objects crashed into the young Earth, causing it to melt. For millions of years, volcanoes erupted. Comets and asteroids crashed into the surface. About 4.2 billion years ago, Earth cooled enough for solid rocks to form. Rain fell, and oceans formed.

The Early Atmosphere The early atmosphere held little or no oxygen. It was mostly carbon dioxide, water vapor, and nitrogen. It also had smaller amounts of carbon monoxide, hydrogen sulfide, and hydrogen cyanide. A few deep breaths would have killed you! These gases probably made the sky orange. Dissolved iron probably made the oceans brown. This was the Earth on which life began.

Key Question What do scientists hypothesize about early Earth? **Earth's early atmosphere was mainly carbon dioxide, water vapor, and nitrogen, with lesser amounts of carbon monoxide, hydrogen sulfide, and hydrogen cyanide. It contained little or no oxygen.**

The First Organic Molecules Could organic molecules have formed on early Earth? In 1953, Stanley Miller and Harold Urey did an experiment to answer that question. They built a system of tubes and containers filled with water vapor, methane, ammonia, and hydrogen. They thought that this mixture of gases was like that of Earth's early atmosphere. To represent lightning, they hit the gases with sparks of electricity. After a week, they had made 12 amino acids. Amino acids are the building blocks of proteins!

We now know that Miller and Urey were wrong about the mixture of gases in the early atmosphere. But new experiments based on more current ideas have also made organic compounds. In 1995, Miller repeated the experiment with a more accurate mix of gases. This time, he made cytosine and uracil, two bases found in RNA.

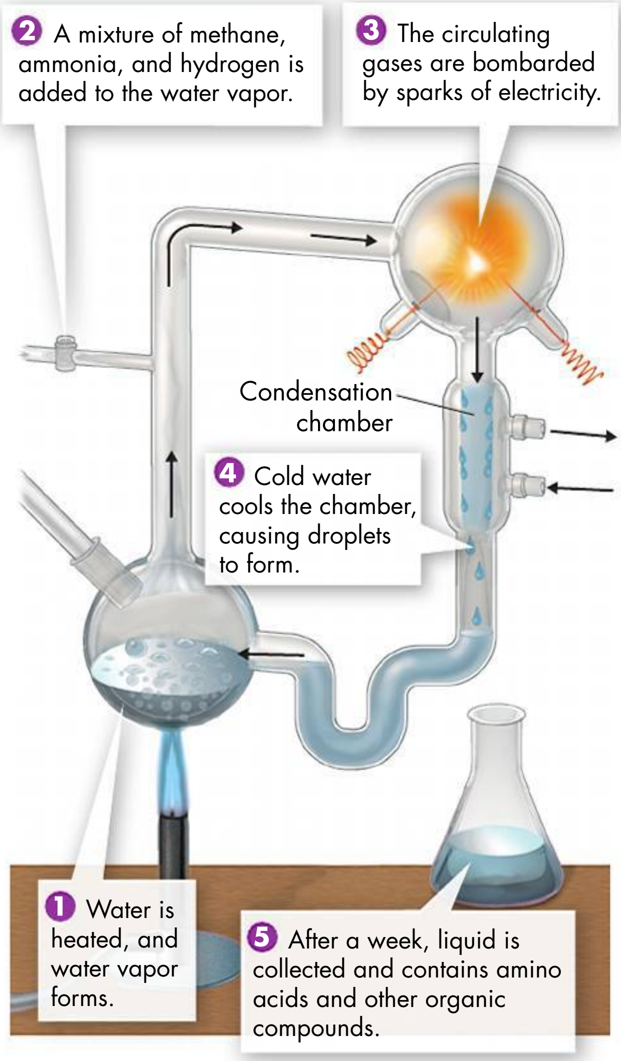
Key Question What do scientists hypothesize about the origin of life? **Miller and Urey's experiment suggested how mixtures of the organic compounds necessary for life could have arisen from simpler compounds in the atmosphere of early Earth.**

Formation of Microspheres The compounds made by the Miller-Urey experiments are a long way from living cells. How could living cells develop from this "stew" of organic compounds? The leap from nonlife to life is the greatest gap in scientific hypotheses about the history of life.

Large organic compounds sometimes form tiny bubbles called *microspheres*. Microspheres might have played a role in the evolution of cells. Like cells, they have selectively permeable membranes that allow water to pass through. Microspheres also have a simple means of storing and releasing energy. Several hypotheses suggest that microspheres may have developed the characteristics of living cells as early as 3.8 billion years ago.

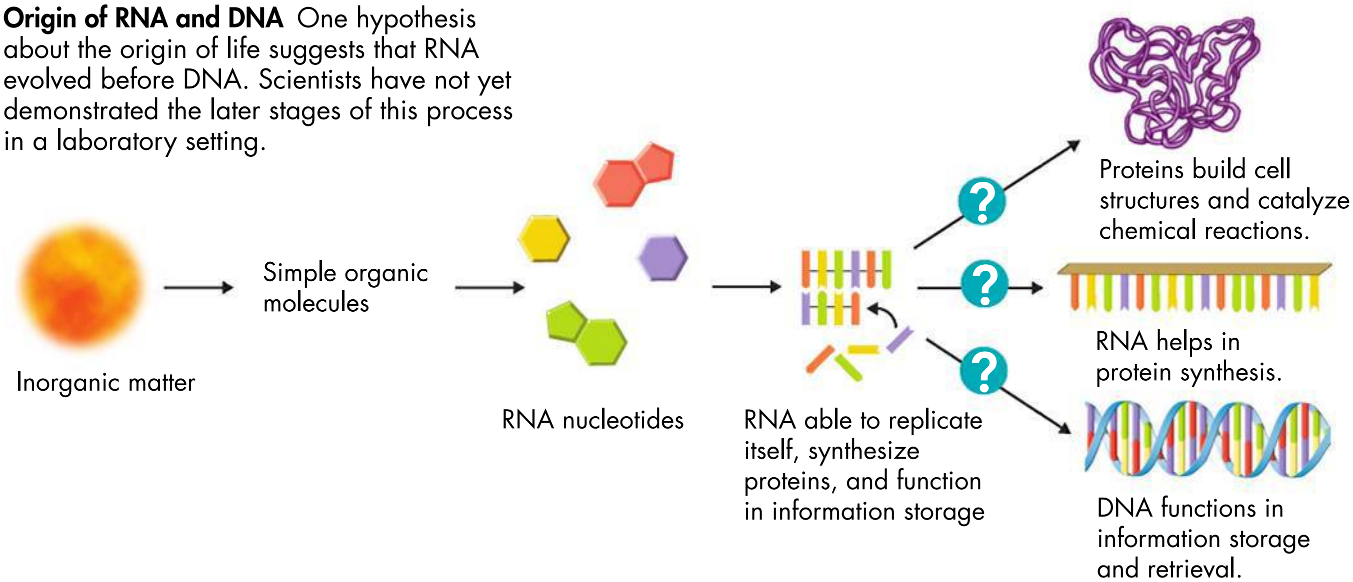
Evolution of RNA and DNA Another unanswered question is the origin of RNA and DNA. Remember that cells are controlled by information stored in DNA. The information on DNA is transcribed onto RNA, which is used to form proteins. How could such a complex system evolve? The key to the answer may be RNA. Modern RNA is involved in many of life's reactions. The "RNA world" hypothesis suggests that RNA existed before DNA. The RNA-based system could then have evolved into the more complex DNA-based system.

Key Question What do scientists hypothesize about the origins of DNA and RNA?
The "RNA world" hypothesis proposes that RNA existed by itself before DNA. From this simple RNA-based system, several steps could have led to DNA-directed protein synthesis.



Miller-Urey Experiment Miller and Urey modeled conditions on ancient Earth. They produced amino acids by passing sparks through a mixture of gases.

Origin of RNA and DNA One hypothesis about the origin of life suggests that RNA evolved before DNA. Scientists have not yet demonstrated the later stages of this process in a laboratory setting.



BUILD Vocabulary

endosymbiotic theory
the theory that proposes that eukaryotic cells formed from a symbiotic relationship among several different prokaryotic cells

PREFIXES

The prefix *endo-* in *endosymbiotic theory* means "within." The endosymbiotic theory involves a symbiotic relationship between eukaryotic cells and the bacteria within them.

Production of Free Oxygen The oldest fossils are found in rocks that are more than 3.5 billion years old. These prokaryotic cells evolved without oxygen. (Remember that the early atmosphere had very little oxygen.) Later, photosynthetic bacteria became common. By 2.2 billion years ago, photosynthetic cells were giving off great amounts of oxygen. This oxygen changed the atmosphere. In a few hundred million years, the amount of oxygen reached today's levels. For early life, this new gas was a deadly poison! It caused many early life forms to die out. Other organisms evolved ways to protect themselves from oxygen. Many organisms evolved the ability to use oxygen for respiration.

Origin of Eukaryotic Cells

One of the most important events in the history of life was the evolution of eukaryotic cells. How did these complex cells evolve from their prokaryotic ancestors?

Endosymbiotic Theory About 2.2 billion years ago, some kinds of prokaryotes began to evolve features found in eukaryotes. According to the **endosymbiotic theory,** prokaryotes became part of those early eukaryotes. At first, prokaryotic "guests" lived inside the eukaryotes. Over time, the "guests" became a part of their hosts. The "guests" became the mitochondria and chloroplasts of modern eukaryotic cells. Mitochondria evolved from bacteria that helped their hosts use oxygen. Chloroplasts evolved from photosynthetic bacteria that made food for their host cells.

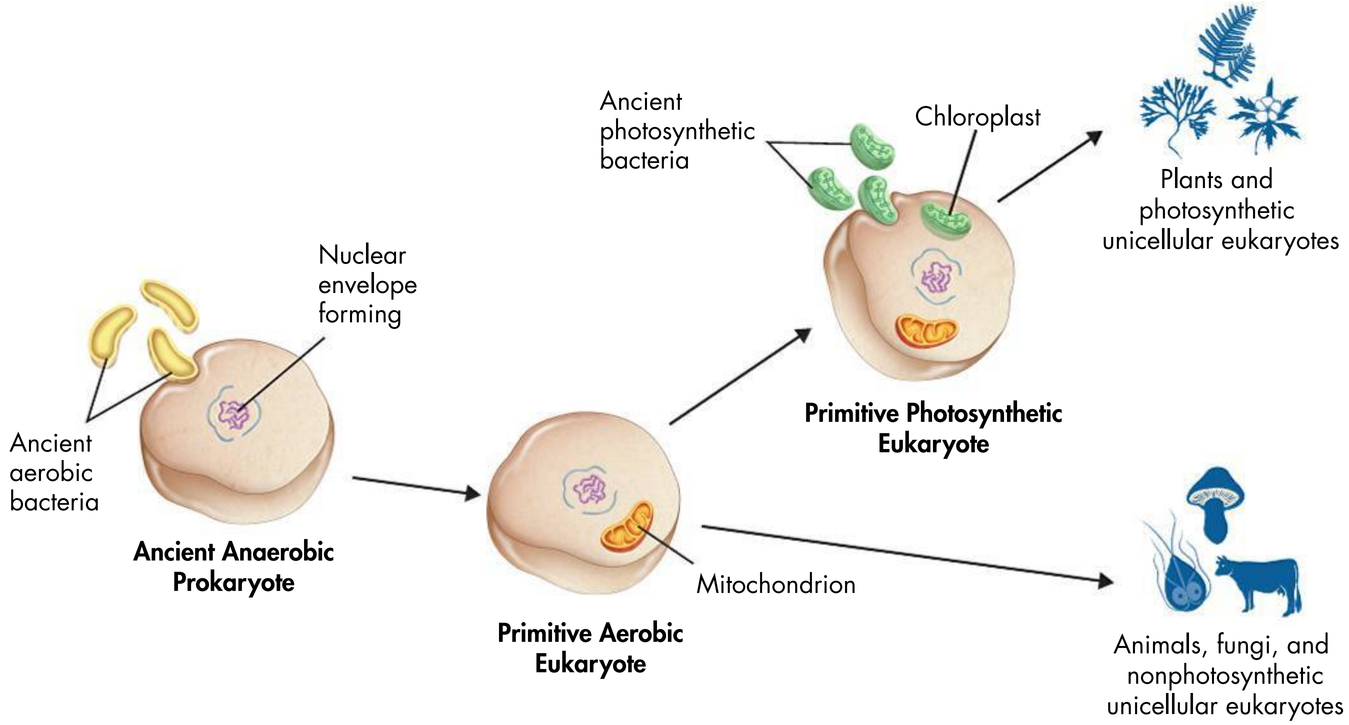
Modern Evidence In 1963, the American biologist Lynn Margulis found that the DNA of chloroplasts and mitochondria was like the DNA of bacteria. She also noted that the ribosomes of these organelles are very similar to those of bacteria. Finally, these organelles divide by fission, just like bacteria. The similarities between mitochondria, chloroplasts, and bacteria provide strong support for the endosymbiotic theory.

Key Question What theory explains the origin of eukaryotic cells? **The endosymbiotic theory proposes that a symbiotic relationship evolved over time between early eukaryotic cells and prokaryotic cells that lived inside them.**

Sexual Reproduction and Multicellularity

Sometime after eukaryotic cells first evolved, they began to reproduce sexually. This ability helped to increase the pace of evolution.

Sexual Reproduction Prokaryotes reproduce asexually. They copy their genes before dividing by fission into two daughter cells. The daughter cells have exactly the same genes as the parent cell. Genetic variation is possible only because of mutations in DNA.



Endosymbiotic Theory
The endosymbiotic theory states that eukaryotic cells evolved from a relationship formed with bacteria. Ancient bacteria may have entered primitive eukaryotic cells and remained there as organelles.

When eukaryotes reproduce sexually, the offspring receive genes from two parents. Meiosis and fertilization increase genetic variation through new gene combinations. Genetic variation is the raw material for natural selection. More variation means a population can evolve more quickly. Genetic variation helps populations adapt to new conditions.

Multicellularity Multicellular organisms evolved a few hundred million years after the evolution of sexual reproduction. Early multicellular organisms underwent a series of adaptive radiations. The result was a great diversity of organisms.

Key Question What is the evolutionary significance of sexual reproduction? **The development of sexual reproduction sped up evolutionary change because it increased genetic variation.**

CHECK Understanding

Apply Vocabulary

Use the highlighted word from the lesson to complete the sentence correctly.

1. The _______ states that mitochondria and chloroplasts evolved from symbiotic bacteria living inside eukaryotes.

Critical Thinking

2. Apply Concepts What evidence supports the endosymbiotic theory?

3. Review Describe Earth's early atmosphere.

4. Relate Cause and Effect Why is the development of sexual reproduction so important in the history of life?

5. Sequence Put the following events in the order in which they occurred: *sexual reproduction, development of eukaryotic cells, free oxygen in atmosphere,* and *development of photosynthesis.*

6. Write to Learn Write a paragraph that describes the experiment conducted by Miller and Urey. What was their hypothesis? What was their procedure? What conclusion could they draw from their results?

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PHANEROZOIC EON

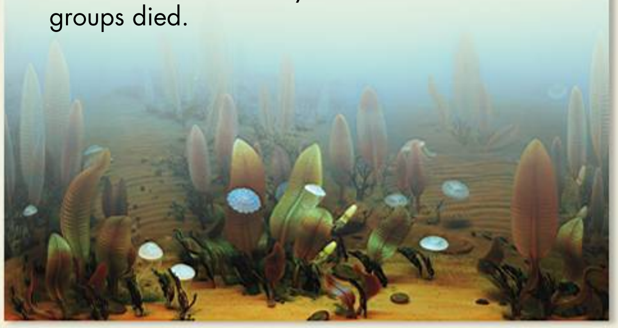
PALEOZOIC ERA

Cambrian Period | Ordovician Period | Silurian Period

Cambrian Period

▲ Elrathia

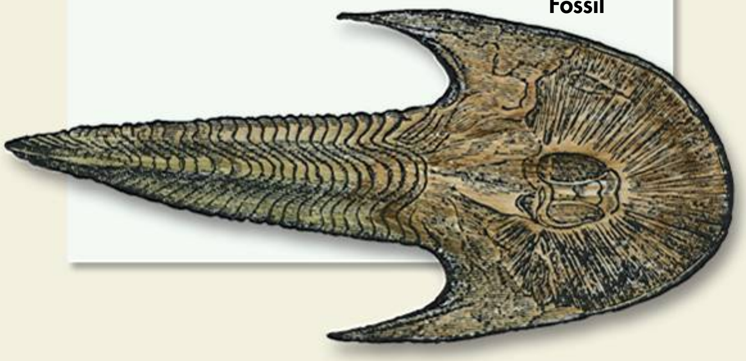
During the Cambrian Period, multicellular life had its greatest adaptive radiation. This adaptive radiation is called the Cambrian Explosion. Continents moved in ways that created shallow seas over much of Earth. Many organisms in the seas evolved hard shells and outer skeletons. The first jawless fishes appeared. The Cambrian ended with a mass extinction. Nearly one third of all animal groups died.



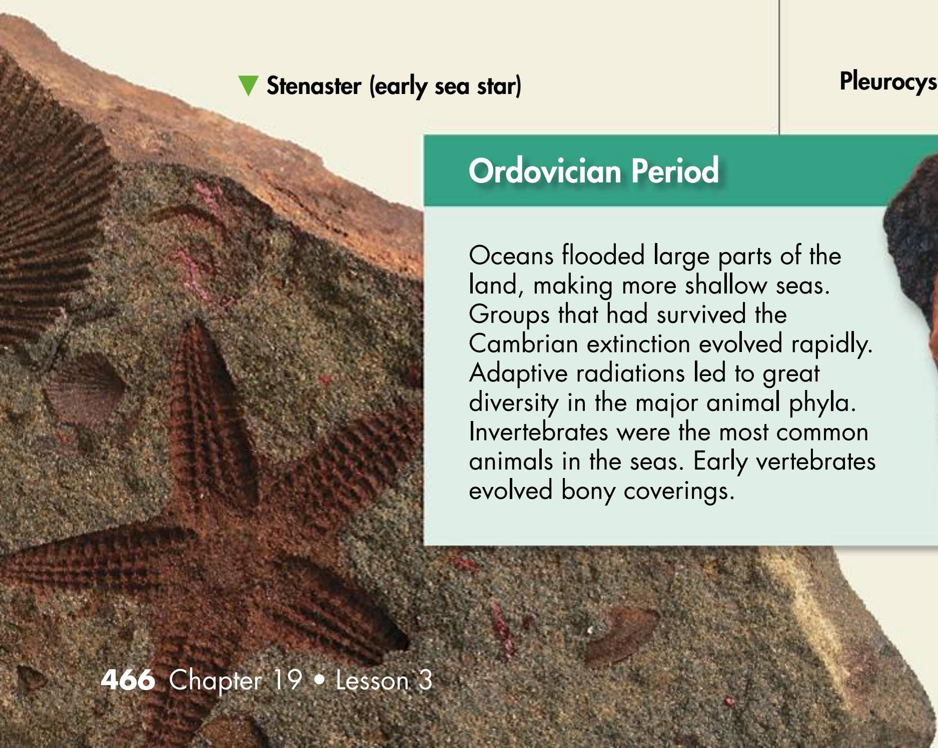
Silurian Period

▲ Sea Lily Fossil

During the Silurian Period, land areas rose, draining the shallow seas. Moist tropical habitats formed. Many different jawless fishes evolved. The first fishes with true jaws appeared. The first multicellular land plants evolved from green algae. Arthropods become the first animals to live on land.



▲ Cephalaspis (raylike jawless fish)



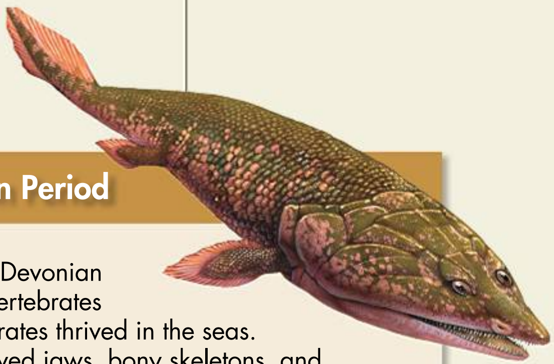
▼ Stenaster (early sea star)

Pleurocystes (early echinoderms) ▼

Ordovician Period

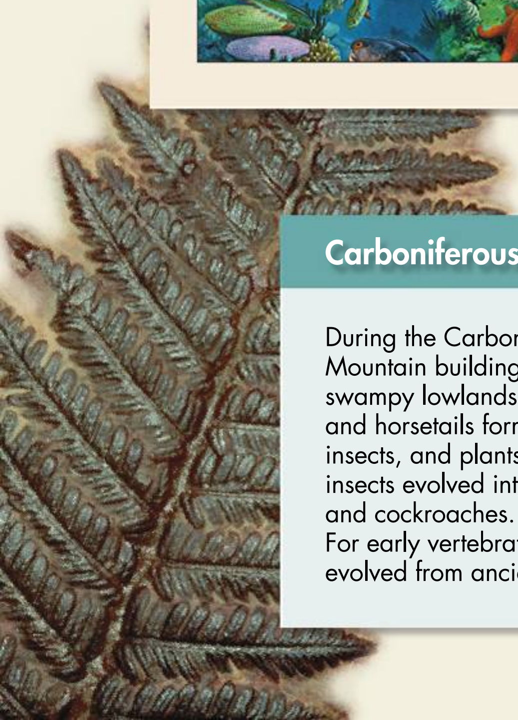
Oceans flooded large parts of the land, making more shallow seas. Groups that had survived the Cambrian extinction evolved rapidly. Adaptive radiations led to great diversity in the major animal phyla. Invertebrates were the most common animals in the seas. Early vertebrates evolved bony coverings.

Devonian Period | Carboniferous Period | Permian Period



Devonian Period

During the Devonian Period, invertebrates and vertebrates thrived in the seas. Fishes evolved jaws, bony skeletons, and scales. Sharks began their adaptive radiation. Certain groups of fishes evolved leglike fins; some of these evolved into the first amphibians. Some land plants, such as ferns, adapted to drier areas. Insects began their adaptive radiation on land.



◀ **Fossil Fern From Carboniferous Period**

Permian Period

▲ **Crinoid**

During the Permian Period, the diversity of invertebrates, vertebrates, and plants on land increased. Reptiles experienced their first adaptive radiation. This produced the ancestors of modern reptiles, dinosaurs, and mammals. The Permian Period ended with the biggest mass extinction of all time. More than 50 percent of animal families on land disappeared. More than 95 percent of species in the oceans became extinct.

Early Amphibian ▼

Carboniferous Period

During the Carboniferous Period, mountains pushed upward. Mountain building formed a wide range of habitats, from swampy lowlands to drier uplands. Giant ferns, club mosses, and horsetails formed huge swampy forests. Amphibians, insects, and plants had major adaptive radiations. Winged insects evolved into many forms, including huge dragonflies and cockroaches. For early plants, insects were predators. For early vertebrates, insects were food. The first reptiles evolved from ancient amphibians.

PHANEROZOIC EON

MESOZOIC ERA

Triassic Period | Jurassic Period | Cretaceous Period

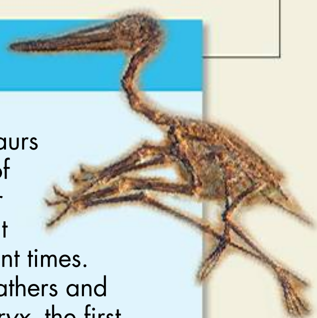
Triassic Period

During the Triassic Period, fishes, insects, reptiles, and cone-bearing plants that survived the Permian extinction evolved rapidly. The first dinosaurs evolved. During the late Triassic, the earliest mammals evolved. These mammals were about the size of a mouse.

▲ Living Horsetail

▲ Horsetail Fossil

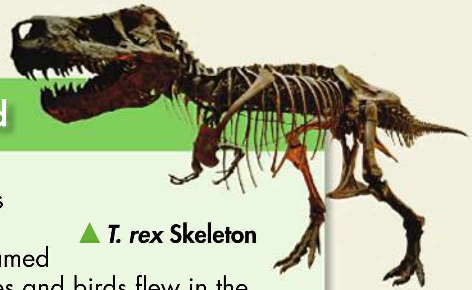
Jurassic Period



◀ Pterodactyl Fossil

During the Jurassic Period, dinosaurs became the most diverse group of animals on land. They "ruled" for about 150 million years. Different types of dinosaurs lived at different times. One line of dinosaurs evolved feathers and led to modern birds. *Archaeopteryx*, the first feathered fossil to be discovered, evolved during this time.

Cretaceous Period



▲ ***T. rex*** **Skeleton**

During the Cretaceous Period, dinosaurs like *Tyrannosaurus rex* roamed the land. Flying reptiles and birds flew in the sky. Turtles, crocodiles, and other reptiles swam with fishes and invertebrates in the seas. Leafy trees, shrubs, and flowering plants evolved and experienced adaptive radiations. The Cretaceous ended with another mass extinction. More than half of all plant and animal groups were wiped out. All dinosaurs except the ancestors of modern birds became extinct.

▼ ***Maiasaura*** **Nest**

CENOZOIC ERA

Paleogene Period | Neogene Period | Quaternary Period

Paleogene Period

During the Paleogene Period, climates changed from warm and moist to cool and dry. Flowering plants, grasses, and insects thrived. In drier areas, open woods and grasslands replaced forests. After the extinction of the dinosaurs, mammals underwent a major adaptive radiation. Ancestors of cattle, deer, and sheep evolved and spread across the grasslands. In the oceans, the first whales evolved.

▲ Early Mammal

Neogene Period

During the Neogene Period, crashing continents pushed up modern mountain ranges. In North America, the Rockies, Cascades, and Sierra Nevada formed. Ice and snow built up at higher elevations and in the Arctic. Falling sea levels and moving continents created connections between North and South America, and between Africa, Europe, and Asia. These connections allowed land animals to move between continents. As climates became cooler and drier, grasslands increased. Grazing animals evolved digestive systems that allowed them to digest the grasses.

◀ Neanderthal Skull

Quaternary Period

During the Quaternary Period, Earth cooled. In a series of ice ages, glaciers moved over parts of Europe and North America. So much water was frozen in glaciers that sea levels fell by more than 100 meters. Then, about 20,000 years ago, the climate began to warm. Glaciers slowly melted, and sea levels rose. In the oceans, algae, coral, mollusks, fishes, and mammals thrived. Insects and birds shared the skies. On land, mammals, including bats, cats, dogs, cattle, and mammoths, became common. Between 6 and 7 million years ago, one group of mammals began an adaptive radiation that led to the ancestors and relatives of modern humans.

▲ Cave Painting

Forensics Lab

GUIDED INQUIRY

Pre-Lab: Using Index Fossils

Problem How can fossils be used to determine the relative ages of rock layers?

Materials scissors

Lab Manual Chapter 19 Lab

Skills Focus Interpret Visuals, Sequence, Draw Conclusions

Connect to the Big idea When detectives work on a case, they may look for items with a time stamp, such as parking tickets and credit card slips. Such items can help detectives piece together a sequence of events. Events related to a crime usually occur within a relatively short period of time. In contrast, the events that paleontologists study will have occurred over millions of years. Placing these events in their proper order can be challenging. The clues that a paleontologist uses to sequence events in the history of life are fossils buried in rock layers. In this lab, you will use fossils to place rock layers in order from oldest to youngest.

Background Questions

a. **Review** What is a fossil? What are the characteristics of a good index fossil?

b. **Explain** What characteristic of radioactive decay allows scientists to assign specific ages to rock layers?

c. **Classify** How do fossils help geologists decide where one division of geologic time should end and another division begin?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Organize Data** After you cut out the drawings of the rock layers, how will you begin the process of sorting the layers by age?

2. **Infer** *Desmatosuchus* was a crocodile relative that lived only during the Triassic Period. Horsetails are plants that first appeared in the Triassic Period and still exist. Which of these organisms would be more useful as an index fossil for the Triassic Period? Why?

3. **Use Analogies** Luke found a box of photos labeled 1970–1995. Each photo shows his entire extended family. No dates appear on the photos. Luke knows that his grandmother died in 1985 and his uncle was born in 1975. Luke's sister was born in 1990. How can Luke use this information to sort the photos into four batches? How are Luke's relatives similar to index fossils?

BIOLOGY.com Search Chapter 19 GO

Visit Chapter 19 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Go back in time with the Untamed Science crew to find out what fossils reveal.

Art in Motion View a short animation that shows how fossils form.

Art Review Review your understanding of the composition of Earth's early atmosphere as compared with the composition of Earth's current atmosphere.

Visual Analogy Compare geologic time to a 24-hour clock.

19 CHAPTER Summary

19.1 The Fossil Record

- From the fossil record, paleontologists learn about the structure of ancient organisms, their environment, and the way in which they lived.
- Relative dating allows paleontologists to determine whether a fossil is older or younger than other fossils. Radiometric dating uses the proportion of radioactive to nonradioactive isotopes to calculate the absolute age of a sample.
- The geologic time scale is based on both relative and absolute dating. The major divisions of the geologic time scale are eons, eras, and periods.
- Throughout Earth's history, geological forces, changing climates, and collisions with objects from space have changed the habitats of living organisms. Over time, the actions of living organisms have also changed conditions in the land, water, and atmosphere of Earth.

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paleontologist (p. 450)
extinct (p. 450)
relative dating (p. 451)
index fossil (p. 451)
radiometric dating (p. 452)
half-life (p. 452)
geologic time scale (p. 453)
era (p. 454)
period (p. 454)
plate tectonics (p. 454)

19.2 Patterns and Processes of Evolution

- If the rate of speciation in a clade is equal to or greater than the rate of extinction, the clade will survive. If the rate of extinction in a clade is greater than the rate of speciation, the clade will become extinct.
- Evidence shows that evolution has moved at different rates for different organisms at different times over the long history of life on Earth.
- Two important patterns of macroevolution are adaptive radiation and convergent evolution.
- Adaptive radiation is the process by which a single species or a small group of species evolves quickly into several different species that live in different ways.
- Convergent evolution is the process by which unrelated organisms evolve into similar forms.
- The relationship between two organisms that are coevolving often becomes so specific that neither organism can survive without the other. Thus, an evolutionary change in one organism is usually followed by a change in the other organism.

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macroevolutionary patterns (p. 456)
background extinction (p. 457)
mass extinction (p. 457)
gradualism (p. 458)
punctuated equilibrium (p. 458)
adaptive radiation (p. 459)
convergent evolution (p. 460)
coevolution (p. 460)

19.3 Earth's Early History

- Earth's early atmosphere contained little or no oxygen. It was mostly carbon dioxide, water vapor, and nitrogen, with lesser amounts of carbon monoxide, hydrogen sulfide, and hydrogen cyanide.
- Miller and Urey's experiment suggested how mixtures of the organic compounds necessary for life could have arisen from simpler compounds found in the atmosphere of early Earth.
- The "RNA world" hypothesis proposes that RNA existed by itself before DNA. From this simple RNA-based system, several steps could have led to DNA-directed protein synthesis.
- The endosymbiotic theory proposes that a symbiotic relationship evolved over time between early eukaryotic cells and the prokaryotic cells within them.
- The development of sexual reproduction sped up evolutionary change because sexual reproduction increases genetic variation.

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endosymbiotic theory (p. 464)

19 CHECK Understanding

Assess the Big idea Evolution

Write an answer to the question below.

Q: How do fossils help biologists understand the history of life on Earth?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each numbered question should be one or two paragraphs long. To help you begin, read the **Hints** below the questions.

1. **Why doesn't the fossil record always show a progression of changing fossils for the evolution of each species?**

   Hint Fossils can only form under the right conditions.

   Hint Use the terms *equilibrium* and *punctuated equilibrium* in your answer.

2. **What role have mass extinctions played in the history of life?**

   Hint Think of what happened to the mammals after most of the dinosaurs became extinct.

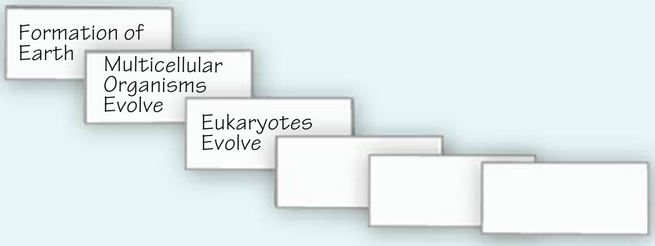
3. **How does the formation of sedimentary rock give paleontologists information about the sequence in which life forms appeared on Earth?**

   Hint To help plan your answer, review the art of index fossils on page 451.

Foundations for Learning Wrap-Up

Use the tabs that you made at the beginning of the chapter as a tool for review.

Activity 1 Lay your folded tabs on your desk, with the titles on top. Mix them so they are out of order. Then arrange them in order like the fossils in layers of rock, with the oldest events on the bottom. Repeat this activity until it becomes easy.



Activity 2 Work with a partner to make a time line out of your tabs. Cut a piece of string so it is 10 meters long. Fasten the string to a sturdy object at eye level. Attach the other end to an object or wall so that the string is level and tight. Hang the "Formation of Earth" tab at one end of the string. Then arrange all the tabs in order according to time.

Next, use the geologic time scale to place each event in the correct place on your string. Each meter of length stands for 400 million years. Each centimeter stands for 4 million years. Use the information from your textbook to help date each event. Your tabs will be very crowded at the end of the string!

19.1 The Fossil Record

Understand Key Concepts

1. Scientists who specialize in the study of fossils are called
   a. biologists.
   b. zoologists.
   c. geologists.
   d. paleontologists.

Test-Taking Tip

Read Answers Carefully! In multiple choice questions, you might be tempted to answer the first response that seems correct. In question 1, you might answer **a** or **c.** But "**d.** paleontologists" is the best choice. Try to think of the answer before you read the choices. Then read each choice.

2. According to the theory of plate tectonics,
   a. Earth's climate has changed many times.
   b. Earth's continents move very slowly.
   c. evolution occurs at different rates.
   d. giant asteroids crashed into Earth in the past.
3. An isotope that can be used to determine the age of recent fossils is
   a. carbon-14.
   b. potassium-40.
   c. rubidium-87.
   d. uranium-238.
4. How have the activities of organisms affected Earth's environment?

Think Critically

5. **Relate Cause and Effect** Why have so few organisms become fossils?
6. **Calculate** The half-life of carbon-14 is 5730 years. What is the age of a fossil containing ¼ the amount of carbon-14 found in living organisms? Explain your calculation.

19.2 Patterns and Processes of Evolution

Understand Key Concepts

7. The process that produces similar structures in unrelated groups of organisms is
   a. adaptive radiation.
   b. coevolution.
   c. convergent evolution.
   d. macroevolution.
8. Cladograms that are based on the fossil record always show
   a. only organisms that are direct ancestors of the others.
   b. relationships based on shared derived characters.
   c. that clades contain only extinct species.
   d. relative ages of organisms in the clade.
9. Explain the process of adaptive radiation, and give an example.

Think Critically

10. **Compare and Contrast** How is mass extinction different from background extinction?
11. **Infer** What do you think would have happened to the evolution of flowering plants if there had been no pollinators present?

19.3 Earth's Early History

Understand Key Concepts

12. Earth's early atmosphere contained little or no
    a. water vapor.
    b. carbon dioxide.
    c. nitrogen.
    d. oxygen.
13. In their experiment that modeled conditions on early Earth, Miller and Urey used electric sparks to
    a. simulate temperature.
    b. simulate sunlight.
    c. simulate lightning.
    d. simulate atmospheric gases.

19 CHECK Understanding

14. How are microspheres similar to living cells?

15. How did the addition of oxygen to Earth's atmosphere affect the evolution of life?

Think Critically

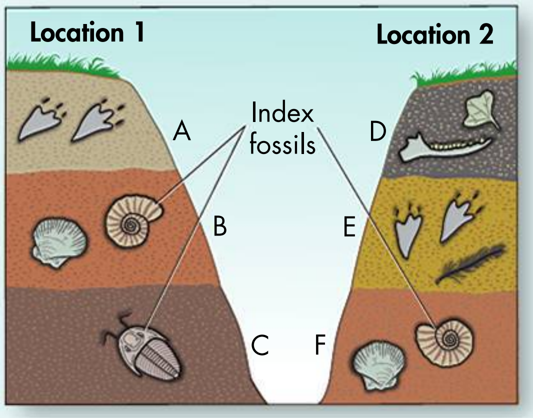
16. **Use Models** In the Miller-Urey experiment, what did the water and gases represent? What part of Miller and Urey's set-up represents rain?

17. **Relate Cause and Effect** How do you think that the eukaryotic cells that took in the ancestors of mitochondria and chloroplasts benefited from the relationship?

Connecting Concepts

Use Science Graphs

The diagram shows rock layers in two different places. Use the diagram to answer questions 18–20.



18. **Interpret Visuals** Which fossils are probably older, those in layer A or those in layer C? How do you know?

19. **Infer** Which rock layer in location 2 is probably about the same age as layer B in location 1? How do you know?

20. **Apply Concepts** What are the characteristics of a useful index fossil?

solve the CHAPTER MYSTERY

MURDER IN THE PERMIAN

Serving a mystery that is 250 million years old is not easy! Scientists have been working to solve this puzzle for years, and they are still working on it. Recently, scientists have studied the chemistry of Permian rocks and changes in the fossil record. These scientists have concluded that huge, long-lasting volcanic eruptions in Siberia released enormous amounts of carbon dioxide. This carbon dioxide caused massive changes in global climate. Was this the cause of the mass extinction?

Other researchers found that during the Permian, oxygen levels dropped to roughly half of what they are today. Huge parts of the oceans lost all oxygen. On land, there would have been very little oxygen. Mystery solved?

Finally, there is evidence that an asteroid hit Earth! Such a collision would throw so much dust into the air that global climates would have changed. To this day, paleontologists are testing different hypotheses to explain what caused the mass extinction. These hypotheses are constantly changing. In fact, they have probably changed again since this book was written!

1. **Compare and Contrast** How do current hypotheses about the Permian extinction compare with the main theory about the Cretaceous extinction?

2. **Form a Hypothesis** From the information in this book, suggest an explanation for the Permian mass extinction.

UntamedScience™ **Never Stop Exploring Your World.** Solving the mystery of the mass extinction is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Index fossils are from species that lived
- **A** in a small area for a short time.
- **B** in a small area for a long time.
- **C** over a large area for a short time.
- **D** over a large area for a long time.

2. What happens if the rate of extinction in a clade is greater than the rate of speciation?
- **A** The clade will eventually become extinct.
- **B** The clade will continue to exist.
- **C** The species in the clade will become more varied.
- **D** The number of species in the clade will stay the same.

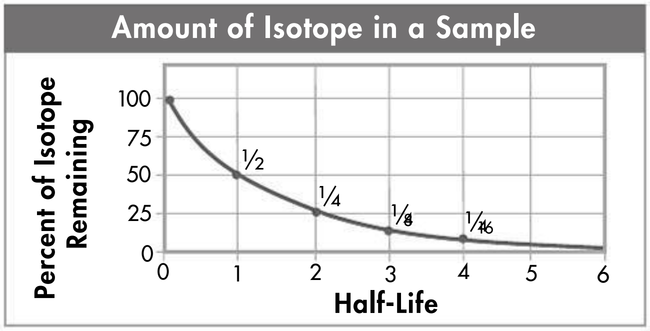
3. Which of the following is evidence for the endosymbiotic theory?
- **A** Mitochondria and chloroplasts contain DNA similar to bacterial DNA.
- **B** Mitochondria and chloroplasts have similar functions in the cell.
- **C** Mitochondria and chloroplasts have no DNA of their own.
- **D** Mitochondria and chloroplasts can live when removed from the eukaryotic cell.

4. Potassium-40 is useful for dating very old fossils because
- **A** it has a very long half-life.
- **B** it has a very short half-life.
- **C** most organisms contain more potassium than carbon.
- **D** it is found only in certain rock layers.

5. The movement of continents has played a significant role in evolution because
- **A** continents move rapidly and some organisms cannot adjust.
- **B** without the movement of continents, there would be no water on Earth.
- **C** the movement of continents has caused environments to change.
- **D** all mass extinctions are the result of continental drift.

Questions 6 and 7

The graph shows the decay of radioactive isotope atoms. Use the information in the graph to answer the questions that follow.



6. The half-life of thorium-230 is 75,000 years. How long will it take for $\frac{7}{8}$ of the original amount of thorium-230 in a sample to decay?
- **A** 75,000 years
- **B** 225,000 years
- **C** 25,000 years
- **D** 150,000 years

7. The half-life of potassium-40 is about 1.3 billion years. After four half-lives have passed, how much of the original sample will be left?
- **A** $\frac{1}{16}$
- **B** $\frac{1}{16} \times$ 1300 million grams
- **C** $\frac{1}{4}$
- **D** $\frac{1}{4} \times$ 1300 million grams

Open-Ended Response

8. How does the process by which sedimentary rock forms allow scientists to determine the relative ages of fossils?

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8
See Lesson	19.1	19.2	19.3	19.1	19.1	19.1	19.1	19.1

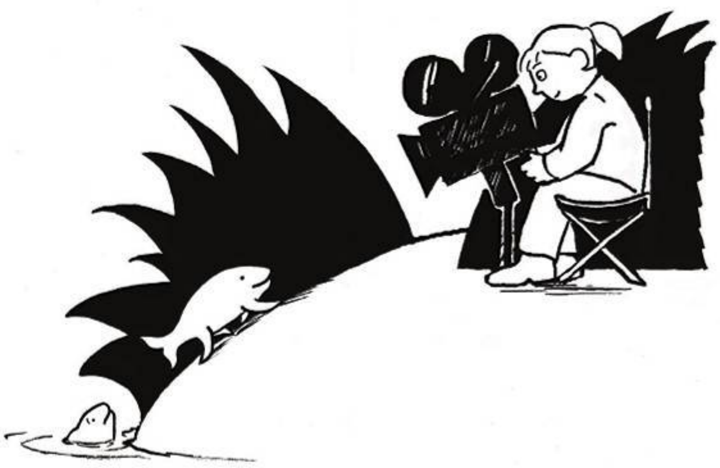
Unit Project

Evolution Documentary

Have you ever flipped through the channels and stopped on a documentary that caught your eye? And before you knew it an hour had passed? Documentaries can be a great way to learn about fascinating topics. Imagine you are a TV producer and have been hired to produce a documentary on evolution for a public television station. Your target audience is the general public.

Your Task Write a script for a 5–10 minute segment of an evolution documentary and present it to your class.

Be sure to
- discuss evidence for evolution by bringing in specific examples.
- present the information clearly and in an engaging manner.
- explain why the misconceptions listed below are *not* true:
  1) Evolution causes organisms to improve—life has gotten better over time.
  2) Evolution is not observable or testable.
  3) Gaps in the fossil record disprove evolution.
  4) Natural selection involves organisms "trying" to adapt.
  5) Natural selection is the only way that populations can change over time.



Reflection Questions

1. **Score your documentary using the rubric below. What score did you give yourself?**
2. **What did you do well in this project?**
3. **What needs improvement?**
4. **What do you think a member of the general public would learn from your documentary?**

Assessment Rubric

Score	Scientific Content	Quality of Documentary Script
4	Documentary provides accurate evidence for evolution and clearly corrects several misconceptions.	Information is presented in a clear, organized, and engaging manner.
3	Documentary provides some accurate evidence for evolution and attempts to correct misconceptions.	Information is presented in a clear and organized manner, but it could be more engaging.
2	Documentary provides little evidence for evolution and does not correct misconceptions well.	Information could be presented in a clearer manner. The script needs editing.
1	Documentary does not provide evidence for evolution and does not attempt to correct misconceptions.	Information is presented in a disorganized and confusing manner. The script needs a lot of editing.

From Microorganisms to Plants

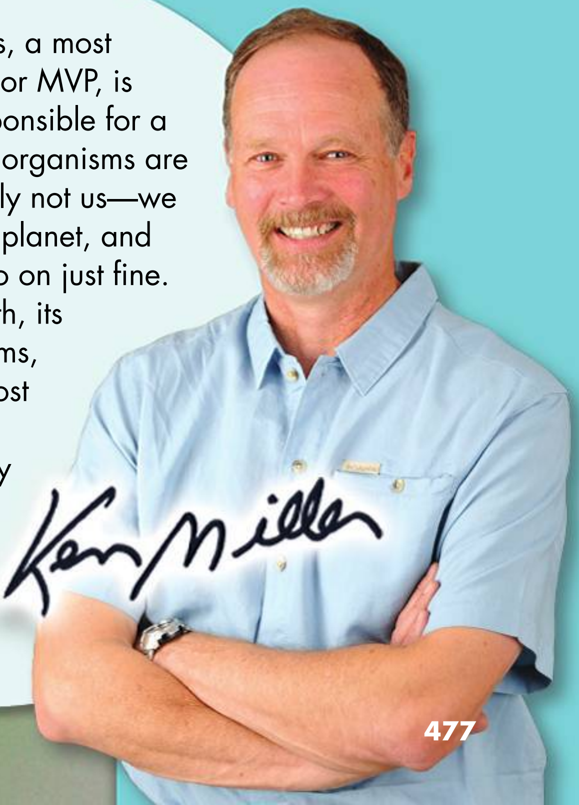
UNIT 6

Chapters

INTRODUCE the **Big ideas**

- **Unity and Diversity of Life**
- **Structure and Function**
- **Growth, Development, and Reproduction**
- **Cellular Basis of Life**
- **Interdependence in Nature**

“In sports, a most valuable player, or MVP, is the person most responsible for a team’s success. Which organisms are the MVPs of life? Certainly not us—we could disappear from this planet, and other forms of life would go on just fine. The real stars of life on Earth, its MVPs, are its microorganisms, fungi, and plants. We almost never notice these superstars, unless we look very closely, but without them our lives would be impossible.”

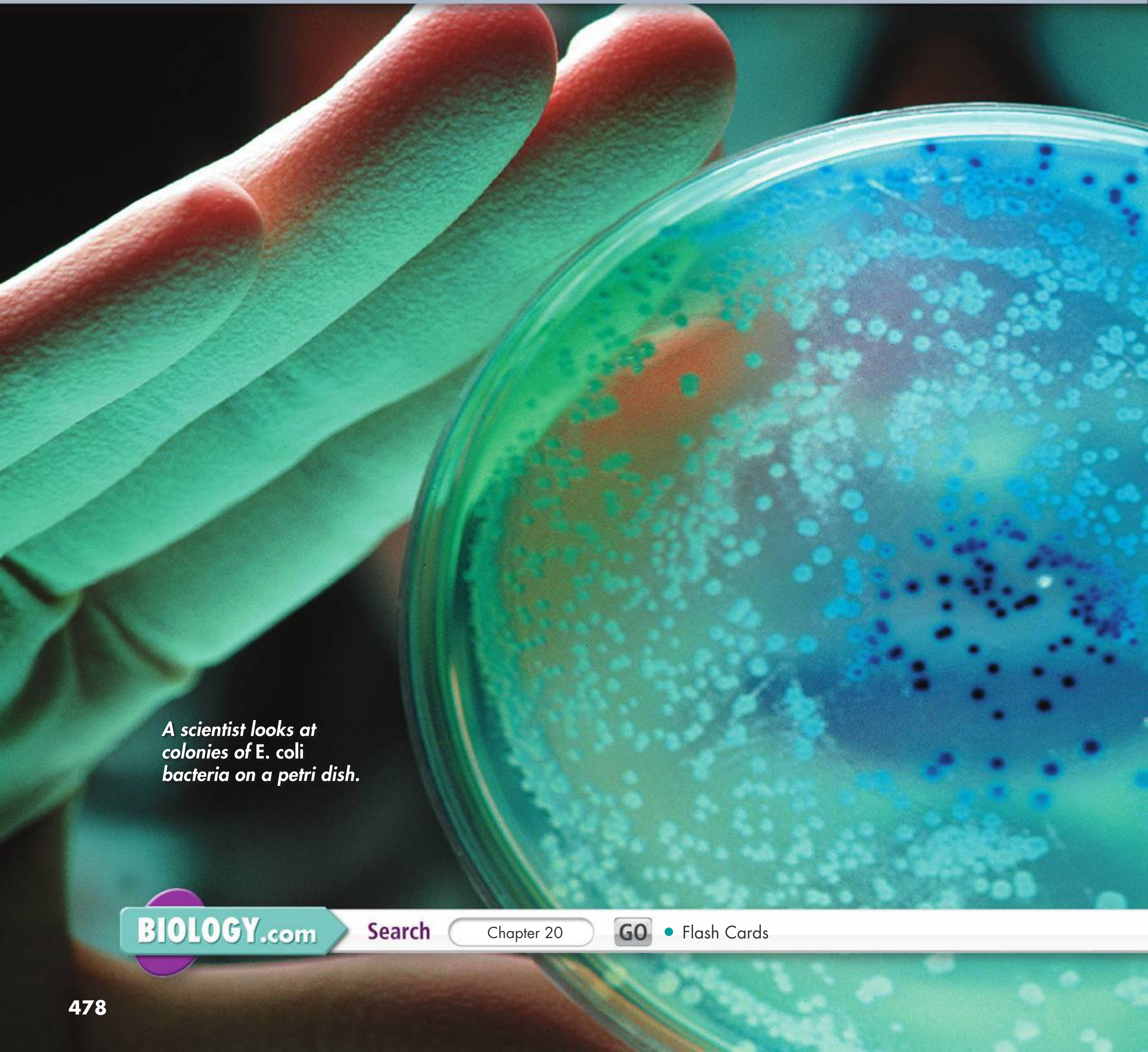


Ken Miller

20 Viruses and Prokaryotes

Big idea **Cellular Basis of Life**

Q: Are all microbes that make us sick made of living cells?

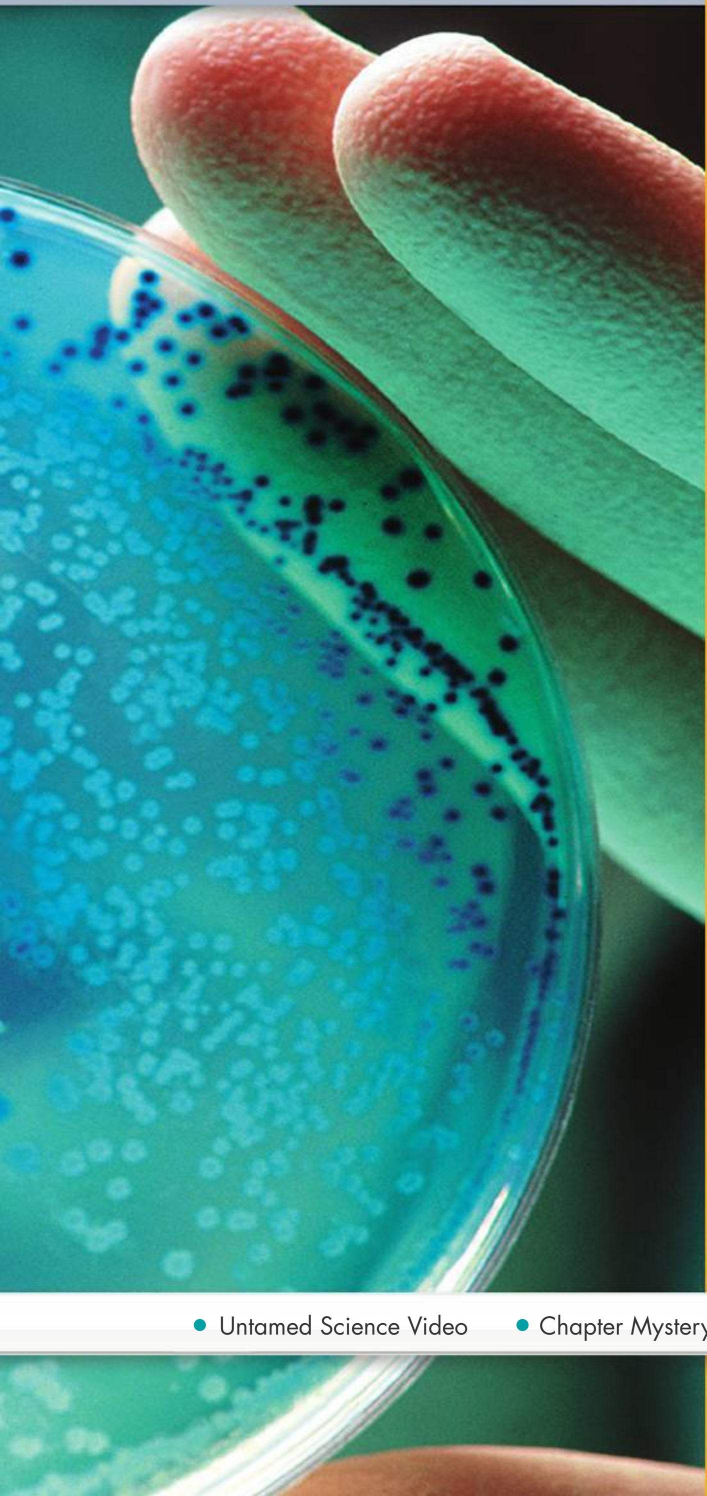


A scientist looks at colonies of E. coli *bacteria on a petri dish.*

BIOLOGY.com Search Chapter 20 GO • Flash Cards

INSIDE:

- 20.1 Viruses
- 20.2 Prokaryotes
- 20.3 Diseases Caused by Bacteria and Viruses



- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

THE MAD COWS

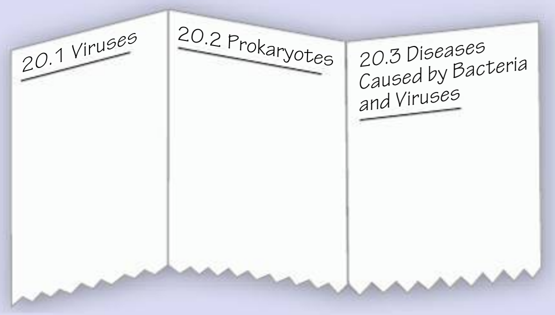
In 1986, something strange began to happen to cattle in Great Britain. Without warning, the animals began acting strangely. They lost control of their movements and eventually died. Farmers watched helplessly as this "mad cow disease" spread through their cattle. In 1991, the disease affected more than 30,000 cattle.

Scientists studied the brains of cattle killed by mad cow disease. They found that large areas of the animals' brains had been destroyed. Under a microscope, holes in the diseased tissue made the brain look like a sponge. Because of this, the disease was given the name bovine spongiform encephalopathy, or BSE.

Read for Mystery Clues What caused BSE? As you read this chapter, look for clues that explain the cause of the disease. Then, solve the mystery.

FOUNDATIONS for Learning

Use a sheet of paper to make a z-fold similar to the one shown below. Use one column of the z-fold for each lesson. Write down what you learn as you read each lesson. At the end of the chapter are two activities that will help you answer the question: Are all microbes that make us sick made of living cells?



20.1 Viruses

Key Questions

How do viruses reproduce?

What happens after a virus infects a cell?

BUILD Understanding

Venn Diagram Make a Venn diagram to compare viruses and cells. List similarities and differences between viruses and cells. Fill in the Venn diagram as you read the lesson.

In Your Workbook Go to your workbook to learn more about Venn diagrams. Complete the Venn diagram for Lesson 20.1.

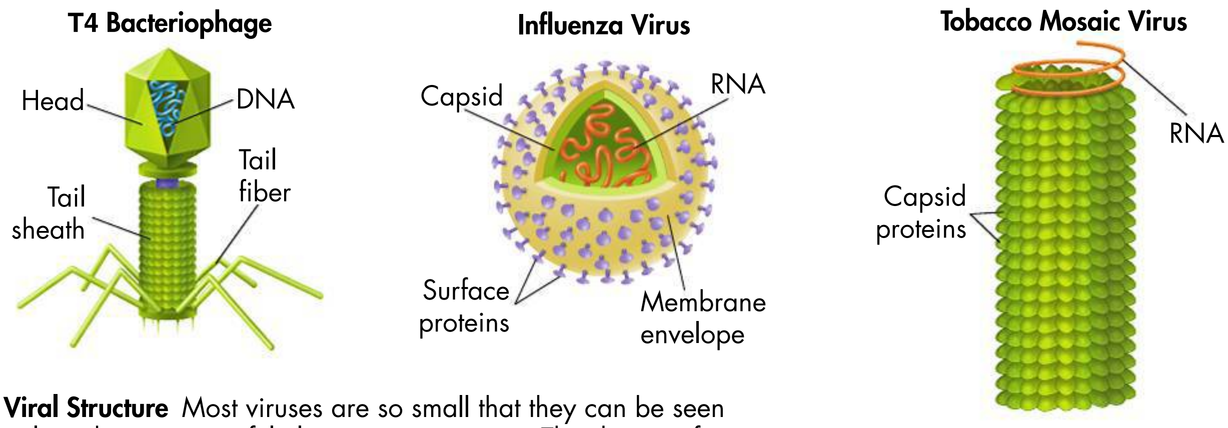
The Discovery of Viruses

Imagine that you have to solve a mystery. Farmers have begun to lose their tobacco crop to tobacco mosaic disease. First, the leaves turn yellow. Eventually, the leaves fall off, killing the plant. You use a light microscope to search for the pathogen, or disease-causing agent. But it is too small, even for a microscope. Although you cannot see the pathogen, you are sure that it is there.

Discovery of Viruses In 1892, the Russian biologist Dmitri Ivanovski studied tobacco mosaic disease. He showed that liquid taken from infected plants could cause the disease. But he could not find the pathogen itself. In 1897, the Dutch scientist Martinus Beijerinck suggested that tiny particles caused the disease. He named these particles *viruses*, after the Latin word for "poison."

Then, in 1935, the American biochemist Wendell Stanley produced crystals of tobacco mosaic virus. Living organisms do not crystallize. So, Stanley concluded that viruses were not truly alive. Most biologists still think this today. A **virus** is a nonliving particle. It is made of proteins, nucleic acids, and sometimes lipids. Viruses can reproduce only by infecting living cells.

Key Question How do viruses reproduce?
Viruses can reproduce only by infecting living cells.



Viral Structure Most viruses are so small that they can be seen only with very powerful electron microscopes. The shapes of three kinds of viruses are shown here.

Viral Structure and Function Viruses come in many shapes and sizes. A protein coat called a **capsid** surrounds a virus particle. Some viruses also have a membrane around the capsid. The simplest viruses have only a few genes. Complex viruses may have hundreds of genes.

The structure of a virus allows it to infect living cells. Most viruses have proteins on their surface. These proteins bind to proteins on the surface of a host cell. Viral proteins "trick" the host cell into taking in the virus or its genetic material. Viruses must bind exactly to proteins on the host cell's surface. Therefore, most viruses infect only specific kinds of cells. Plant viruses infect plant cells. Most animal viruses infect only certain kinds of animals. Viruses that infect bacteria are called **bacteriophages** (bak TEER ee uh fayj uz). They infect only certain kinds of bacteria.

BUILD Vocabulary

virus a particle made of proteins, nucleic acids, and sometimes lipids that can replicate only by infecting living cells

capsid the protein coat surrounding a virus

bacteriophage a kind of virus that infects bacteria

WORD ORIGINS

The word *capsid* comes from the Latin word *capsa*, which means "box."

Viral Infections

What happens after a virus enters a host cell? The virus uses the host cell's genetic information to make copies of itself! Some viruses copy themselves immediately. This type of infection is called a lytic infection. Other viruses stay inactive for a period of time within the host cell. This type of infection is called a lysogenic infection.

BUILD Connections

HOW A LYTIC VIRUS IS LIKE AN OUTLAW

A virus that causes a lytic infection works much like an outlaw in the Wild West. Imagine that the virus is an outlaw. Then, imagine that the cell the virus takes over is a town.

First, the outlaw eliminates the town's existing authority.
Lytic Infection The host cell's DNA is chopped up.

Next, the outlaw demands to be outfitted with new equipment from the local townspeople.
Lytic Infection Viruses use the host cell to make viral DNA and viral proteins.

Finally, the outlaw forms a gang that leaves the town to attack new communities.
Lytic Infection The host cell bursts, releasing hundreds of virus particles.

BUILD Vocabulary

lytic infection
a type of infection in which a virus enters a cell, makes copies of itself, and causes the cell to burst

lysogenic infection
a type of infection in which a virus embeds its DNA into the DNA of the host cell and is replicated along with the host cell's DNA

retrovirus
an RNA virus that contains RNA as its genetic information

WORD ORIGINS

The adjective *lytic*, the verb *lyse*, and the prefix *lyso-* all come from the Greek word *luein*. This word means "to loosen or break up."

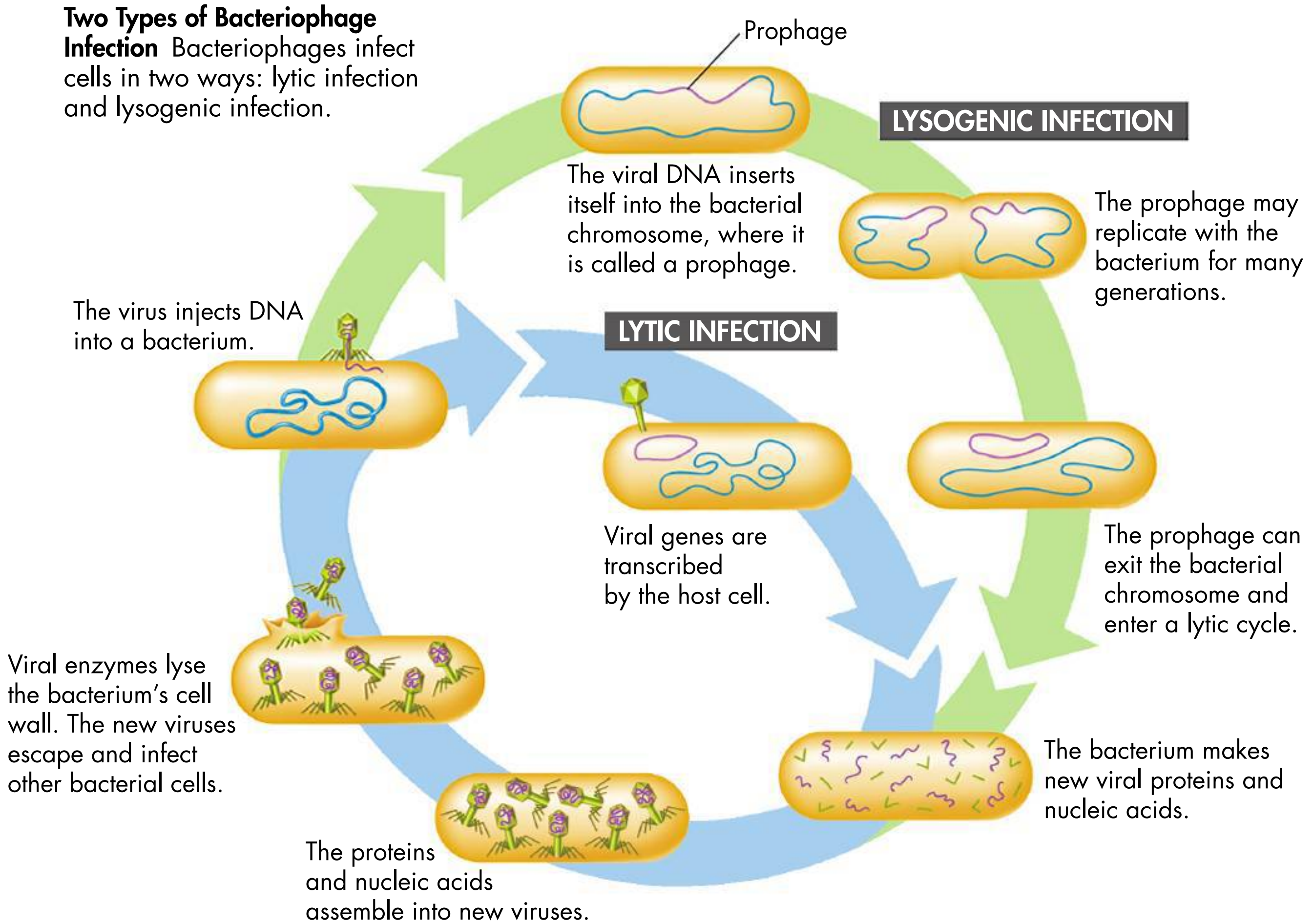
Lytic Infection In a **lytic infection,** a virus enters a cell, makes copies of itself, then causes the cell to burst. For example, a bacteriophage injects its DNA into a bacterial cell. Then the bacterial cell makes messenger RNA (mRNA) from the viral genes. This mRNA is translated into viral proteins that chop up the cell's DNA. The host cell makes new virus particles. Before long, the cell bursts open. Copies of the bacteriophage are released to infect other cells.

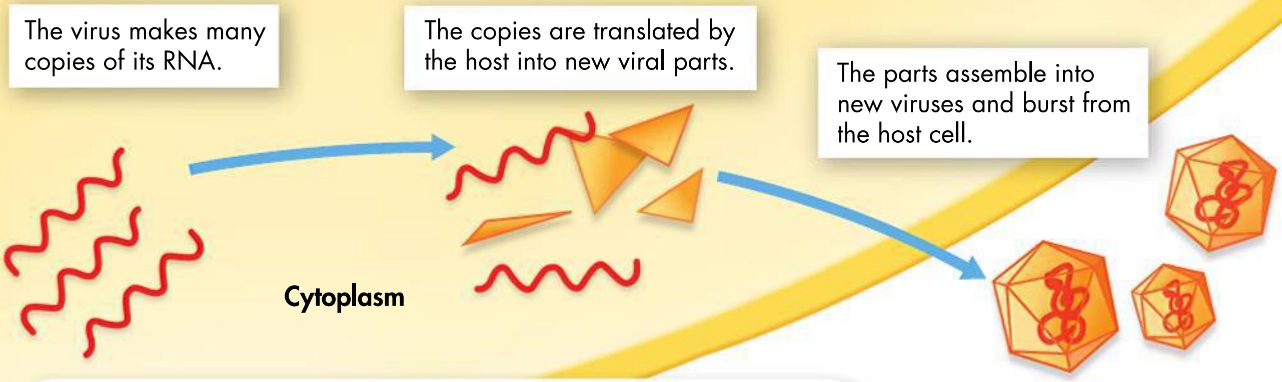
Lysogenic Infection In a **lysogenic infection,** the host cell is not taken over right away. Instead, the virus inserts its nucleic acid into the host cell's DNA. The viral DNA is copied along with the cell's DNA. The cell is not damaged. Daughter cells are infected by the virus.

Bacteriophage DNA that becomes part of the bacterial host's DNA is called a prophage. A prophage may be a part of the host cell's DNA for many generations. Changes in the environment, such as heat or chemicals, can cause the prophage to become active. Then the lysogenic infection becomes a lytic infection.

Key Question What happens after a virus infects a cell?
Inside living cells, viruses use their host's genetic information to make many copies of themselves. Some viruses replicate right away. Other viruses stay inactive for a long period of time within the host cell.

Two Types of Bacteriophage Infection Bacteriophages infect cells in two ways: lytic infection and lysogenic infection.





Common Cold Infection Once a cold virus has entered the host cell, it uses the host cell to copy itself.

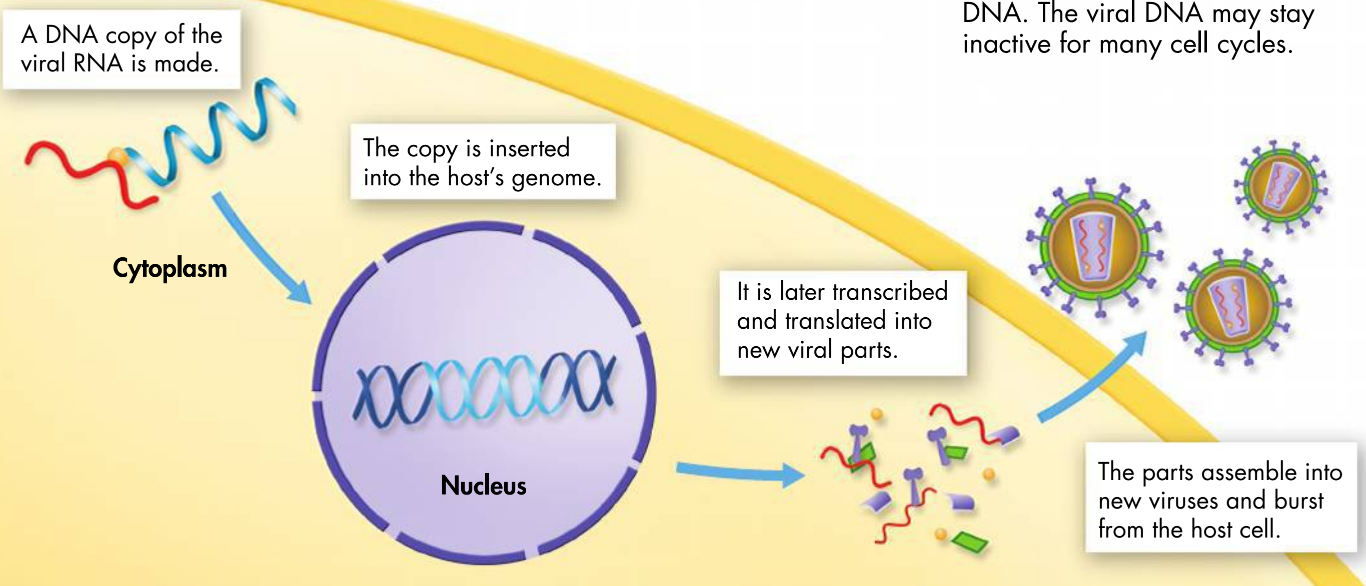
A Closer Look at Two RNA Viruses About 70 percent of viruses have RNA rather than DNA. In humans, RNA viruses cause a wide range of infections, from mild colds to AIDS.

▶ ***The Common Cold*** What happens when you get a cold? A capsid lands on a cell, often in your nose, and is brought inside a host cell. Inside the host cell, a viral protein makes many new copies of the viral RNA. The host cell's ribosomes mistake the viral RNA for the host's own mRNA. Viral RNA is translated into capsids and other viral proteins. New virus particles form. Within 8 hours, the host cell bursts. Hundreds of new virus particles then infect other cells.

▶ ***HIV*** The disease called acquired immune deficiency syndrome (AIDS) is caused by the human immunodeficiency virus (HIV). HIV belongs to a group of RNA viruses called **retroviruses.** The genetic information of a retrovirus is copied from RNA to DNA instead of from DNA to RNA.

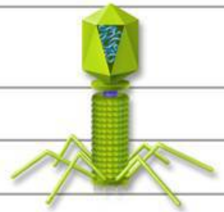
Retroviral infections are similar to lysogenic infections. When a retrovirus infects a cell, it makes a DNA copy of its RNA. This DNA copy is inserted into the DNA of the host cell. Like a prophage, the viral DNA may remain inactive for many cell cycles. Eventually, it makes new virus particles. These new particles attack the cells of the host's immune system—the system that normally fights infection.

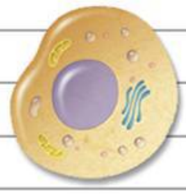
HIV Infection A retrovirus such as HIV makes a DNA copy of itself and inserts it into the host cell's DNA. The viral DNA may stay inactive for many cell cycles.



Viruses and Cells

Characteristic	Virus	Cell
Structure	DNA or RNA in capsid, some with envelope	Cell membrane, cytoplasm; eukaryotes also contain nucleus and many organelles
Reproduction	Only within a host cell	Independent cell division, either asexually or sexually
Genetic Code	DNA or RNA	DNA
Growth and Development	No	Yes; in multicellular organisms, cells increase in number and differentiate
Obtain and Use Energy	No	Yes
Response to Environment	No	Yes
Change Over Time	Yes	Yes





Comparing Viruses and Cells
The table above lists differences and similarities between viruses and living cells.

Viruses and Cells

To grow and reproduce, viruses must infect living cells. Viruses rely on the nutrients and cellular machinery of their hosts. Therefore, viruses are parasites. Parasites rely on a host, harming it in the process.

Viruses are not alive. But they do have several characteristics of living things. After infecting living cells, viruses can reproduce. They have genetic material. They can evolve.

Although viruses are smaller and simpler than the smallest cells, it is unlikely that they appeared before living things. Because they depend on living organisms, viruses probably developed after living cells. Perhaps the first viruses evolved from the genetic material of living cells. Viruses, and the cells they infect, have been evolving for billions of years.

CHECK Understanding

Apply Vocabulary

Use the highlighted terms from the lesson to complete each sentence correctly.

1. A virus is surrounded by a ________ made up of proteins.
2. During a ________, viral DNA remains inactive as part of the host cell's DNA.
3. A ________ causes the host cell to burst open and release many virus particles.
4. ________ have genetic information that is copied from RNA instead of DNA.

Critical Thinking

5. **Compare and Contrast** How is viral reproduction different from the reproduction of a living cell?
6. **Compare and Contrast** How are the lytic and lysogenic cycles similar? How are they different?
7. **Write to Learn** Answer the mystery clue below.

MYSTERY CLUE

Scientists injected BSE-infected material from cow brain tissue into mice. The mice developed BSE. The BSE-infected material contained no nucleic acids. Could a virus be the cause of BSE? (Hint: See above.)

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20.2 Prokaryotes

Classifying Prokaryotes

When the microscope was first invented, we humans discovered something amazing: We share every corner of our world with microorganisms! The smallest and most abundant of these microorganisms are **prokaryotes** (pro KAR ee ohts). Prokaryotes are single-celled organisms that lack a nucleus. The DNA of prokayotes is found in their cytoplasm. Biologists classify prokaryotes as either Bacteria or Archaea.

Key Question How are prokaryotes classified?
Prokaryotes are classified as Bacteria or Archaea, which are two of the three domains of life.

Bacteria Bacteria live almost everywhere—in fresh water, in salt water, and on land. They even live inside the bodies of humans and other eukaryotes. The art below shows the structure of a bacterium that lives in human intestines.

Most bacteria are surrounded by a cell wall that contains peptidoglycan. This molecule is made up of sugars and amino acids. Some bacteria are also protected by a membrane outside the cell wall. Bacteria may use flagella or pili (PY ly; singular: pilus) for movement. Pili also help them attach to surfaces or to other bacteria.

Key Questions

How are prokaryotes classified?

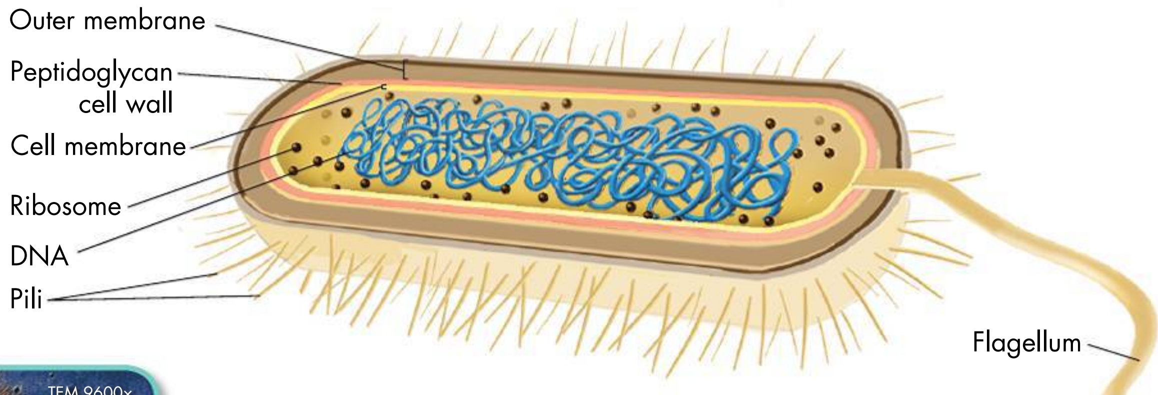
How do prokaryotes vary in their structure and function?

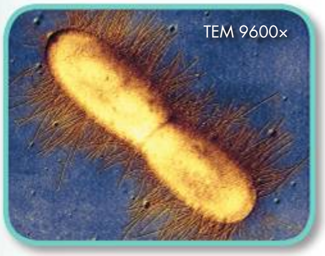
What roles do prokaryotes play in the living world?

BUILD Understanding

Preview Visuals Look at the Prokaryotic Shapes figure on the next page. In your own words, describe the three shapes shown.

In Your Workbook Go to your workbook to complete the activity for Lesson 20.2.





Typical Bacterial Structure The bacterium *Escherichia coli* is shown here. It has a structure typical of most prokaryotes. *E. coli* has an outer membrane that is not found in all prokaryotes. The photograph shows *E. coli* reproducing by binary fission.

For more on the diversity of Bacteria and Archaea, go to the Visual Guide. **pp. DOL 6–9.**

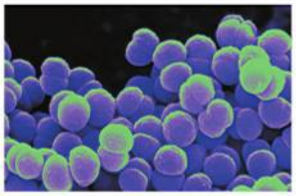
Archaea Archaea look very much like bacteria. Both are tiny, lack nuclei, and have cell walls. However, the cell walls of archaea do not have peptidoglycan. Also, their cell membranes contain different lipids. The DNA of archaea is more like the DNA of eukaryotes than the DNA of bacteria. Many archaea live in harsh environments. Some live in places with little or no oxygen, such as mud and animal digestive tracts. Others live in very salty water or hot springs.

Structure and Function

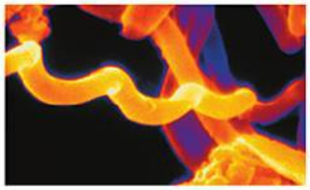
Prokaryotes come in many sizes and shapes. They also get and use energy in a number of different ways.

Prokaryotic Shapes Prokaryotes usually come in one of three shapes: rod-shaped bacilli (left), spherical cocci (middle), and corkscrew-shaped spirilla (right).

SEM 8500×



SEM 9200×



SEM 2400×

Size, Shape, and Movement Prokaryotes are much smaller than most eukaryotic cells. They range in size from 1 to 5 micrometers. Rod-shaped prokaryotes are called bacilli (buh SIL eye; singular: bacillus). Sphere-shaped prokaryotes are called cocci (KAHK sy; singular: coccus). Spiral and corkscrew-shaped prokaryotes are called spirilla (spy RIL uh; singular: spirillum). Some prokaryotes use flagella to move. Others put down a layer of slime and slowly glide along it. And some prokaryotes do not move at all.

Energy Capture and Release in Prokaryotes Prokaryotes have different ways of getting food and releasing energy from food. Some bacteria can get food and release energy in more than one way.

Energy Capture by Prokaryotes

Mode of Nutrition	How Energy Is Captured	Habitat	Example
Heterotroph "other feeder"	Take in organic molecules from environment or other organisms to use as both energy and carbon supply	Wide range of environments	*Clostridium*
Photoheterotroph "light and other feeder"	Like basic heterotrophs, but also use light energy	Where light is plentiful	*Rhodobacter, Chloroflexus*
Photoautotroph "light self-feeder"	Use light energy to convert CO_2 into carbon compounds	Where light is plentiful	*Anabaena*
Chemoautotroph "chemical self-feeder"	Use energy released by chemical reactions involving ammonia, hydrogen sulfide, etc.	In chemically harsh and/or dark environments: deep in the ocean, in thick mud, in digestive tracts of animals, in boiling hot springs	*Nitrosomonas*

Nutrition and Metabolism Like all organisms, prokaryotes need chemical energy, which they store in molecules such as sugars. Some prokaryotes make their own food. Others take in food for energy. Some can do both. Prokaryotes get energy from food by cellular respiration, fermentation, or both. Some can change the way they get or release energy depending on conditions in their environment.

Key Question How do prokaryotes vary in their structure and function? **Prokaryotes vary in their size and shape, in the way they move, and in the way they get and release energy.**

Growth, Reproduction, and Recombination When a prokaryote has nearly doubled in size, it can reproduce. First, it copies its DNA. Then, it divides in half, forming two identical cells. This kind of reproduction is known as **binary fission.** Binary fission is a form of asexual reproduction. When conditions are good, prokaryotes can divide quickly. Some can divide once every 20 minutes!

In organisms that reproduce sexually, genes are shuffled during meiosis. But prokaryotes reproduce asexually. How do their populations evolve? One way is through mutations. Mutations are random changes in DNA. These changes are passed on to daughter cells formed by binary fission.

Many prokaryotes exchange genetic information by **conjugation.** During conjugation, a hollow bridge forms between two bacterial cells. Genetic material moves from one cell to the other. This process makes populations more genetically diverse.

Formation of Endospores When conditions are not good, many prokaryotic cells can form an **endospore.** A thick internal wall forms around the DNA and part of the cytoplasm. Endospores can remain dormant for months or even years. By forming endospores, prokaryotes are able to live through very harsh conditions.

BUILD Vocabulary

prokaryote
a unicellular organism that lacks a nucleus

binary fission
a type of asexual reproduction in which an organism replicates its DNA and divides in half, producing two identical daughter cells

conjugation
the process in which paramecia and some prokaryotes exchange genetic information

endospore
a structure produced by prokaryotes in unfavorable conditions; a thick internal wall that encloses the DNA and a portion of the cytoplasm

PREFIXES
The prefix *endo-* comes from a Greek word that means "within." An endospore forms when a thick wall encloses DNA within a bacterial cell.

Energy Release by Prokaryotes

Mode of Metabolism	How Energy Is Released	Habitat	Example
Obligate aerobe "requiring oxygen"	Cellular respiration; must have ready supply of O_2 to release fuel energy	Oxygen-rich environments, such as near water surface or in animal lungs	*Mycobacterium tuberculosis*: Sometimes found in human lungs
Obligate anaerobe "requiring a lack of oxygen"	Fermentation; die in presence of oxygen	Environments lacking O_2, such as deep soil, animal intestines, or airtight containers	*Clostridium botulinum*: Sometimes found in improperly sterilized canned food, causing food poisoning
Facultative anaerobe "surviving without oxygen when necessary"	Can use either cellular respiration or fermentation as necessary	Oxygen-rich or oxygen-poor environments	*E. coli*: Lives aerobically in sewage and anaerobically in human large intestine

Rhizobium The root nodules of this soybean plant contain *Rhizobium* bacteria. These bacteria are nitrogen fixers.

The Importance of Prokaryotes

Prokaryotes are necessary to the balance of the living world. How can such tiny organisms be so important?

Decomposers Prokaryotes break down, or decompose, dead organisms and wastes. This makes raw materials available to other organisms. If these materials were not recycled, life could not go on.

Producers Photosynthetic prokaryotes are some of the world's most important producers. They form the base of many food chains. For example, the tiny bacterium *Prochlorococcus* may be responsible for more than half of the primary production in the open ocean.

Nitrogen Fixers All organisms need nitrogen to make proteins, nucleic acids, and other molecules. Although nitrogen gas (N_2) makes up 80 percent of Earth's atmosphere, most organisms cannot use N_2 directly. Fortunately, a few prokaryotes can change N_2 into forms that can be used by other living things. This process is called nitrogen fixation. Nitrogen-fixing prokaryotes provide 90 percent of the nitrogen used by other organisms.

A few plants have symbiotic relationships with nitrogen-fixing bacteria. Nitrogen-fixing bacteria grow in nodules on the roots of plants such as clover and soybeans. The bacteria change nitrogen in the air into nitrogen that the plants need.

Human Use of Prokaryotes Bacteria are used to make many different foods and other products. For example, yogurt is made by the bacterium *Lactobacillus*. Some bacteria remove waste products from water. Others are used to make drugs in genetic engineering.

Key Question What roles do prokaryotes play in the living world? **Prokaryotes are decomposers, producers, and nitrogen fixers. In addition, some species are used in human industry.**

CHECK Understanding

Apply Vocabulary

Use the highlighted terms from the lesson to complete each sentence correctly.

1. To survive long periods of harsh conditions, bacteria may form ________.

2. A bacterium undergoes ________, forming two identical daughter cells.

3. ________ increases the genetic diversity of prokaryote populations.

Critical Thinking

4. Classify Which two domains of life contain only prokaryotes?

5. Apply Concepts Many farmers practice crop rotation. They may plant a field with corn one year and plant soybeans the next year. Why might they do this?

6. Write to Learn Write a paragraph comparing and contrasting archaea and bacteria.

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20.3 Diseases Caused by Bacteria and Viruses

Bacterial Diseases

The first person to clearly show that bacteria cause disease was the French chemist Louis Pasteur. Pasteur helped establish the *germ theory of disease*. The germ theory states that viruses and prokaryotes cause many human and animal diseases. An agent that can cause sickness is a **pathogen.**

Disease Mechanisms Bacteria cause disease in two main ways. Some bacteria destroy living cells and tissues. Others release chemicals that upset the normal activities of the host. These chemicals are called toxins.

Key Question How do bacteria cause disease? **Bacteria cause disease by damaging host cells and tissues or by releasing chemicals that upset homeostasis.**

Controlling Bacteria One of the most important things you can do to control bacteria is to wash your hands well and often. Also wash surfaces where bacteria might settle. Washing removes, but does not kill, bacteria. Disinfectants kill bacteria. Sterilization, or heating objects above 100°C, will also kill most bacteria. It is important to store and cook foods properly. The cold temperature in a refrigerator will slow the growth of bacteria.

Key Questions

How do bacteria cause disease?

How do viruses cause disease?

Why are emerging diseases a threat to human health?

BUILD Understanding

Two-Column Chart Make a two-column chart. In the left column, write the key questions from the lesson. In the right column, write answers to the questions.

In Your Workbook Go to your workbook for help completing this two-column chart. Complete the chart for Lesson 20.3.

Human Bacterial Diseases Some common bacterial diseases are described in the table.

Some Human Bacterial Diseases

Disease	Effect on Body	Transmission
Lyme disease	"Bull's-eye" rash at site of tick bite, fever, fatigue, headache	Ticks transmit the bacterium *Borrelia burgdorferi.* ▶
Tetanus	Lockjaw, stiffness in neck and abdomen, difficulty swallowing, fever, elevated blood pressure, severe muscle spasms	Bacteria enter the body through a break in the skin.
Tuberculosis	Fatigue, weight loss, fever, night sweats, chills, appetite loss, bloody sputum from lungs	Bacteria particles are inhaled.
Strep throat	Fever, sore throat, headache, fatigue, nausea	Direct contact with mucus from an infected person or direct contact with infected wounds or breaks in the skin

SEM 7300x

BUILD Vocabulary

pathogen
a disease-causing agent

vaccine
a preparation of weakened or killed pathogens used to produce immunity to a disease

antibiotic
a drug used to block the growth and reproduction of bacterial pathogens

WORD ORIGINS

Pathogen comes from the Greek words *pathos*, which means "suffering," and *genes*, meaning "produced." Infection with a pathogen produces suffering in the form of illness.

Preventing Bacterial Disease Infections can sometimes be prevented by vaccines. A **vaccine** is a preparation of weakened or killed pathogens or inactivated toxins. A vaccine helps the body become immune to a specific disease. Immunity is the body's ability to fight off pathogens or to deal with toxins.

Treating Bacterial Diseases Many drugs can be used to treat a bacterial infection. These drugs include **antibiotics,** such as penicillin and tetracycline. Antibiotics keep bacteria from growing and reproducing by interfering with bacterial proteins or cell processes. Antibiotics affect proteins or cell processes that are found only in bacteria. For this reason, they do not harm the host's cells.

Viral Diseases

Like bacteria, viruses cause disease by upsetting the body's normal homeostasis. Several common diseases caused by viruses are listed below. Viruses also cause serious diseases in plants and animals.

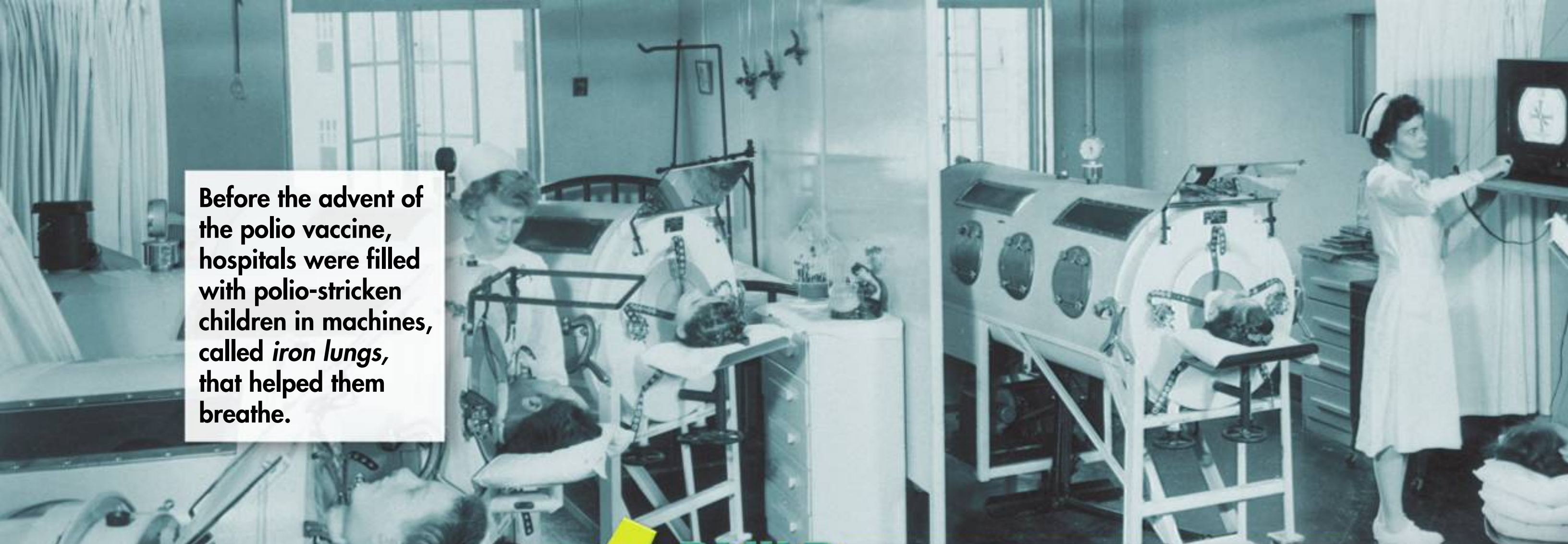
Disease Mechanisms Some viruses cause disease by destroying living cells. They may also change processes in cells and upset homeostasis. Often, viruses attack only certain kinds of cells. For example, poliovirus destroys cells in the nervous system, causing paralysis. Other viruses change the way cells grow and develop. Such changes can lead to cancer.

Key Question How do viruses cause disease?
Viruses cause disease by destroying living cells or by affecting processes in cells in ways that upset homeostasis in the host.

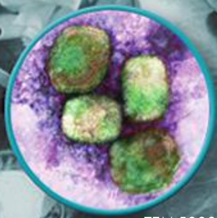
Human Viral Diseases
This table describes some common viral diseases.

Some Human Viral Diseases

Disease	Effect on Body	Transmission
Common cold	Sneezing, sore throat, fever, headache, muscle aches	Contact with contaminated objects; droplet inhalation
Influenza	Body aches, fever, sore throat, headache, dry cough, fatigue, nasal congestion	Flu viruses spread in respiratory droplets caused by coughing and sneezing.
AIDS (HIV)	Helper T cells, which are needed for normal immune-system function, are destroyed.	Sexual contact; contact with contaminated blood or body fluids; can be passed to babies during delivery or during breastfeeding.
Chicken pox	Skin rash of blisterlike lesions	Virus particles are spread in respiratory droplets caused by coughing and sneezing; highly contagious
Hepatitis B	Jaundice, fatigue, abdominal pain, nausea, vomiting, joint pain	Contact with contaminated blood or bodily fluids
West Nile Virus	Fever, headache, body ache	Bite from an infected mosquito ▶
Human papillomavirus (HPV)	Genital or anal warts, also cancer of the cervix, penis, and anus	Sexual contact



Before the advent of the polio vaccine, hospitals were filled with polio-stricken children in machines, called *iron lungs,* that helped them breathe.



TEM 5000×

▲ Smallpox viruses

BUILD Connections

INNOVATIONS IN VACCINES

Many vaccines have been developed in the last 300 years. Today, there are vaccines against more than 20 diseases.

1769 Edward Jenner performs the first inoculation against smallpox, using the less harmful but similar cowpox virus.

1880s Louis Pasteur develops vaccines against anthrax and rabies.

1923 Albert Calmette and Camille Guerin develop a vaccine against tuberculosis.

1950s Jonas Salk develops a polio vaccine that uses killed viruses. Albert Sabin develops a polio vaccine that uses weakened viruses.

1981 A vaccine against hepatitis B that uses recombinant DNA gains government approval.

2006 A vaccine against human papillomavirus, a virus known to cause certain cancers, gains approval.

◀ Before vaccine development, the Red Cross made the public aware of the threat of tuberculosis using posters such as this one, circa 1919.

Preventing Viral Diseases In most cases, the best way to protect against viral diseases is prevention. Studies show that cold and flu viruses are passed on by hand-to-mouth contact. So it is important to wash your hands often. Cough or sneeze into a tissue rather than into your hands. Avoid contact with sick people.

Prevention of viral diseases often includes the use of vaccines. Some important events in the development of vaccines are shown above.

Treating Viral Diseases Viral diseases cannot be treated with antibiotics. Yet, there are some antiviral drugs. These drugs attack viral proteins that host cells do not have. Some antiviral drugs help people get over the flu more quickly. Other antiviral drugs help people who are infected with HIV live longer.

BUILD Vocabulary

emerging disease
a disease that appears in the population for the first time, or an old disease that suddenly becomes harder to control

prion
a misfolded protein that causes disease

WORD ORIGINS

The word *prion* is a combination of letters from the words *proteinaceous*, an adjective referring to proteins, and *infectious*. A prion is a misfolded protein that infects cells.

Emerging Diseases

In the last thirty years, a number of new diseases have appeared. Other diseases that once seemed to be under control have become more dangerous. An unknown disease that appears in a population for the first time or a well-known disease that suddenly becomes harder to control is an **emerging disease.** Emerging diseases are dangerous because people have little or no resistance to them. Scientists have not developed medications or vaccinations to fight new diseases.

"Superbugs" Sometimes old diseases become harder to fight as the pathogens that cause them evolve. Pathogens often evolve in response to the medicines used against them. Penicillin was the first antibiotic used to treat infections. At first, it worked well. Diseases that had once killed people were cured. Yet, in just a few decades, penicillin did not work as well. Bacteria had evolved resistance to it. The drug no longer stopped some infections. Many bacteria are now resistant to many antibiotics. Doctors sometimes call these bacteria "superbugs."

New Viruses Sometimes, a virus evolves and jumps from one host species to another. Researchers have evidence that HIV did this. It likely moved from nonhuman primates into humans. Public health officials are worried about a new flu virus. A bird flu virus much like the most deadly human flu viruses has evolved. In a few cases, bird flu has infected humans. A major "jump" to humans may be possible.

Key Question Why are emerging diseases a threat to human health? **Humans have little or no resistance to emerging diseases. Scientists have not yet developed ways to control them.**

INQUIRY into Scientific Thinking

MRSA on the Rise

An especially dangerous bacterium has recently appeared. *Staphylococcus aureus* (MRSA) is resistant to many drugs. It causes skin infections that can be spread by close contact. Infection by MRSA can spread very quickly among people in hospitals who have weakened immune systems.

Incidence of MRSA

Year	Hospital Cases Reported
1993	1900
1995	38,100
1997	69,800
1999	108,600
2001	175,000
2003	248,300
2005	368,600

Analyze and Conclude

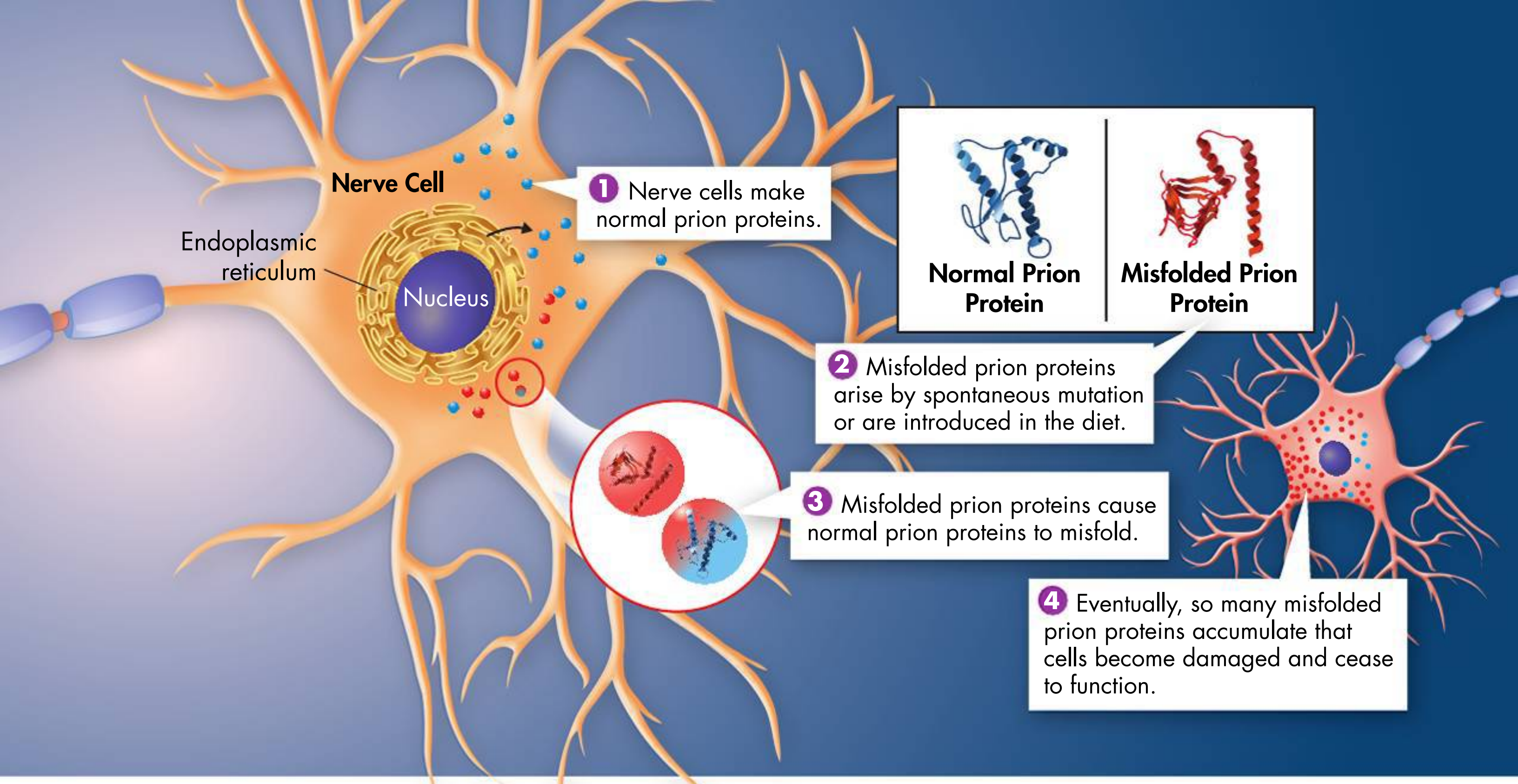
1. Graph The table in the right-hand corner shows the number of MRSA infections in hospitals in the United States from 1993 through 2005. Use the table to make a line graph.

2. Explain What trend does your line graph show?

3. Calculate By what percentage did MRSA infections increase between 1995 and 2005?

4. Relate Cause and Effect The average hospital stay in the United States lasts 4.6 days. That of the average MRSA-infected patient is 10.0 days. If the trend shown by the data above continues, how will MRSA infections affect hospital costs?

In Your Workbook Get more help for this activity in your workbook.



Prion Infections Prions are misfolded proteins in the brain. When prions contact normal proteins, they cause them to misfold. Eventually, the misfolded proteins damage tissues in the brain.

Prions In 1972, the American scientist Stanley Prusiner began to study a disease that was making sheep sick. No one knew the cause. At first, Prusiner thought a virus caused the disease. Then clumps of misfolded proteins were discovered in the brains of infected sheep. Prusiner called these proteins **prions.** Prions cause proteins in the body to fold incorrectly. As misfolded proteins build up, they damage the brain. Prion infections are spread when animals eat other animals that are infected. Prions can infect many animals, including humans.

CHECK Understanding

Apply Vocabulary

Use the highlighted terms from the lesson to complete each sentence correctly.

1. A(n)________ may contain dead or weakened pathogens.
2. ________ are medications that can be used to treat bacterial infections.

Critical Thinking

3. **Compare and Contrast** How does the treatment of viral diseases differ from the treatment of bacterial diseases?
4. **Explain** Why are "superbugs" hard to control?
5. **Write to Learn** Answer the third clue of the chapter mystery. Describe the structure and effect of prion infections in your answer.

MYSTERY CLUE

BSE virtually disappeared when the British government banned the use of ground-up cattle protein in feed. What does this indicate about how the pathogen was passed on? Could prions be the cause of BSE? Why or why not? (Hint: See above.)

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Pre-Lab: Controlling Bacterial Growth

Problem How can you determine the effectiveness of an antibiotic?

Materials agar plates, marker, bacterial cultures, sterile glass beads, sterile pipettes, forceps, antibiotic disks, masking tape, metric ruler

Lab Manual Chapter 20 Lab

Skills Observe, Measure, Draw Conclusions

Connect to the Big idea Bacteria can be found on and within the human body. Most of these bacteria are harmless and some are even beneficial to humans. But others can cause diseases. These pathogens need to be controlled. Physical removal of bacteria through hand washing is one of the most effective control methods. Proper food storage and preparation are also important, as are the vaccines that have been developed to help the body build up immunity to specific bacterial diseases.

What happens if a person does develop a bacterial infection? Then doctors use drugs, such as antibiotics, to fight the infection. These drugs are designed to kill bacteria but not to kill human cells. In this lab, you will compare the ability of two antibiotics to control the growth of two different types of bacteria.

Background Questions

a. **Review** What happens to a bacteria cell after it has grown to nearly double its size? What is this process called?

b. **Explain** How is genetic diversity increased in populations of bacteria?

c. **Review** What are the two general ways that bacteria can cause disease?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Relate Cause and Effect** How will you know whether an antibiotic is able to control the growth of bacteria?

2. **Design An Experiment** Why is it important to leave space between the disks on the agar plates?

3. **Control Variables** Why must you avoid direct contact between your hands and the antibiotic disks?

BIOLOGY.com Search Chapter 20 GO

Visit Chapter 20 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Join the Untamed Science crew as they fire up the microscopes for a look at bacteria and all the ways they are good for us.

Art in Motion View a short animation of prion infection and see how misfolded proteins interact with normal proteins.

Art Review Review your understanding of the structure and classification of prokaryotes.

InterActive Art Build your understanding of lytic and lysogenic cycles.

Visual Analogy Compare an old west outlaw taking over a town to a lytic infection.

20 CHAPTER Summary

20.1 Viruses

- Viruses can reproduce only by infecting living cells.
- Inside living cells, viruses use their host's genetic information to make many copies of themselves. Some viruses replicate right away. Other viruses stay inactive for a long period of time within the host cell.

virus (p. 480)
capsid (p. 481)
bacteriophage (p. 481)
lytic infection (p. 482)
lysogenic infection (p. 482)
retrovirus (p. 483)

20.2 Prokaryotes

- Prokaryotes are classified as Bacteria or Archaea, which are two of the three domains of life.
- Prokaryotes vary in their size and shape, in the way they move, and in the way they get and release energy.
- Prokaryotes are essential in maintaining the balance of the living world. They are decomposers, producers, and nitrogen fixers. In addition, some species are used in human industry.

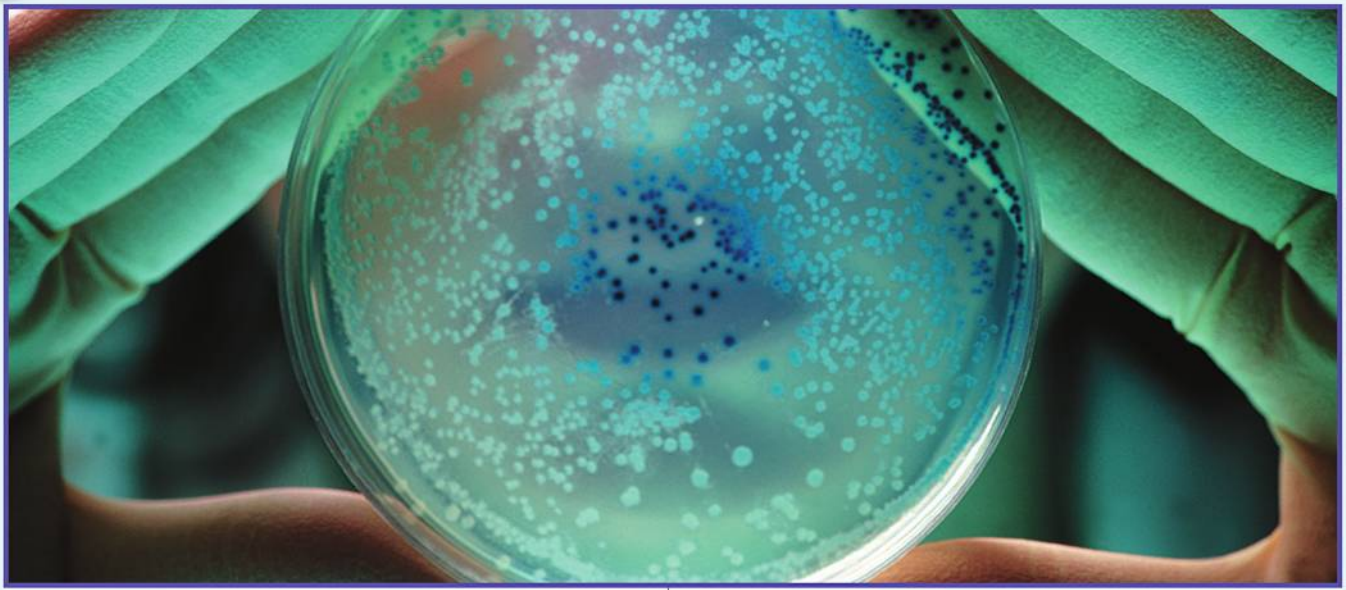
prokaryote (p. 485)
binary fission (p. 487)
conjugation (p. 487)
endospore (p. 487)

20.3 Diseases Caused by Bacteria and Viruses

- Bacteria cause disease by damaging host cells and tissues or by releasing chemicals that upset homeostasis.
- Viruses cause disease by destroying living cells or by affecting processes in cells in ways that upset homeostasis in the host.
- Humans have little or no resistance to emerging diseases. Scientists have not yet developed vaccines or medicines to control them.

pathogen (p. 489)
vaccine (p. 490)
antibiotic (p. 490)
emerging disease (p. 492)
prion (p. 493)

20 CHECK Understanding



Assess the Big idea: Cellular Basis of Life

Write an answer to the question below.

Q: Are all microbes that make us sick made of living cells?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs long. To help you begin, read the **Hints** below each of the questions.

1. **Are viruses living organisms?**

   Hint Viruses form crystals.

   Hint Viruses are able to reproduce, and they have genetic material.

2. **How are prokaryotes classified, and how are they important?**

   Hint Prokaryotes are single celled and lack nuclei.

   Hint Prokaryotes are organized into two groups.

3. **How is the reproduction of viruses similar to that of prokaryotes? How is it different?**

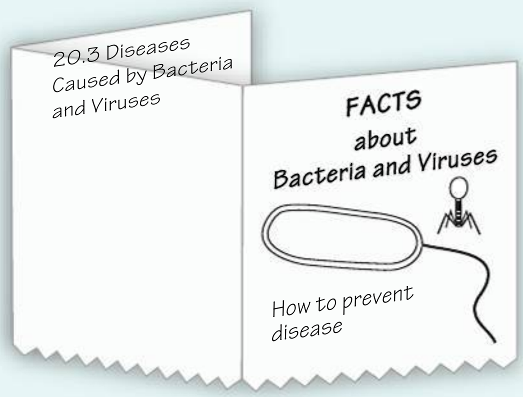
   Hint Refer to the art comparing a virus to an outlaw on page 481.

Foundations for Learning Wrap-Up

Use the z-fold you made as you read the chapter to help organize your thoughts about viruses, bacteria, and disease.

Activity 1 Working in a small group, write questions for a crossword puzzle. Base your questions on the notes you took on your z-fold. Draw your puzzle and trade it with another team.

Activity 2 Working with a partner, use your z-folds to make an informative brochure about viruses, bacteria, and the risks they pose to human health. Your notes on the z-fold will be the facts you present about viruses, bacteria, and disease. Be sure to make an inviting cover for your pamphlet. Add pictures to describe viruses and bacteria.



20.1 Viruses

Understand Key Concepts

1. Particles that are made up of proteins, nucleic acids, and sometimes lipids and that can only reproduce by infecting living cells are called
   a. bacteria.
   b. capsids.
   c. prokaryotes.
   d. viruses.

2. One group of viruses has RNA as their genetic information. These viruses are called
   a. bacteriophages.
   b. capsids.
   c. prophages.
   d. retroviruses.

Test-Taking Tip

Come Back to the Question Sometimes, you might be stumped by a question. If you can't figure out the answer, skip the question and continue the test. Come back to the question after you have completed the other test questions. Doing so can help you organize your thoughts and come up with an answer.

3. Describe the events that take place during a lytic infection.
4. What is a prophage?

Think Critically

5. **Apply Concepts** Explain how a virus can spread in a bacterial population during a lysogenic infection.
6. **Apply Concepts** How could a mutation in a bacterial cell help the bacterial population become resistant to a bacteriophage?

20.2 Prokaryotes

Understand Key Concepts

7. Prokaryotes differ from all other organisms in that their cells
   a. lack nuclei.
   b. have cell walls.
   c. have ribosomes.
   d. lack nucleic acids.

8. Prokaryotes reproduce asexually by
   a. binary fission.
   b. conjugation.
   c. endospores.
   d. mutation.

9. List and describe the three main cell shapes of prokaryotes.
10. Describe two ways by which prokaryotes move.

Think Critically

11. **Apply Concepts** A scientist finds a new organism. The organism is single celled and has a cell wall containing peptidoglycan. The cell lacks a nucleus. To what domain does the organism belong? Explain your reasoning.
12. **Infer** Imagine that nitrogen-fixing bacteria disappeared. How would this affect other organisms in the world?

20.3 Diseases Caused by Bacteria and Viruses

Understand Key Concepts

13. Viruses cause disease by
    a. releasing toxins.
    b. undergoing conjugation.
    c. infecting then destroying cells.
    d. causing mutations in the host's DNA.

20 CHECK Understanding

14. Which of the following can be used to treat bacterial diseases but NOT viral diseases?
    a. antibiotics
    b. antiviral drugs
    c. pathogens
    d. vaccines

15. What is meant by the term *emerging disease*?

16. How do prions cause disease?

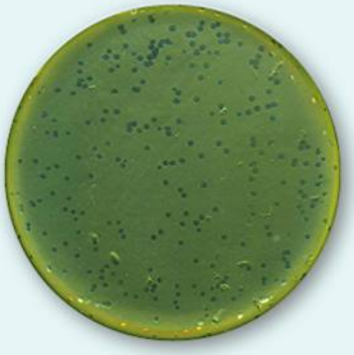
Think Critically

17. **Infer** Would antibiotics be effective in treating an outbreak of bird flu? Explain.

Connecting Concepts

Use Science Graphics

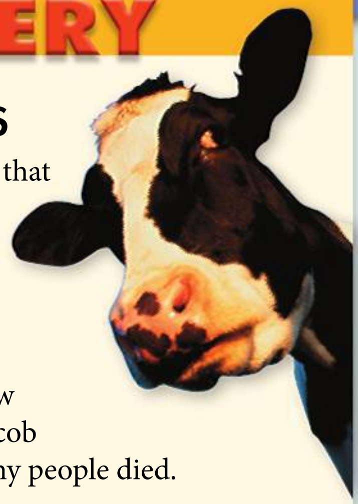
E. coli *bacteria can be grown on agar in a petri dish. The bacteria cloud the agar surface, forming a bacterial "lawn." This photograph shows a lawn over which a solution containing bacteriophage particles has been poured. Use the photograph to answer questions 18–19.*



18. **Interpret Visuals** What is the most reasonable explanation for the small, circular, clear areas on the bacterial lawn?

19. **Form a Hypothesis** Suppose you touched the tip of a glass rod to one of the clear areas and then touched it again to the surface of a petri dish with a fresh lawn of *E. coli*. What would happen to the new lawn of bacteria after several days?

solve the CHAPTER MYSTERY



THE MAD COWS

The mad cow disease that appeared in 1986 spread quickly among British cattle herds. People got a similar disease. This disease was called new variant Creutzfeld-Jacob disease (nvCJD). Many people died.

The British government made a law against feeding cattle using ground-up cattle. BSE and nvCJD almost disappeared. It now seems clear that "mad cow" and nvCJD were caused by prions. These prions were in the meat and brain tissue of infected cattle. When cattle ate the infected meat, the prions spread. People who ate meat from infected animals were also infected. Officials in Europe and the United States have made new laws about meat production to try to make sure there are no more outbreaks of BSE and nvCJD.

1. **Infer** The rapid rise of BSE between 1986 and 1991 ended when British authorities banned the use of meat and bone meal in cattle food. How does this support the hypothesis that BSE is caused by prions?

2. **Apply Concepts** Why did most scientists conclude that BSE was not caused by either viruses or bacteria?

UntamedScience™ **Never Stop Exploring Your World.** Finding what caused this disease is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to explore the other side of the story. You'll see that not all microbes are "bad."

Standardized Test Prep

Multiple Choice

1. A type of virus that infects bacterial cells is called a
A capsid.
B prion.
C bacteriophage.
D retrovirus.

2. Prokaryotic cells that have a spherical shape are called
A cocci.
B methanogens.
C spirilli.
D bacilli.

3. What is a capsid?
A viral DNA that inserts into a host's DNA
B a protein coat surrounding a virus
C a type of plant virus
D a rod-shaped bacterium

4. Which of the following is NOT used to identify specific prokaryotes?
A type of nucleic acid
B shape
C movement
D energy source

5. Which method is NOT used to protect food against microorganisms?
A heating
B freezing
C sterilization
D vaccination

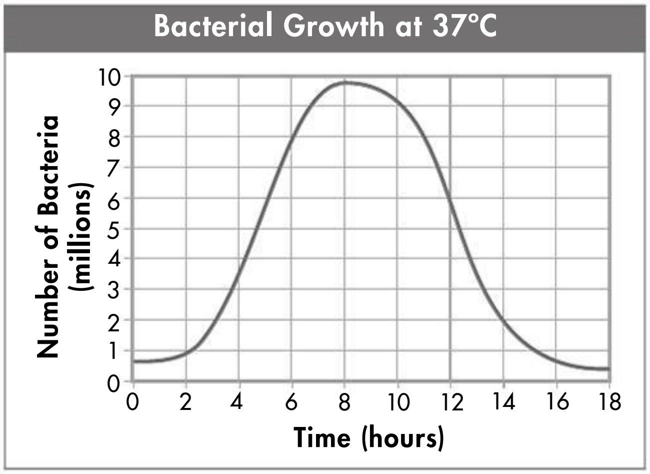
6. Which illness is caused by a bacterium?
A AIDS
B polio
C tuberculosis
D common cold

7. Which process is used for the exchange of genetic information between two bacterial cells?
A endospore formation
B lysogenic cycle
C conjugation
D binary fission

8. All bacteria are classified as
A eukaryotes.
B protists.
C archaea.
D prokaryotes.

Questions 9–10

Use the graph below to answer the questions.



9. At which interval in the graph does the number of living bacteria increase at the greatest rate?
A between hours 2 and 4
B between hours 4 and 6
C between hours 6 and 8
D between hours 10 and 12

10. Which is the most likely reason for the decrease in bacteria shown?
A The temperature of the bacterial culture was too high after 8 hours.
B The bacteria stopped reproducing after 8 hours.
C More nutrients were added to the culture at regular intervals.
D Waste products from the bacteria accumulated in the nutrient solution.

Open-Ended Response

11. Explain why antibiotics can be useful in treating bacterial diseases but not in treating viral diseases.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10	11
See Lesson	20.1	20.2	20.1	20.2	20.3	20.3	20.2	20.2	20.2	20.2	20.3

21 Protists and Fungi

Big idea

Interdependence in Nature

Q: How do protists and fungi affect the homeostasis of other organisms and ecosystems?

This goldcrest is perched on a branch covered with lichen. A lichen is a symbiotic relationship between a fungus and a photosynthetic organism, such as a green alga.

BIOLOGY.com Search Chapter 21 GO • Flash Cards

INSIDE:

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

"A BLIGHT OF UNUSUAL CHARACTER"

In the early 1800s, Irish farmers became heavily dependent on growing potatoes. Potatoes grew very well in the cool wet climate of Ireland. Soon potatoes became the main source of food for Irish families.

Then, during the summer of 1845, something strange began to happen. One magazine reported that "a blight of unusual character" was attacking the potatoes. Everywhere in Ireland, potatoes began to rot and turn black. Without their main food crop, many people starved. Others left Ireland to go to countries such as the United States. By the early 1900s, the population of Ireland was cut in half.

Read for Mystery Clues What caused this disaster? As you read this chapter, look for clues to help you find the cause of the potato blight. Then, solve the mystery.

FOUNDATIONS for Learning

If protists and fungi disappeared, our world would be a very different place. Make a double-door fold like the one shown below. Under Protists, write these headings: Autotrophs, Heterotrophs, Mutualists, Parasites. Under Fungi write Decomposers, Mutualists, Parasites. As you read the chapter, make notes under each of these headings. At the end of the chapter, you will find two activities that will help you answer the question: How do protists and fungi affect the homeostasis of other organisms and ecosystems?

21.1 Protist Classification

Key Questions

- *What are protists?*
- *How are protists related to other eukaryotes?*

BUILD Understanding

Preview Visuals Look at the photos in the cladogram about protist classification. Do you recognize any of these protists? Write down two questions that you have about the cladogram. As you read the lesson, try to answer the questions.

In Your Workbook Go to your workbook to learn more about previewing visuals. Complete the activity for Lesson 21.1.

The First Eukaryotes

More than a billion years ago, a new kind of organism appeared. These organisms had one cell. Their fossils show they were the first eukaryotes. Eukaryotes have cells with nuclei. Single-celled eukaryotes are still with us today. They are often called *protists*, which means "first." Protists are eukaryotes that are not fungi, plants, or animals.

Most protists are single celled, but some have many cells. The largest protists—brown algae called kelp—have millions of cells. They also have tissues. Kelp is considered to be a protist because it is more closely related to certain single-celled protists than it is to members of any other kingdom.

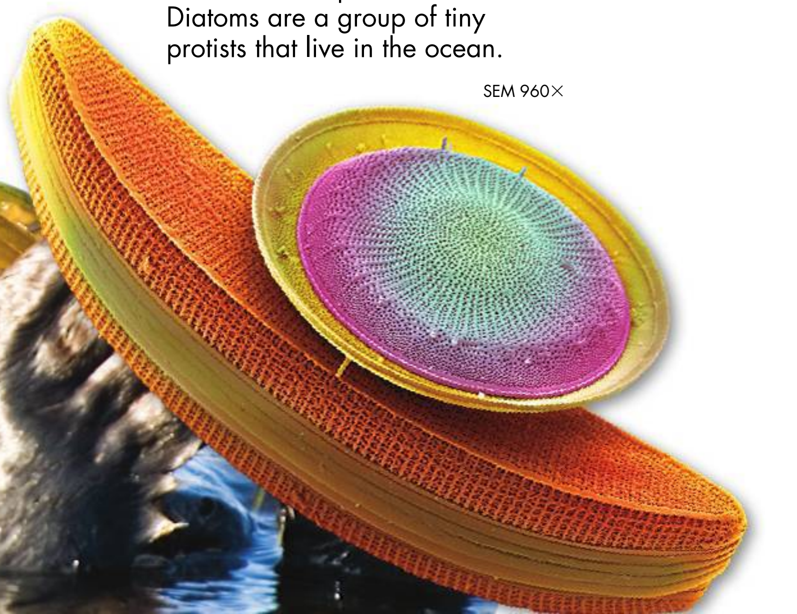
Key Question What are protists? **Protists are eukaryotes that are not members of the fungi, plant, or animal kingdoms.**

Kingdom Protista Protists were once classified in kingdom Protista. But in recent years, biologists have discovered that kingdom Protista is far more diverse than any other eukaryotic kingdom. Many protists are more closely related to members of other kingdoms than to other protists. This causes a problem in classification. The members of a kingdom should be more like one another than they are like members of other kingdoms. This is not true of protists. As a result, biologists are still undecided as to the best way to classify protists.

Giant Kelp Otters wrap themselves in giant kelp, a multicellular protist, to keep from drifting out to sea while they sleep.

Diatoms The shells of diatoms have beautiful patterns. Diatoms are a group of tiny protists that live in the ocean.

SEM 960×



INQUIRY into Scientific Thinking

What Are Protists?

Protists can be found in oceans, rivers, streams, lakes, and ponds. Many are too small to see without a microscope.

Procedure

1. Place a drop of pond water on a microscope slide. Add a drop of methyl cellulose. Cover the sample with a coverslip. Look at the slide under the microscope at low and high magnifications.
2. Write down your observations. Draw each kind of organism that you see. Label any structures, such as the nucleus, that you can identify.

Analyze and Conclude

1. **Explain** For any of the organisms that move, describe their motion. Describe any structures involved in producing the motion.
2. **Evaluate** Did you see any structures that you think are used to gather food? That are used for reproduction? Explain.
3. **Apply Concepts** Are any of the organisms you saw bacteria, plants, or animals? Explain your answer.

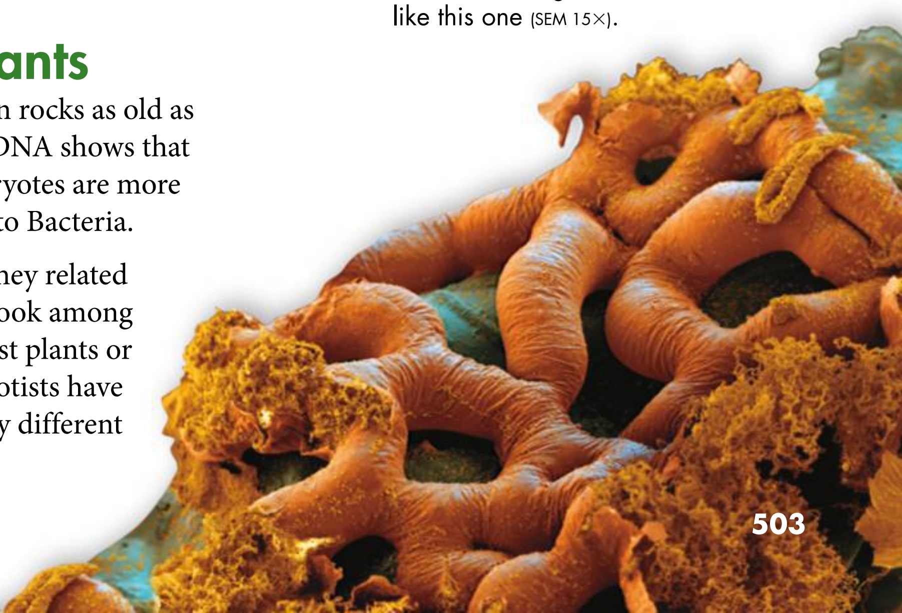
In Your Workbook
Get more help for this activity in your workbook.

Euglena Photosynthetic *Euglena* are common freshwater protists that can move (LM 250×).

Multiple Kingdoms? The most recent studies of protists divide them into six major groups, or clades. Each could be considered a kingdom. The fungi, plant, and animal kingdoms fit among these six protist groups. In fact, animals and fungi likely evolved from the same protist ancestor.

The Name "Protist" Most biologists today agree that the protists should not be lumped together into a single kingdom. Even so, they continue to call these organisms "protists." So, in this book, we will use the word "protist" to refer to these organisms.

Slime Molds At a certain stage of their life cycle, protists called slime molds come together into colonies like this one (SEM 15×).



Ancestors and Descendants

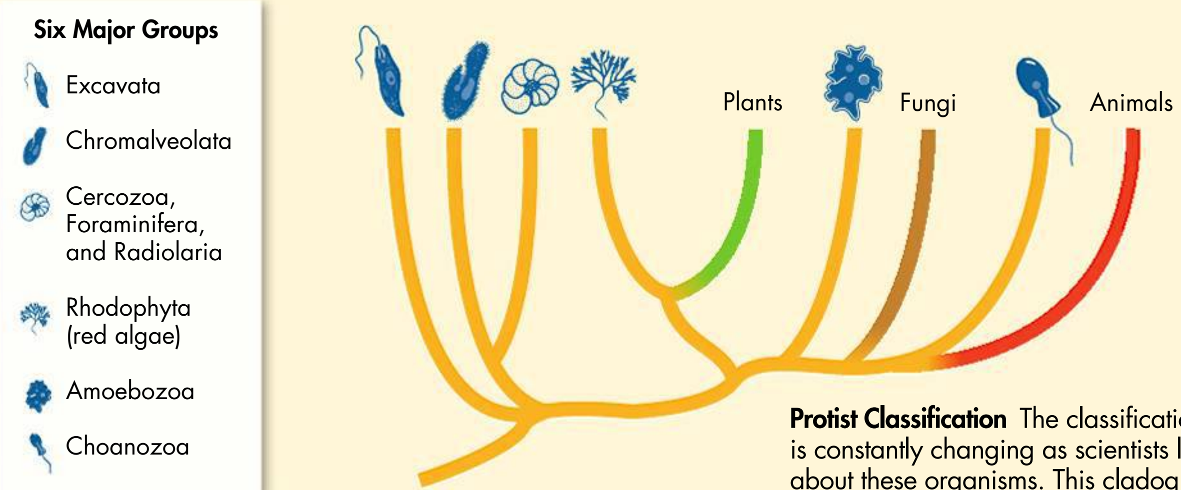
Fossils of eukaryotic cells have been found in rocks as old as 1.5 billion years. Evidence from fossils and DNA shows that eukaryotes evolved from prokaryotes. Eukaryotes are more closely related to present-day Archaea than to Bacteria.

Protists were the first eukaryotes. How are they related to other eukaryotes? It may be tempting to look among living protists to find the ancestors of the first plants or fungi. But it would be a mistake to do so. Protists have evolved over time. Those alive today are very different from their ancestors.

Euglena is classified as an excavate.

Brown algae, such as kelp (left), and diatoms (right) are examples of chromalveolates.

Slime molds are classified with the Amoebozoa.



Protist Classification The classification of protists is constantly changing as scientists learn more about these organisms. This cladogram shows a classification of protists based on recent research.

For more on the diversity of protists, go to the Visual Guide. **pp. DOL 10–15**

Today there are as many as 300,000 species of protists. Most are single celled. Some live in colonies. Two groups of protists—the red algae and the brown algae—include true multicellular organisms. Fungi, plants, and animals evolved from the ancestors of these two groups. Biologists continue to study protists closely. They know that clues about the beginnings of diversity in plants, animals, and fungi can be found among the protists.

Key Question How are protists related to other eukaryotes? **Today's protists include groups whose ancestors were among the last to split from the ancestors of plants, animals, and fungi.**

CHECK Understanding

Critical Thinking

1. **Explain** What is a protist?
2. **Compare and Contrast** Traditionally, protists were classified in kingdom Protista. How has the classification of protists changed?
3. **Relate Cause and Effect** What is a major reason why scientists need to reclassify protists?
4. **Apply Concepts** What three kingdoms arose from protist ancestors?
5. **Write to Learn** Scientists say that we should not look for the earliest ancestors of animals among modern-day protists. Write a short paragraph that explains why.

21.2 Protist Structure and Function

How Protists Move

Your body is packed with specialized systems. Organ systems help you move, break down food, and sense your environment. Imagine having only one cell. How would you carry out these functions? Single-celled protists don't have organs or organ systems. They have to do it all within a single cell. Despite these challenges, protists are very successful organisms. They successfully carry out all the activities necessary for life.

Protists move in several different ways. Some move by changing their shape. Others have specialized organelles for movement. Many protists do not move actively. These protists are carried by wind, water, or other organisms.

Amoeboid Movement Many single-celled protists move by changing their cell shape. First, a projection, or bulge, forms on the side of the cell. This projection is called a **pseudopod** (soo doh pahd). The pseudopod fills with cytoplasm. As cytoplasm flows into the pseudopod, the rest of the cell follows. This causes the cell to move. Amoebas are the best-known group of protists that move this way. As a result, this type of motion is called amoeboid movement.

Amoeboid movement is powered by a protein called actin. Actin is also found in the muscles of animals. In animals, actin plays an important role in muscle contraction.

Key Questions

How do protists move in the environment?

How do protists reproduce?

BUILD Understanding

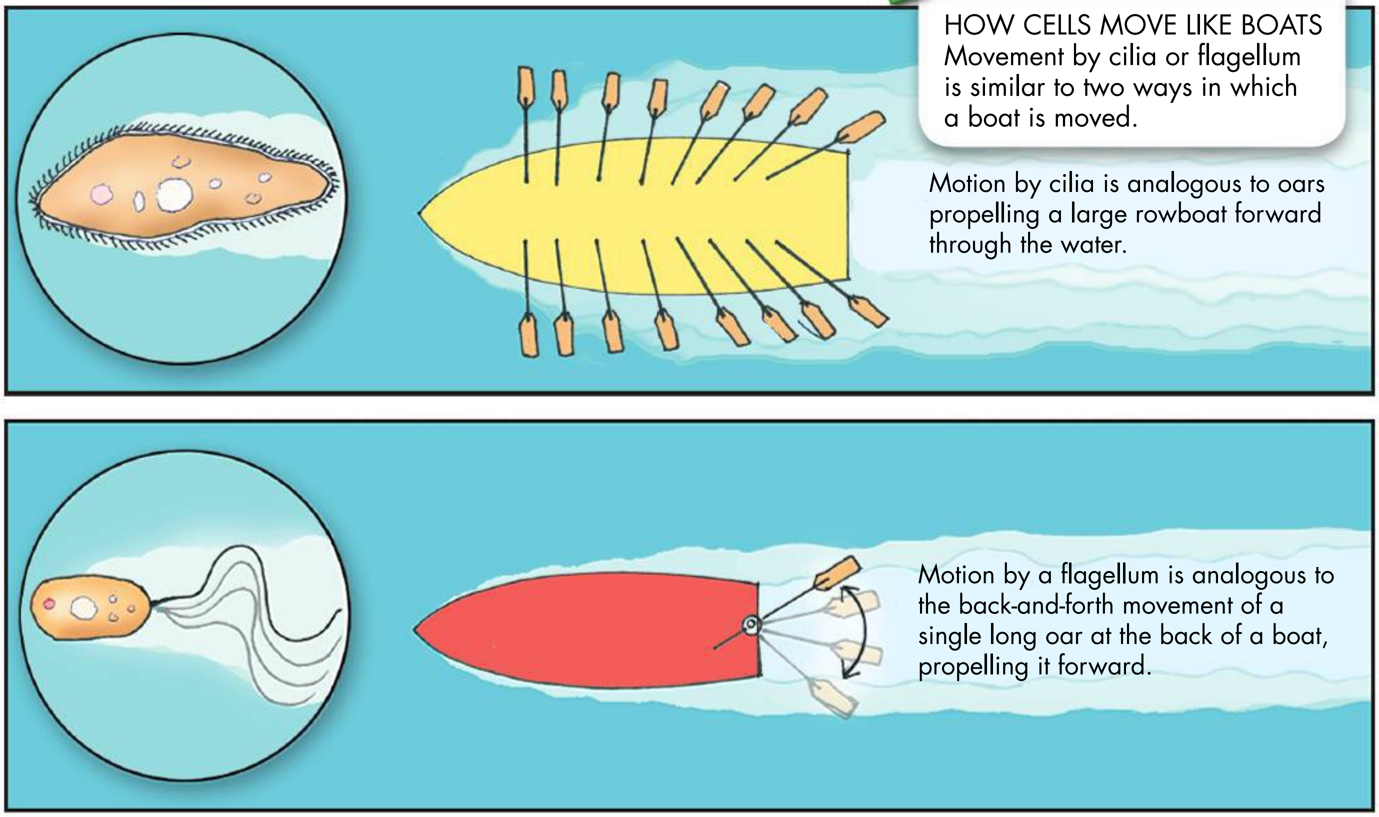
Compare/Contrast Table As you read the lesson, make a table that compares and contrasts the ways in which protists move.

In Your Workbook Go to your workbook to learn more about comparing and contrasting. Complete the table for Lesson 21.2.

(LM 220×)

Amoeboid Movement An amoeba moves by extending a pseudopod away from its body. Cytoplasm streams into the pseudopod. Then the rest of the cell follows. Amoebas also use pseudopods to surround and take in food. In these photos, the amoeba is consuming algae.

BUILD Connections



BUILD Vocabulary

pseudopod a temporary cytoplasmic projection used by some protists for movement

cilium a short, hairlike projection that produces movement

flagellum a structure used by protists for movement; produces movement in a wavelike motion

spore in prokaryotes, protists, and fungi, any of a variety of thick-walled life-cycle stages capable of surviving unfavorable conditions

conjugation a process in which paramecium and some prokaryotes exchange genetic information

alternation of generations a life cycle that has two alternating phases—a haploid (N) phase and a diploid (2N) phase

WORD ORIGINS

The word *pseudopod* comes from the Greek root *pseudo*, which means "false," and *pod*, which means "foot."

Cilia and Flagella Many protists move by means of cilia (SIL ee uh) and flagella (fluh JEL uh). These structures are supported by microtubules. Recall that microtubules are part of a cell's cytoskeleton. Cilia and flagella have nearly identical internal structures. However, they produce motion in different ways.

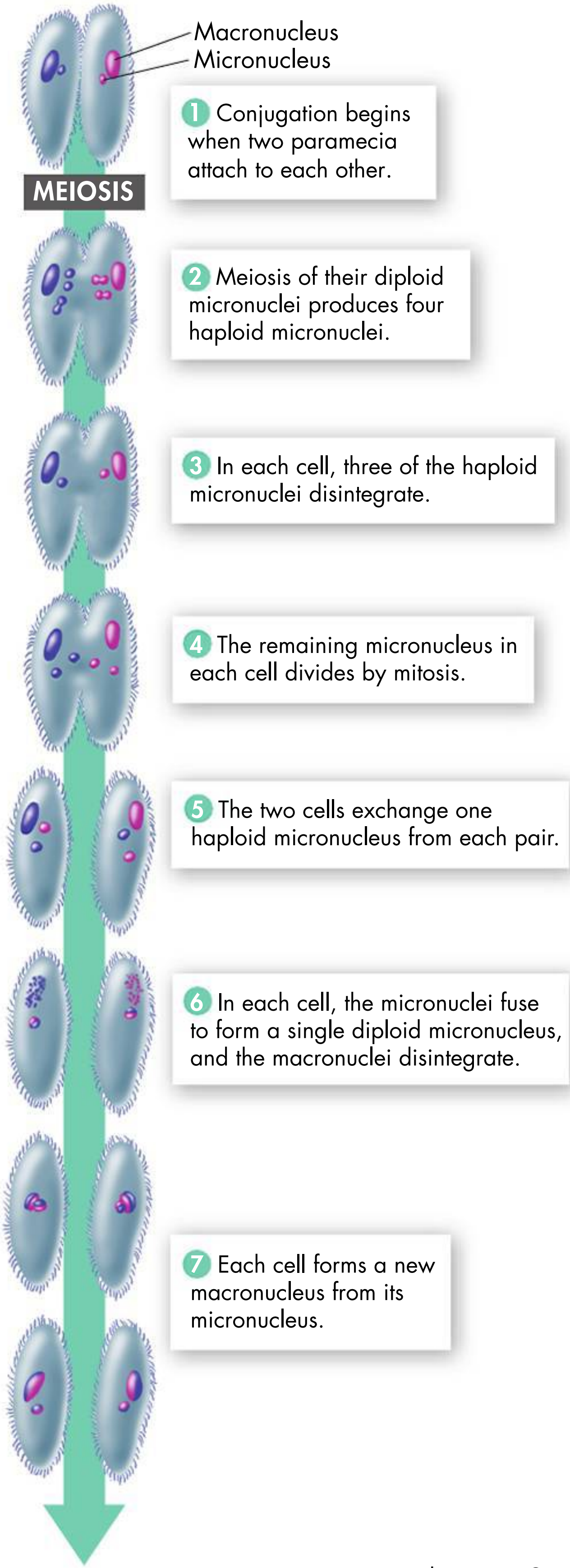
Cilia (singular: cilium) are short and numerous. They move somewhat like oars on a boat. Protists that move with cilia are known as ciliates.

Flagella (singular: flagellum) are relatively long. Usually a cell has one or two. Some flagella spin like tiny propellers. But most flagella move like a wave from base to tip. Protists that move by flagella are called flagellates.

Passive Movement Many protists depend on air, water currents, or other organisms to carry them around. These protists form reproductive cells called **spores.** Some spores can enter other organisms and live as parasites. One spore-forming protist is *Plasmodium*. *Plasmodium* is carried by mosquitoes. It causes malaria. *Cryptosporidium* is spread through contaminated drinking water. It causes severe intestinal disease in humans.

Key Question How do protists move in the environment?
Some protists move by changing their cell shape. Some use cilia or flagella. Others do not move actively but are carried by wind, water, or other organisms.

Conjugation During conjugation, two paramecia attach to each other and exchange genetic information.



Protist Reproduction

Some protists reproduce asexually. A few protists exchange genetic material during conjugation. Other protists have a life cycle that combines both asexual and sexual reproduction.

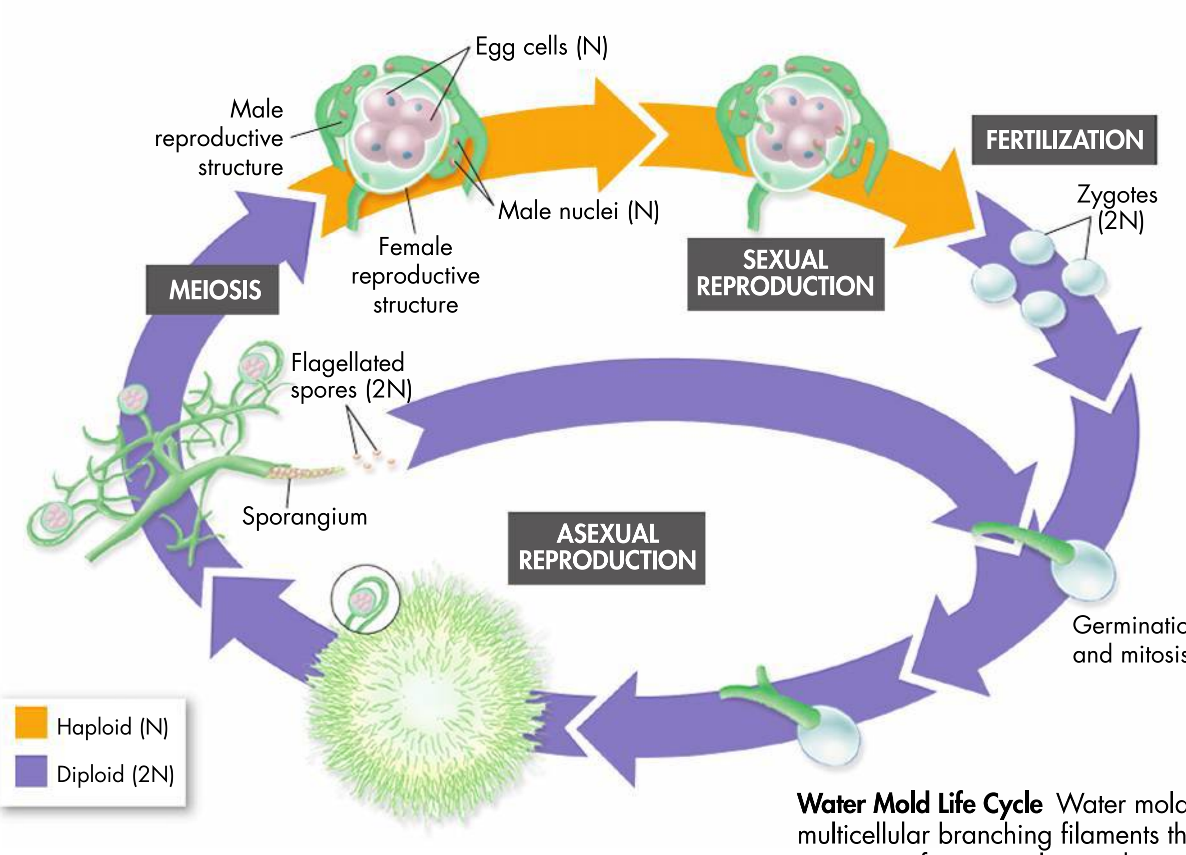
Cell Division Amoebas and other protists reproduce asexually by mitosis. First, the protist copies its genetic material. Then, the parent cell divides into two identical daughter cells. Mitosis lets protists reproduce quickly. However, mitosis produces cells that are genetically identical to the parent. Identical cells limit genetic diversity.

Conjugation Paramecia and most other ciliates reproduce asexually by mitosis. But when conditions are unfavorable, paramecia undergo conjugation. **Conjugation** is a process in which two organisms exchange genetic material. After conjugating, the cells reproduce by mitosis.

Paramecia have two types of nuclei: a macronucleus and one or more smaller micronuclei. The macronucleus controls the daily activities of the cell. Micronuclei contain the cell's chromosomes. During conjugation, the cells exchange haploid micronuclei. These micronuclei fuse to form a diploid micronucleus. Conjugation produces new combinations of genes, which can aid in evolution.

Sexual Reproduction Many protists have sexual life cycles that are complex. They alternate between diploid and haploid phases, in a process that is called **alternation of generations.** Water molds are one group of protists that have alternation of generations. Water molds reproduce asexually by producing diploid spores in a structure called a sporangium (spoh RAN jee um). Water molds also reproduce sexually. They undergo meiosis, forming male and female structures. These structures produce haploid nuclei. The nuclei fuse during fertilization, forming a diploid zygote.

Key Question How do protists reproduce? **Some protists reproduce asexually by mitosis. Others have life cycles that combine sexual and asexual forms of reproduction.**



Water Mold Life Cycle Water molds grow into multicellular branching filaments that produce sporangia for asexual reproduction or male and female structures for sexual reproduction.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. During amoeboid movement, a protist produces ________, or projections that fill with cytoplasm.

2. During ________, protists exchange genetic information.

3. Some protists form ________, reproductive cells that can enter the cells of other organisms and live as parasites.

Critical Thinking

4. **Explain** Summarize three ways in which protists move.

5. **Compare and Contrast** How does movement by means of cilia differ from movement by means of flagella?

6. **Review** Describe how protists reproduce.

7. **Write to Learn** Answer the first mystery clue. Use the words *asexual reproduction* and *sexual reproduction* in your answer.

MYSTERY CLUE

To produce more potatoes, Irish farmers cut the eyes, or buds, from a crop and saved them for the next year. As a result, the potatoes grown were genetically identical. How might this practice have made the potato blight worse? (Hint: See p. 507.)

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21.3 The Ecology of Protists

Autotrophic Protists

Seaweed in the ocean and the green scum on a pond are both commonly called *algae*. Many kinds of algae are protists.

Diversity of Algae Organisms called *algae* belong to several different groups. Some are prokaryotes. Others, such as green algae, are plants. Many are protists. All these organisms are autotrophs. They use energy from sunlight to make their own food by photosynthesis. Photosynthetic protists include many species of phytoplankton. Phytoplankton are small algae that float near the water's surface. Red and brown algae, euglenas, and dinoflagellates are also photosynthetic protists.

Ecological Roles Photosynthetic protists form the base of food chains in the ocean and in fresh water.

▶ ***Feeding Fish and Other Animals*** Phytoplankton carry out about half of the photosynthesis that takes place on Earth. Phytoplankton are eaten by organisms as diverse as shrimp and baleen whales. And when you eat fish such as tuna, you are indirectly getting energy from phytoplankton.

▶ ***Supporting Coral Reefs*** Algae play two key roles in coral reefs. They provide nutrients from photosynthesis to coral animals. They also provide the calcium carbonate that coral reefs need to grow.

Key Questions

How are photosynthetic protists important to ecosystems?

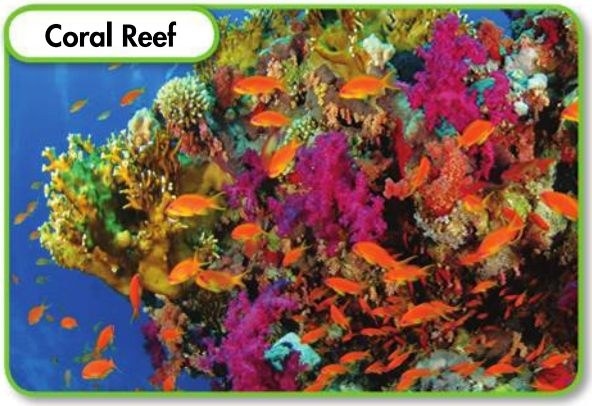
How do heterotrophic protists get food?

What types of symbiotic relationships involve protists?

BUILD Understanding

KWL Chart Before you read Lesson 21.3, make a chart with four columns. In the left column, write the titles and headings in the lesson. In the second column, write what you already know about each topic. In the third column, write what you expect to learn. After you read the lesson, write what you learned in the last column.

In Your Workbook Go to your workbook to learn more about making a KWL chart.



Producers in the Food Chains Many ocean animals, including baleen whales, fishes, and coral animals, rely on photosynthetic protists for food.

BUILD Vocabulary

algal bloom
an increase in the amount of algae and other producers that results from a large input of a limiting nutrient

food vacuole
a small cavity in the cytoplasm of a protist that temporarily stores food

gullet
a dent in one side of a ciliate that allows food to enter the cell

plasmodium
the amoeboid feeding stage in the life cycle of a plasmodial slime mold

MULTIPLE MEANINGS

The name *Amoeba* refers to a genus of protists. Without italics or capitalization, the word *amoeba* can describe any protist that moves with pseudopods. In this sense, the adjective *amoeboid* describes the single-celled form of slime molds.

▶ ***Providing Shelter*** Giant kelp and *Sargassum* are multicellular brown algae. They provide shelter for marine species, such as sea otters and many kinds of fishes.

▶ ***Recycling Wastes*** Protists help break down and recycle nutrients in sewage and other waste materials. But if there is too much waste, populations of protists can quickly grow to huge numbers. This situation is called an **algal bloom.** An algal bloom can use up nutrients. As these protists die, their bodies decay. This decay removes oxygen from the water, killing fish and invertebrates. Blooms of protists called dinoflagellates cause red tides. Toxins from dinoflagellates can poison fish and shellfish.

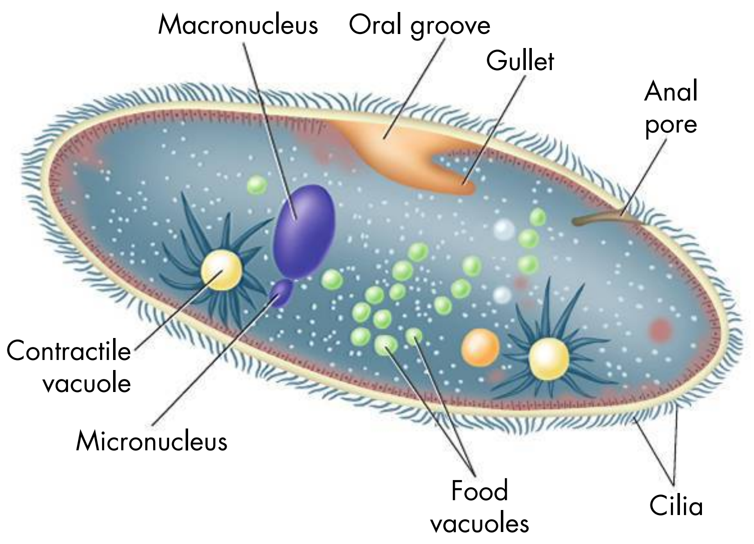
Key Question How are photosynthetic protists important to ecosystems? **Photosynthetic protists form the base of food chains in the oceans and in freshwater environments.**

Heterotrophic Protists

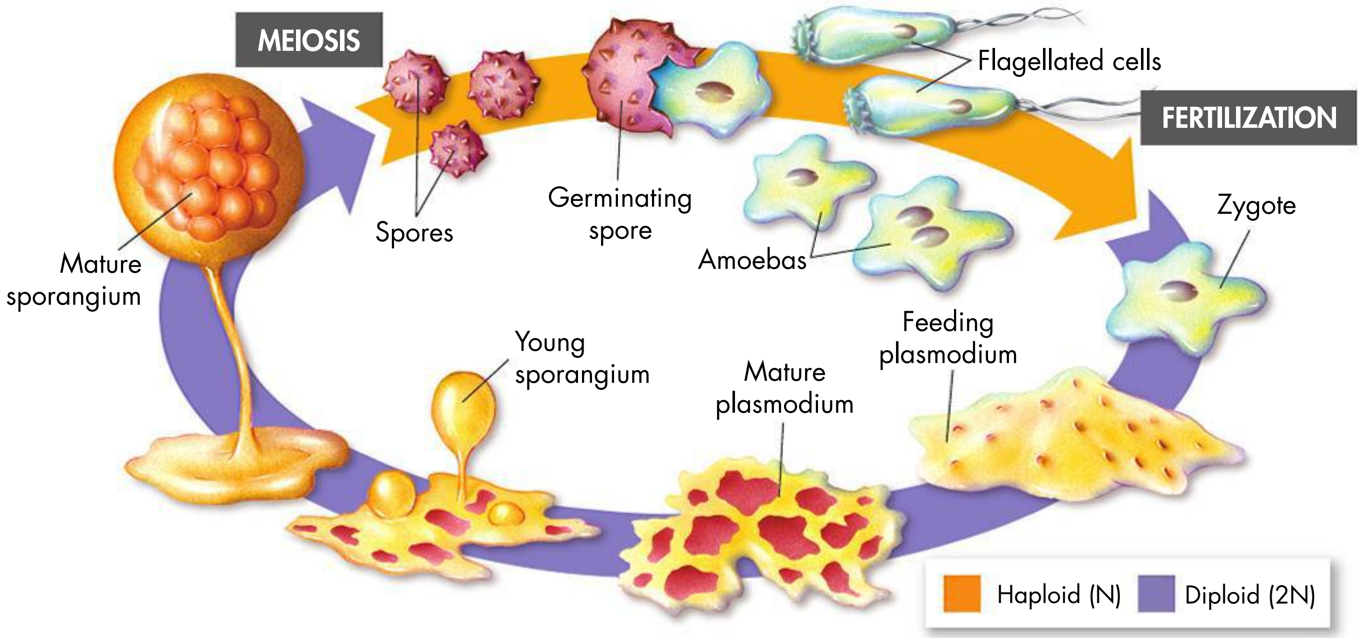
Many protists are heterotrophs. They get food from other organisms. Some heterotrophic protists surround and digest their food. Others absorb nutrients from their surroundings.

Amoebas Amoebas feed by surrounding a cell or food particle. This food is held in a food vacuole. A **food vacuole** is a small cavity in the cytoplasm that temporarily stores food. The food is digested, and the nutrients are passed to the rest of the cell. The vacuole releases waste materials outside the cell.

Ciliates Ciliates sweep food into their **gullet,** a dent in one side of the organism. The particles are forced into food vacuoles at the base of the gullet. The food vacuoles fuse with lysosomes, which contain digestive enzymes. The vacuole releases waste materials through the anal pore.



Feeding Structures of *Paramecium*
Cilia that line the oral groove and gullet move food into the cell. The food particles are surrounded, forming food vacuoles. Wastes are released through the anal pore.



Slime Mold Life Cycle In the life cycle of a slime mold, the diploid feeding stage involves a collection of slime mold amoebas called a plasmodium. The plasmodium produces sporangia, which undergo meiosis and produce haploid spores. The spores grow into amoebalike or flagellated cells. Then the flagellated cells fuse to form diploid zygotes that repeat the cycle.

Slime Molds Slime molds live in damp places that are rich in dead organic matter, such as a forest floor or a compost pile. Because they are decomposers, slime molds play key roles in recycling nutrients.

Slime molds have complex life cycles. In the haploid phase, slime molds are single-celled amoebas or flagellated cells. In the diploid phase, the amoebas form a multicellular structure called a **plasmodium.** The plasmodium develops sporangia, which produce haploid spores.

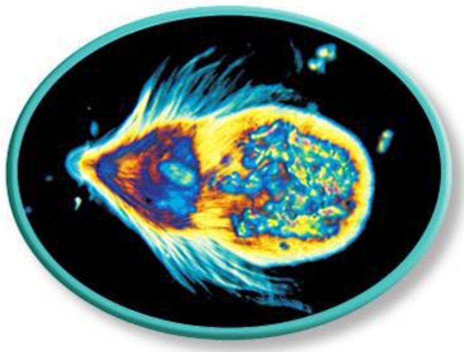
Protists That Absorb Food Some protists absorb nutrients that other organisms have released into the environment. For example, water molds absorb molecules from decaying plants and animals through their cell walls and cell membranes.

Key Question How do heterotrophic protists get food? **Some protists surround and digest their food. Other protists absorb food molecules from their surroundings.**

Symbiotic Protists

Many protists are involved in symbiotic relationships with other organisms. Recall that symbiosis is a relationship in which two species live closely together. Mutualism and parasitism are two kinds of symbiosis.

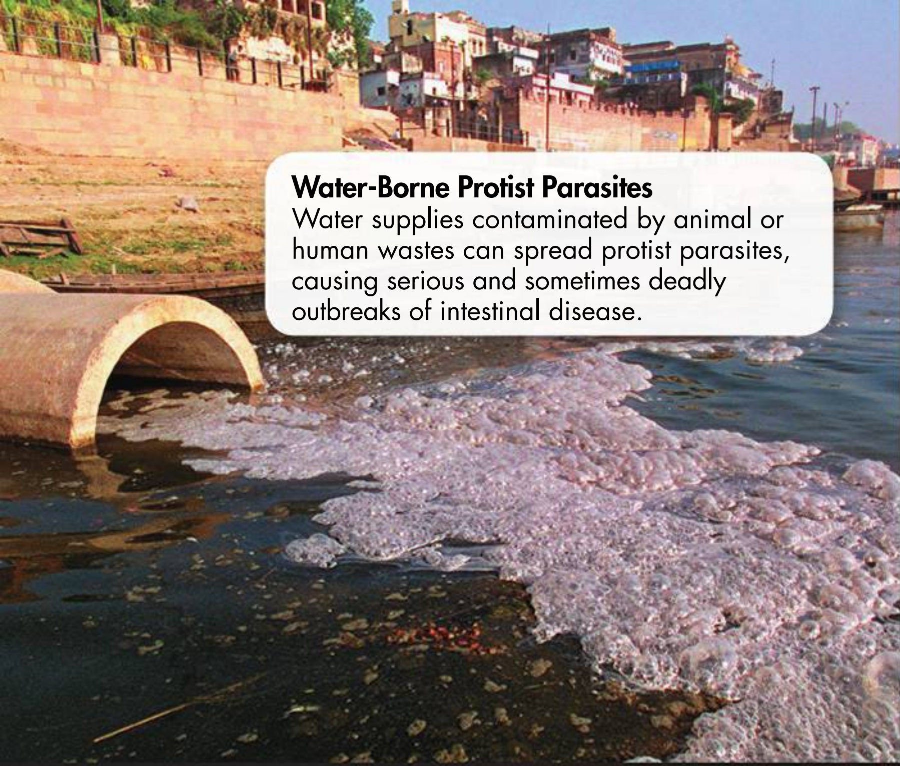
Mutualists Many protists are involved in mutualistic relationships. Both the protist and its host benefit. Termites and the protist *Trichonympha* are an example. Termites eat wood, but cannot break down the cellulose in wood. *Trichonympha* lives in the gut of the termite. It makes an enzyme called cellulase, which breaks down cellulose. This enzyme allows the termite to get energy from wood.

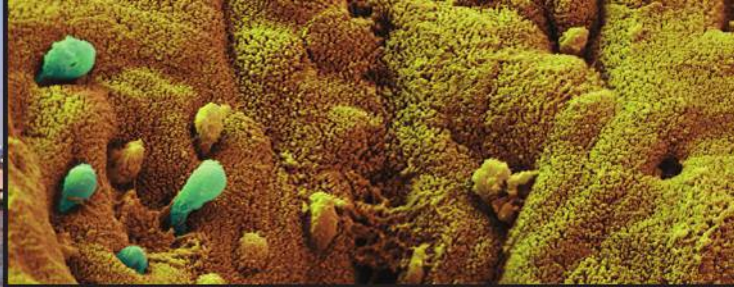


A Protist Mutualist *Trichonympha* lives in the gut of termites. This protist makes enzymes that break down the cellulose in wood (LM 250×).

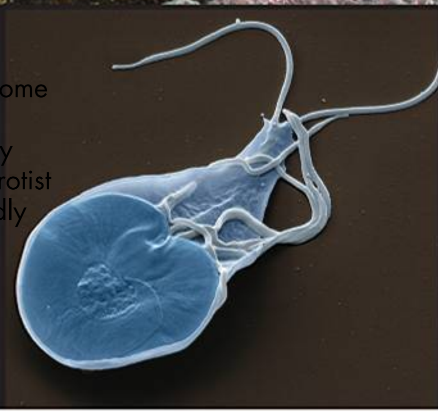
Water-Borne Protist Parasites

Water supplies contaminated by animal or human wastes can spread protist parasites, causing serious and sometimes deadly outbreaks of intestinal disease.

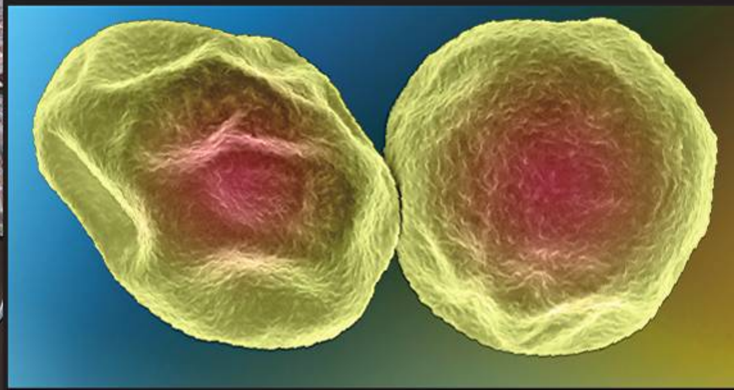




▲ *Entamoeba* causes a disease known as amebic dysentery. The amoebas live in the intestines, where they absorb food from the host. They also attack the wall of the intestine itself, shown above, destroying parts of it and causing severe bleeding. (SEM 2500×)



▶ The flagellated protist *Giardia* causes severe diarrhea and digestive system problems. Even crystal-clear streams may be contaminated with *Giardia*. It can be killed only by boiling water thoroughly or by adding iodine to the water. (SEM 1500×)



▲ *Cryptosporidium* is resistant to the chlorine compounds often used to sanitize drinking water. Therefore, it poses a special threat to public water systems. (SEM 16,000×)

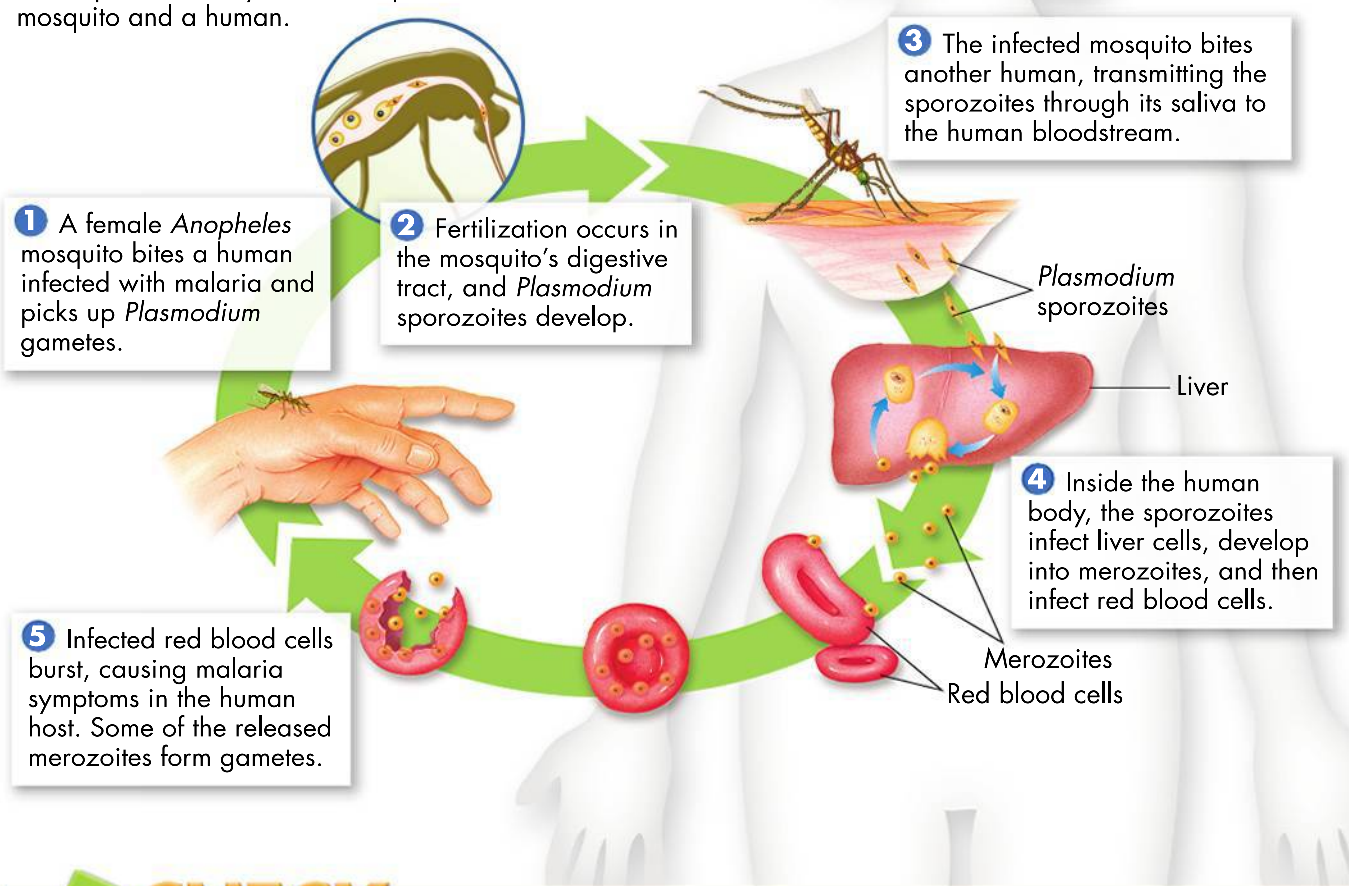
Parasites and Disease Parasitic protists cause some of the world's deadliest diseases. In humans, they cause African sleeping sickness, malaria, and several intestinal diseases.

▶ ***African Sleeping Sickness*** Protists in the genus *Trypanosoma* cause African sleeping sickness. These protists destroy blood cells. They also infect other tissues, including nerve cells. Damage to the nervous system makes some people fall into a deep sleep, or even die. Trypanosomes are spread from person to person by the bite of the tsetse fly.

▶ ***Malaria*** Malaria is one of the world's most serious infectious diseases. More than 1 million people die from malaria every year. Malaria is caused by *Plasmodium*. This spore-forming protist is carried by the *Anopheles* mosquito. The art on the next page shows the life cycle of *Plasmodium*.

Key Question What types of symbiotic relationships involve protists? **Many protists are involved in mutualistic symbiosis, in which both they and their hosts benefit. Parasitic protists cause some of the world's deadliest diseases.**

***Plasmodium* Life Cycle** *Plasmodium*, which causes malaria, needs two hosts to complete its life cycle: an *Anopheles* mosquito and a human.



CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. During the feeding stage, slime molds form a(n) ________.

2. During a(n) ________, the population of algae increases greatly.

3. A ciliate has a small dent on one side called a(n) ________, through which food enters the cell.

Critical Thinking

4. Explain What is the role of autotrophic protists in ocean ecosystems?

5. Compare and Contrast Compare how amoebas, ciliates, and water molds get food.

6. Explain Give one example of mutualism and one example of parasitism by protists.

7. Write to Learn Answer the second clue of the chapter mystery. Explain how the blight organism gets nutrients. Include the words *symbiosis* and *parasite.*

MYSTERY CLUE

The organism that caused the potato blight absorbs nutrients through its cell walls. What organism described in this lesson gets nutrients in a similar way? (Hint: See p. 511.)

BIOLOGY.com Search Lesson 21.3 GO • Lesson Assessment

21.4 Fungi

Key Questions

What are the basic characteristics of fungi?

How do fungi affect homeostasis in the environment?

BUILD Understanding

Concept Map As you read the lesson, use the new terms you learn to make a concept map. In your concept map, show how fungi affect other organisms in the environment.

In Your Workbook Go to your workbook to learn more about concept maps. Complete the concept map for Lesson 21.4.

What Are Fungi?

Imagine walking through the woods. Around a tree, you see a ring of many mushrooms. Which organism is bigger, the tree or the mushrooms? You may be surprised to learn that all the mushrooms are part of a single fungus. Most of this fungus is growing underground. It may be bigger than the tree!

Because many fungi grow from the ground, scientists once classified them as plants. But instead of carrying out photosynthesis, fungi are heterotrophs. They produce enzymes that digest food outside their bodies. Then their bodies absorb the resulting nutrients. Many fungi absorb nutrients from decomposing matter in soil. Others live as parasites, absorbing nutrients from their hosts.

Scarlet Cup Fungus

Fungi are eukaryotes. They have cells walls that contain chitin (KY tun). **Chitin** is a complex carbohydrate that is also found in the skeletons of insects. The presence of chitin shows that fungi are more closely related to animals than to plants. (The cell walls of plants contain cellulose, not chitin.)

Key Question What are the basic characteristics of fungi?
Fungi are heterotrophic eukaryotes. They have chitin in their cell walls.

Structure and Function Fungi may have one cell or many. Yeasts are tiny fungi that live most of their lives as single cells.

Mushrooms and other fungi grow much larger. Their bodies are made up of cells that form long, slender branching filaments called **hyphae** (HY fee; singular: hypha). In most fungi, cross walls divide the hyphae into compartments resembling cells. Each compartment has one or two nuclei. Cytoplasm and organelles can move through openings in the cross walls.

What we call a mushroom is actually the **fruiting body,** or reproductive structure of the fungus. It grows from the **mycelium** (my SEE lee um; plural: mycelia), a mass of branching hyphae below the soil. The structure of a fungus is shown in the art below. The mycelia of some fungi live for many years and grow very large. Clusters and rings of mushrooms are often part of the same mycelium. That means they are all part of one organism.

BUILD Vocabulary

chitin
a complex carbohydrate that makes up the cell walls of fungi; also found in the exoskeletons of insects

hypha (pl. hyphae)
one of the many long, slender filaments that make up the body of a fungus

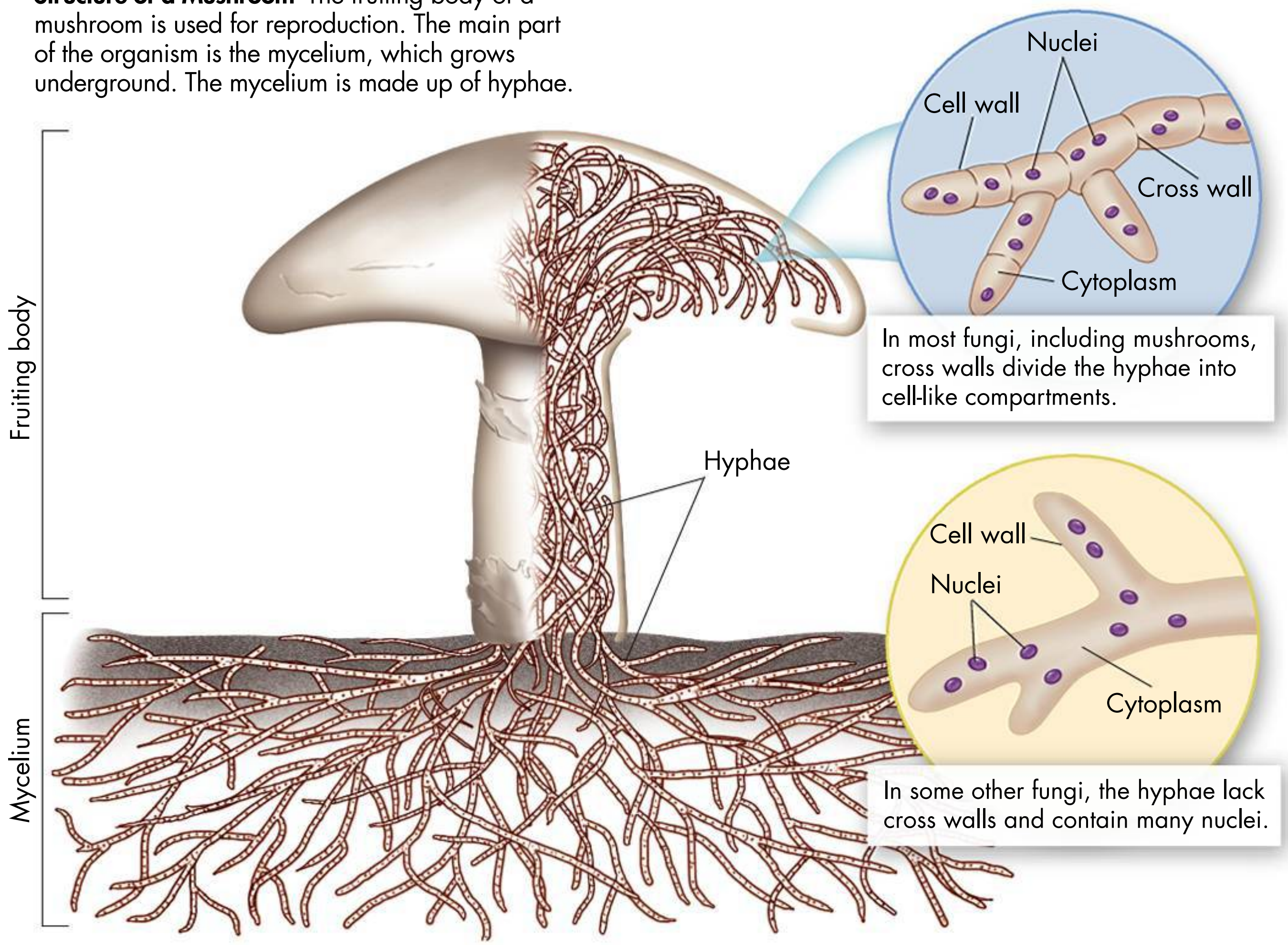
fruiting body
the reproductive structure of a fungus that grows from the mycelium

mycelium
a densely branched network of the hyphae of a fungus

WORD ORIGINS

The word *hypha* comes from a Greek word that means "web." If you look closely at the hyphae in a mushroom, they will look much like a tangled web.

Structure of a Mushroom The fruiting body of a mushroom is used for reproduction. The main part of the organism is the mycelium, which grows underground. The mycelium is made up of hyphae.



In most fungi, including mushrooms, cross walls divide the hyphae into cell-like compartments.

In some other fungi, the hyphae lack cross walls and contain many nuclei.

Reproduction Fungi can reproduce asexually. They do so mainly by releasing spores that can travel through air and water. Other kinds of asexual reproduction include breaking off a hypha or budding off a cell.

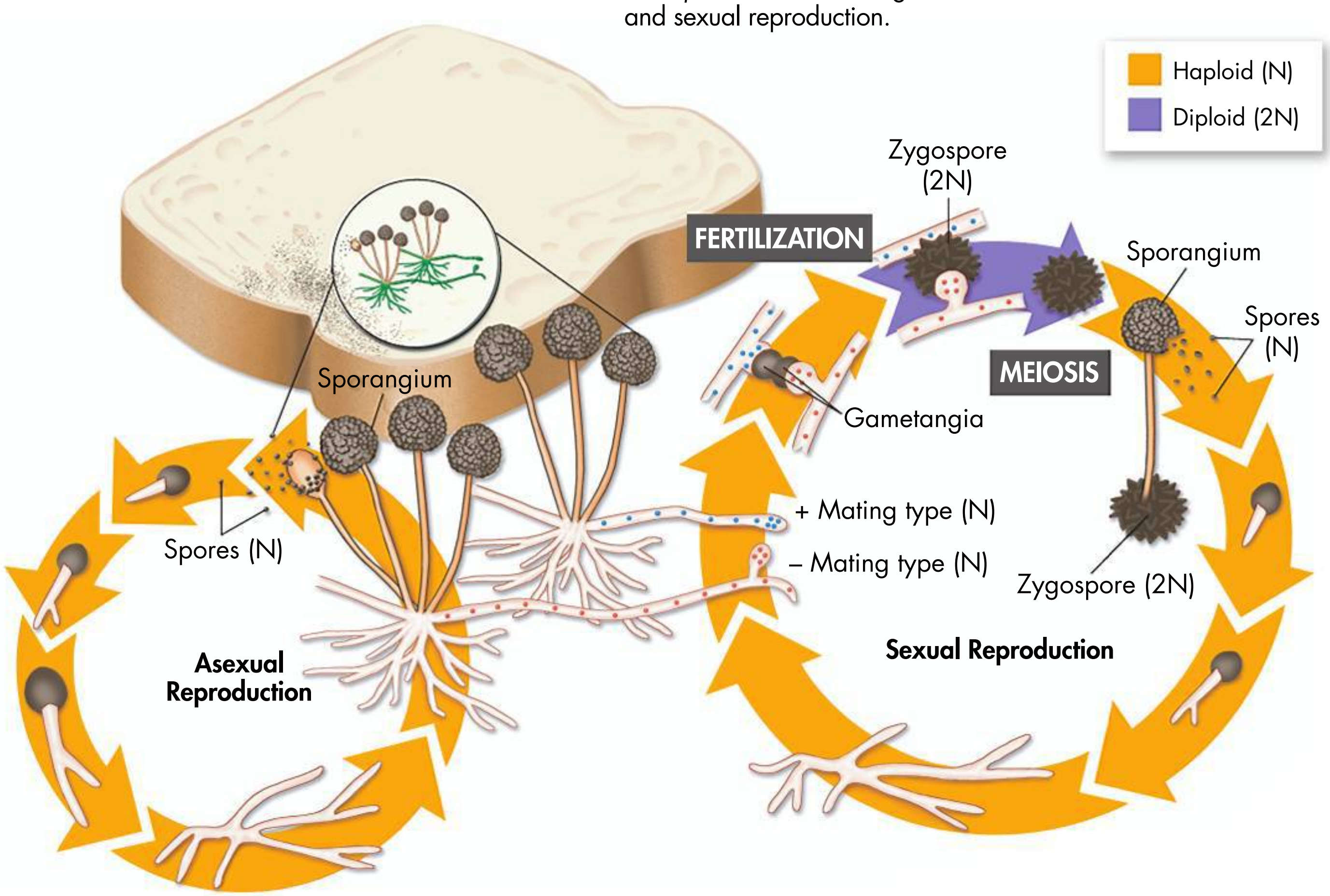
Most fungi also reproduce sexually. Sexual reproduction often involves two mating types. They are not called male and female. Instead, they are called *plus* (+) and *minus* (−). When hyphae of opposite mating types meet, they fuse. The + and − nuclei are brought together in the same cell. The nuclei form pairs that divide together as the mycelium grows.

Many of the paired nuclei fuse to form diploid zygotes. Zygotes form within a structure called a zygospore. The zygospore germinates, producing a sporangium. The sporangium releases haploid spores that form by meiosis. Each spore has a different combination of parental genes. Each can grow into a new mycelium.

For more on the diversity of fungi, go to the Visual Guide. **DOL 16–19**

Diversity of Fungi More than 100,000 species of fungi have been identified. Biologists have used similarities and differences, along with DNA comparisons, to place the fungi into several groups. A major way in which these groups differ is their reproductive structures.

Bread Mold Life Cycle The bread mold *Rhizopus stolonifer* undergoes both asexual and sexual reproduction.



The Major Phyla of Fungi

Phylum	Distinguishing Features	Examples
Basidiomycota (club fungi) 	Sexual spores found in club-shaped cell called a basidium	Mushrooms, puffballs, earthstars, shelf fungi, jelly fungi, rusts
Ascomycota (sac fungi) 	Sexual spores found in saclike structure called an ascus	Morels, truffles, *Penicillium* species, yeasts
Zygomycota (common molds) 	Tough zygospore produced during sexual reproduction that can stay dormant for long periods	*Rhizopus stolonifer* (black bread mold), molds found on rotting strawberries and other soft fruits, mycorrhizae associated with plant roots
Chytridomycota (chytrids) 	Only fungi with flagellated spores	Many species are decomposers found in lakes and moist soil.

Phyla of Fungi This table summarizes the main differences among four phyla of fungi.

The Ecology of Fungi

Fungi play a major role in nearly every ecosystem. Some fungi that are parasites cause diseases in plants and animals.

Decomposition Many fungi feed by releasing digestive enzymes. These enzymes break down leaves, fruit, and other organic material into simple molecules. The molecules then diffuse into the fungus. Enzymes from mycelia of mushrooms speed up the decomposition of wastes and dead organisms.

Fungi are champions of decomposition. Fungi help recycle essential elements and nutrients. Many plants remove important elements and nutrients from the soil. If these materials were not returned to the soil, other organisms could not use them. Without these nutrients, organisms would die. Eventually, Earth would become barren and lifeless.

Key Question How do fungi affect homeostasis in the environment? **Many fungi are decomposers that help ecosystems maintain homeostasis by breaking down dead organisms and recycling essential elements and nutrients.**

Parasitism Many fungi are helpful to other organisms. But parasitic fungi cause many serious diseases.

▶ ***Plant Diseases*** Several parasitic fungi cause diseases that threaten food crops. Corn smut, for example, destroys corn kernels. Wheat rust affects North American wheat crops. Some mildews, which infect many different plants, are also fungi. In temperate areas, fungi destroy about 15 percent of crops. In tropical areas, a greater percentage is lost to fungal diseases.

Parasitic Fungi Some fungi are parasites.

Corn smut infests the kernels of a corn plant, reducing the farmer's crop yield.

A moth is infected by a *Cordyceps* fungus.

BUILD Vocabulary

lichen
a symbiotic relationship between a fungus and a photosynthetic organism

mycorrhiza
a symbiotic association of plant roots and fungi

RELATED WORD FORMS

Symbiosis is a noun that describes two unlike organisms living closely together. *Symbiotic* is an adjective referring to a symbiosis.

▶ ***Animal Diseases*** Fungal diseases also affect animals, including insects, frogs, and mammals. One deadly example is caused by a fungus in the genus *Cordyceps*. This fungus infects grasshoppers in rain forests in Costa Rica. Microscopic spores become lodged in the grasshopper. The spores germinate and produce enzymes. These enzymes slowly eat through the insect's tough outer skeleton. The spores multiply in the insect's body, digesting cells and tissues. Eventually, the insect dies. Hyphae develop, covering the insect skeleton. Reproductive structures emerge from the grasshopper's remains. They produce more spores and spread the infection.

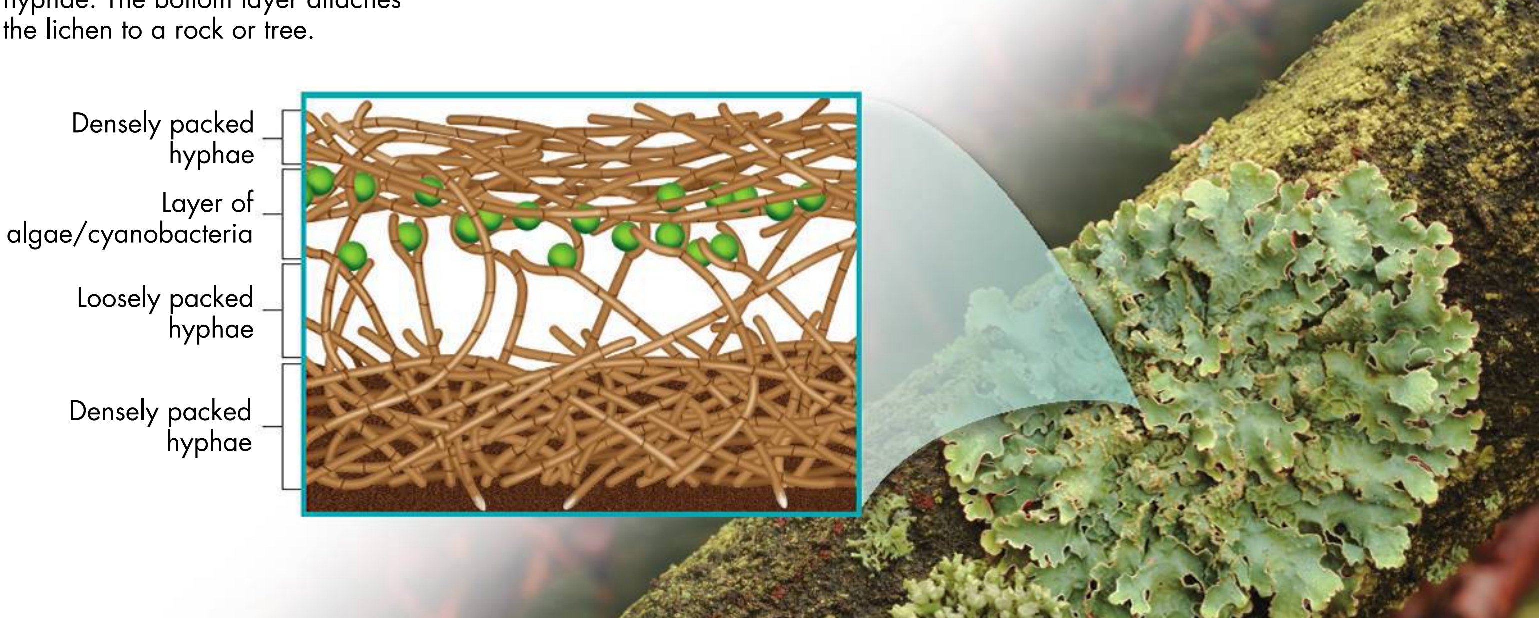
Key Question How do parasitic fungi affect other organisms? **Parasitic fungi can cause serious diseases in plants and animals.**

▶ ***Human Diseases*** Parasitic fungi also infect humans. For example, athlete's foot is caused by a fungus. Its mycelium grows in the outer layers of skin, causing sores. Spores from these sores can easily spread to other people.

The yeast *Candida albicans* also causes human diseases. It usually infects the mouth or vagina. *Candida* is usually kept in check by competition from bacteria and by the body's immune system. This balance can be upset by the use of antibiotics, which kill bacteria, or by damage to the immune system.

Lichens Some fungi form mutualistic relationships with photosynthetic organisms. Both partners benefit from these relationships. For example, a **lichen** (LY kun) is a mutualistic relationship between a fungus and a photosynthetic organism. The photosynthetic organism may be a green alga, or a photosynthetic bacterium called cyanobacteria. The green algae or cyanobacteria carry out photosynthesis. This provides the fungus with food. The fungus provides the green algae or cyanobacteria with water and minerals. The fungal hyphae protect the delicate green cells from bright sunlight.

Inside a Lichen The protective upper surface of a lichen is made up of densely packed fungal hyphae. Below this are layers of green algae or photosynthetic bacteria and loosely packed hyphae. The bottom layer attaches the lichen to a rock or tree.



Lichens can grow in places where few other organisms can survive. For example, they grow on rocks in deserts and on the tops of mountains. They are often the first organisms to enter barren environments. They gradually break down the rocks on which they grow. In this way, lichens help in the early stages of soil formation.

Lichens are very sensitive to air pollution. They are among the first organisms affected when air quality gets worse.

Mycorrhizae Fungi also form mutualistic relationships with plant roots. These relationships are called **mycorrhizae** (my koh RY zee; singular: mycorrhiza). Hyphae of the fungi form a large web connecting the roots and the soil. The hyphae bring water and minerals to the roots. The fungi also make enzymes that free nutrients in the soil. The plants, in turn, give the fungi food from photosynthesis.

The partnership between plant and fungus does not end with a single plant. Mycorrhizae networks connect the roots of many plants. Some networks even connect plants of different species!

Many plants need mycorrhizae to grow. The seeds of orchids, for example, will not grow without mycorrhizal fungi. Many trees cannot live without mycorrhizae. Between 80 and 90 percent of all plant species may form mycorrhizae.

Mycorrhizae Research shows that mycorrhizae on Douglas fir roots help the trees get nutrients from other trees, including trees of other species.

Key Question How do fungi affect homeostasis in other organisms? **Some fungi form mutualistic relationships with photosynthetic organisms that help both partners.**

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The ________ is the reproductive structure of a fungus.
2. Fungal cells that form long, slender filaments are called ________.
3. Fungal cell walls contain ________, a complex carbohydrate.
4. A ________ is the symbiotic association of plant roots and fungi.

Critical Thinking

5. **Apply Concepts** What characteristics do all fungi have in common?
6. **Infer** Tissue from several mushrooms found near the base of a tree were tested. They were found to be genetically identical. How would you explain this?
7. **Explain** Describe two kinds of symbiotic relationships that fungi form.
8. **Apply Concepts** Summarize two ways in which fungi maintain the homeostasis of a forest ecosystem.
9. **Write to Learn** Answer the third mystery clue. In your answer, use the words *chitin* and *hyphae*.

MYSTERY CLUE

Using a microscope, scientists found that the infected tissue from blighted potatoes had a network of hyphae. The hyphae cell walls did not contain chitin. Could the blight be caused by a fungus? (Hint: See p. 514.)

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Design Your Own Lab

GUIDED INQUIRY

Pre-Lab: Mushroom Farming

Problem How does the amount of available light affect mushroom growth?

Materials mushroom growing kits, spray bottle with water, metric ruler

Lab Manual Chapter 21 Lab

Skills Focus Form a Hypothesis, Design an Experiment, Organize Data

Connect to the Big idea Fungi play an essential role in maintaining homeostasis in ecosystems. Many fungi speed up the decay of dead organisms and help recycle nutrients. Some fungi form symbiotic relationships with plants. These fungi deliver water and minerals to the plant roots. In turn, the plants supply the fungi with sugars. Do fungi grow better in some environments than in others? In this lab, you will investigate how the amount of light affects the growth and reproduction of a species of club fungi.

Background Questions

a. **Review** What are fungi?

b. **Review** Describe the general structure of a mushroom.

c. **Explain** How do fungi that are not in a symbiotic relationship obtain nutrients?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Infer** Where will the mushrooms get the nutrients that they need to grow and reproduce?
2. **Relate Cause and Effect** Why will you have to wait about ten days to observe the mushrooms?
3. **Apply Concepts** The mushrooms you will grow are of a variety that is sold in food stores. Why do the instructions warn you not to eat the mushrooms?

BIOLOGY.com Search Chapter 21 GO

Visit Chapter 21 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Have a look at the fascinating world of mushrooms through the lenses of the Untamed Science crew.

Art in Motion View a short animation that shows the plasmodium life cycle and how malaria is transmitted by the *Anopheles* mosquito.

Art Review Review your understanding of the different structures of a mushroom.

InterActive Art Investigate the structures of an amoeba and paramecium.

Visual Analogy Compare the way boats move to the motion of flagella and cilia in a cell.

Chapter 21 Summary

21.1 Protist Classification

- Protists are eukaryotes that are not members of the fungi, plant, or animal kingdoms.
- Today's protists include groups whose ancestors were among the very last to split from the ancestors of plants, animals, and fungi.

21.2 Protist Structure and Function

- Some protists move by changing their cell shape. Some use cilia or flagella. Others do not move actively but are carried by wind, water, or other organisms.
- Some protists reproduce asexually by mitosis. Others have life cycles that combine asexual and sexual forms of reproduction.

pseudopod (p. 505)
cilium (p. 506)
flagellum (p. 506)
spore (p. 506)
conjugation (p. 507)
alternation of generations (p. 507)

SEM 270×

21.3 The Ecology of Protists

- Photosynthetic protists form the base of food chains in the oceans and in freshwater environments.
- Some protists surround and digest their food. Other protists get food by absorbing molecules from their surroundings.
- Many protists are involved in mutualistic symbiosis, in which they and their hosts both benefit.
- These diseases include several kinds of intestinal disease, African sleeping sickness, and malaria. Parasitic protists cause some of the world's deadliest diseases.

algal bloom (p. 510)
food vacuole (p. 510)
gullet (p. 510)
plasmodium (p. 511)

21.4 Fungi

- Fungi are heterotrophic eukaryotes. They have chitin in their cell walls.
- Many fungi are decomposers that help ecosystems maintain homeostasis by breaking down dead organisms and recycling essential elements and nutrients.
- Parasitic fungi can cause serious diseases in plants and animals.
- Some fungi form mutualistic relationships with photosynthetic organisms that help both partners.

chitin (p. 514)
hypha (p. 515)
fruiting body (p. 515)
mycelium (p. 515)
lichen (p. 518)
mycorrhiza (p. 519)

21 CHECK Understanding

Assess the Big idea: Interdependence in Nature

Write an answer to the question below.
Q: How do protists and fungi affect the homeostasis of other organisms and ecosystems?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each numbered question should be one or two paragraphs long. To help get ideas, read the bulleted **Hints** below the question.

1. **Why are photosynthetic protists some of the most important organisms in aquatic environments? Give examples of three ocean ecosystems where protists play a key role.**

   Hint Ocean ecosystems include coral reefs, kelp forests, and the open ocean.

2. **How do protists and fungi recycle materials in an ecosystem?**

   Hint Some protists and many fungi are decomposers.

   Hint Fungi release digestive enzymes.

3. **How do parasites affect humans? Include specific details about at least one protist and one fungal parasite.**

   Hint Study the photos of water-borne parasites on page 512.

   Hint When parasites attack food crops, they also affect humans.

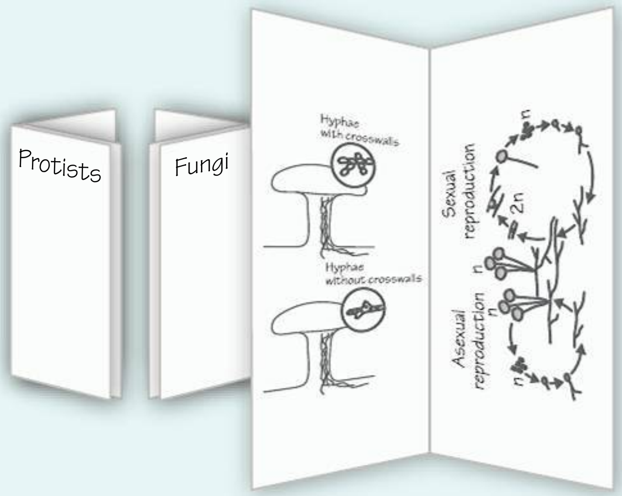
Foundations for Learning Wrap-Up

Use the double-door fold you made while reading the chapter to help review how protists and fungi affect the world.

Activity 1 Work with a partner to review the roles of protists and fungi in ecosystems. One of you will quiz the other. The person who has the double-door fold will ask the questions. For example, you could ask: How do fungi that are decomposers affect an ecosystem?

After four questions, switch sides. Continue reviewing the chapter concepts until you can easily answer the questions.

Activity 2 Cut your double-door fold in half to make two booklets. Add pages to each booklet. On these pages, draw pictures that show examples of protists and fungi for each ecological role. For example, for a protist that is an autotroph, you could draw a picture of a diatom or a giant kelp. Write a caption for each image that explains the concept shown.



21.1 Protist Classification

Understand Key Concepts

1. Which of the following describes most protists?
   a. single-celled eukaryotes
   b. multicellular eukaryotes
   c. single-celled prokaryotes
   d. multicellular prokaryotes

> **Test-Taking Tip**
>
> **Visualization** Sometimes, it helps to picture a concept in your head or to draw it out on a scratch piece of paper. For example, in question 1, picture an organism for each answer. In this way, you can help eliminate incorrect answers and narrow your answer choices.

2. From what organisms did protists likely evolve?
3. Why is the word *protist* sometimes placed in quotation marks?

Think Critically

4. **Evaluate** Once, any organism that moved or that ate food was classified as an animal. Any organism that did not move or that made its own food was classified as a plant. Why can't this system be used to classify protists?

21.2 Protist Structure and Function

Understand Key Concepts

5. Which of the following is NOT true of amoebas?
   a. They have a rigid cell wall.
   b. They reproduce by mitosis.
   c. They move using pseudopods.
   d. The protein actin powers their movement.
6. Alternation of generations is the process of alternating between
   a. spores and eggs.
   b. diploid and haploid phases.
   c. male and female reproductive structures.
   d. positive and negative reproductive structures.
7. Compare the structure of a cilium and flagellum.
8. Is the process of conjugation in paramecia a form of reproduction? Why or why not?

Think Critically

9. **Apply Concepts** Some protists cannot move on their own. What generalization can you make about how these organisms survive?
10. **Infer** How do you think the ability to switch between asexual and sexual reproduction has aided the evolution of water molds and many other protists?

21.3 The Ecology of Protists

Understand Key Concepts

11. African sleeping sickness is caused by
    a. *Amoeba.*
    b. *Plasmodium.*
    c. *Trichonympha.*
    d. *Trypanosoma.*
12. Which of the following statements about photosynthetic protists is TRUE?
    a. Most photosynthetic protists are heterotrophs.
    b. All photosynthetic protists are closely related to plants.
    c. Giant kelp play an important role in the formation of coral reefs.
    d. Small photosynthetic organisms near the ocean's surface are called phytoplankton.
13. How do mosquitos spread malaria?
14. Describe the relationship between a termite and the protists that live in its gut.

Think Critically

15. **Apply Concepts** Holes in Earth's ozone layer may increase the amount of radiation that reaches the surface of the ocean. If this radiation affects the growth of phytoplankton, how do you think other organisms will be affected? Explain your answer.
16. **Infer** Study the diagram of the life cycle of *Plasmodium* on page 513. Do you think malaria could be transmitted by a blood transfusion? Why or why not?

21 CHECK Understanding

21.4 Fungi

Understand Key Concepts

17. Which of these is a symbiotic relationship between a fungus and the roots of a plant?
a. fruiting body **c.** mushroom
b. lichen **d.** mycorrhiza

18. Distinguish between the terms *hypha* and *mycelium*.

19. How are the cell walls of fungi similar to the exoskeleton of insects?

Think Critically

20. Compare and Contrast Both fungi and humans are heterotrophs. Compare the way fungi get food with the way humans do.

Connecting Concepts

Use Science Graphics

This photograph shows a comparison of a corn plant grown without mycorrhizae (left) to a plant of the same age that was grown with mycorrhizae (right). Use the photograph to answer questions 21–22.

21. Compare and Contrast Which corn plant shows more growth?

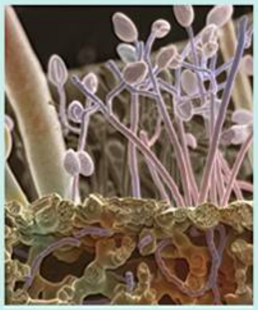
22. Relate Cause and Effect What is the most likely explanation for the results shown?

solve the CHAPTER MYSTERY

"A BLIGHT OF UNUSUAL CHARACTER"

In Ireland in the 1840s, conditions were just right for the rapid spread of potato blight. The disease lasted from year to year because the new crop was grown from potato eyes saved from the previous year's crop. Genetically identical crops could not survive the blight.

What clues in the chapter point to the blight's cause? The blight organism had hyphae. It got food by absorbing molecules through its cell walls. These traits are shared by water molds and fungi. But the organism that caused the blight did not have chitin in its cells. So it could not be a fungus. The organism that caused the blight is a water mold—a protist called *Phytophthora*. This name means "plant eater."



Phytophthora hyphae invading a potato (SEM 100×)

1. Relate Cause and Effect The weather in 1845 was unusually wet and cool. How might these weather conditions have favored the blight organism's life cycle?

2. Infer Scientists think that *Phytophthora* came to Ireland with some potatoes from South America. Why hadn't the same organism caused such widespread destruction there?

UntamedScience Finding the solution to this mystery is just the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

Standardized Test Prep

Multiple Choice

1. All of the following are characteristics of some protists EXCEPT
A peptidoglycan in the cell walls.
B a membrane-bound nucleus.
C flagella.
D cilia.

2. The structure in *Amoeba* that helps the organism move and feed is the
A flagellum.
B cilium.
C food vacuole.
D pseudopod.

3. In protists, the process of conjugation
A is linked to photosynthesis.
B results in an exchange of some genetic material.
C produces offspring that are genetically identical to the parent.
D decreases the genetic diversity of a population.

4. Which of the following statements about slime molds is FALSE?
A Slime molds are eukaryotes.
B Slime molds play an important part in recycling nutrients.
C Slime molds are multicellular at some time during their life cycle.
D Slime molds are photosynthetic protists.

5. Algal blooms can be made up of
A paramecia. **C** dinoflagellates.
B lichens. **D** *Trichonympha.*

6. Alternation of generations BEST describes sexual reproduction in
A *Paramecium.* **C** *Amoeba.*
B water molds. **D** yeast.

7. The primary carbohydrate found in the cell walls of fungi is
A chitin.
B actin.
C cellulose.
D starch.

Questions 8–10

Ripe grapes are covered with a grayish film, or bloom, that contains yeasts and other microorganisms. A group of students prepared three test tubes of fresh mashed grapes. They heated two of the test tubes to boiling and then cooled them. They inoculated one of those test tubes with live yeast, incubated all three test tubes at 30°C for 48 hours, and then examined the test tubes for signs of fermentation—an alcohol odor and bubbles. Their data are summarized in the table below.

Evidence of Fermentation

Test-Tube Contents	Alcohol Odor (yes or no)	Bubbles (yes or no)
Unheated grape mash	yes	yes
Boiled grape mash	no	no
Boiled grape mash inoculated with yeast	yes	yes

8. What is the independent variable in the students' investigation?
A the presence of live yeast **C** bubbles
B an odor of alcohol **D** time

9. What is the dependent variable in the students' investigation?
A an odor of alcohol only
B boiling
C an odor of alcohol and the presence of bubbles
D the yeast in the boiled test tube

10. What can you conclude from the students' results?
A Uninoculated, boiled grape mash does not seem to ferment over a 48-hour period.
B Boiled grape mash that contains live yeast undergoes fermentation.
C Grape mash does not ferment unless live yeast is added.
D Both A and B are correct.

Open-Ended Response

11. How does each of the partners in the lichen symbiosis benefit from the relationship?

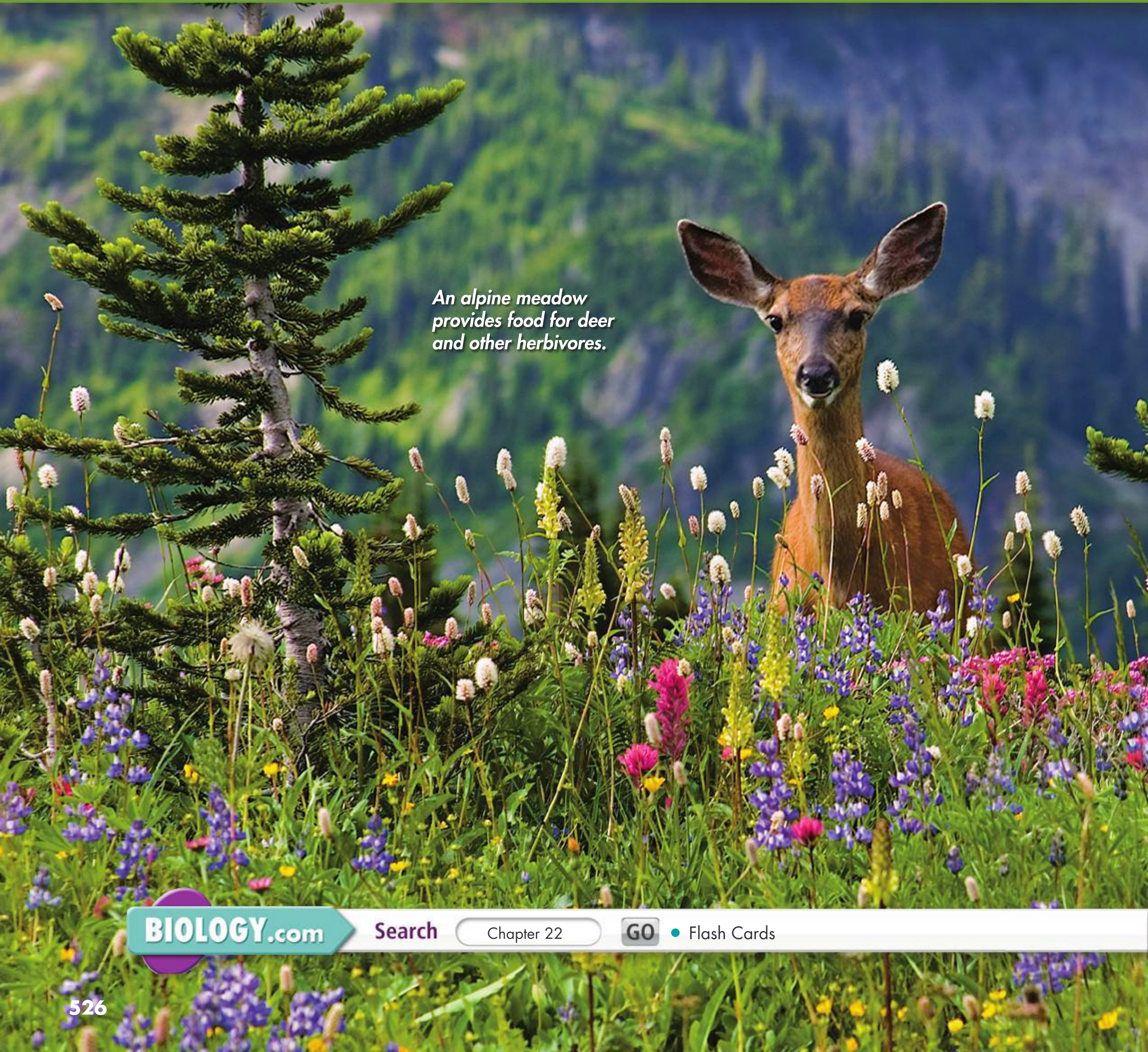
If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10	11
See Lesson	21.2	21.2	21.2	21.3	21.3	21.2	21.4	21.4	21.4	21.4	21.4

22 Introduction to Plants

Big idea: Unity and Diversity of Life

Q: What are the five main groups of plants, and how have four of these groups adapted to life on land?



An alpine meadow provides food for deer and other herbivores.

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INSIDE:

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

STONE AGE STORYTELLERS

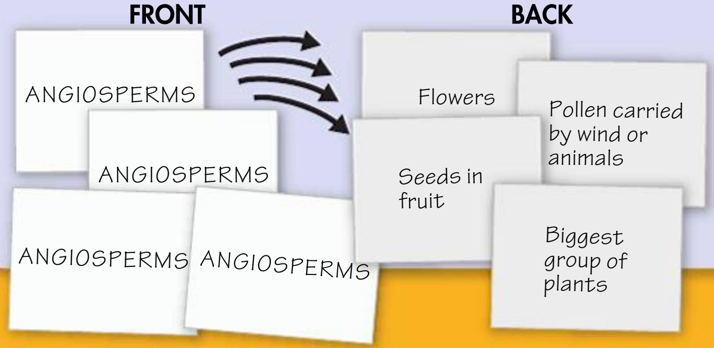
About 5300 years ago, a man died on a mountain pass in the Alps. His body was frozen in a glacier. In 1991, parts of the glacier melted, revealing his body. Scientists who studied the body called him Iceman. The body of Iceman and his possessions have provided an amazing amount of information about his life.

Some of the evidence found with Iceman comes from plants. He had a storage container made from bark and a bow and arrows made of wood. Scientists also found pollen from trees inside Iceman's digestive tract. What might these and other plant-related clues reveal about Iceman?

Read for Mystery Clues As you read the chapter, look for ways that plants can provide clues about the past. Use these clues to help solve the mystery of how Iceman lived and died.

FOUNDATIONS for Learning

You can use index cards to help you learn about the five groups of plants. You will need 20 cards, 4 for each group of plants. As you read, identify the main characteristics of each group. Write one characteristic on each card, as shown below. At the end of the chapter are two activities that use these cards to help you answer the question: What are the five main groups of plants?



22.1 What Is a Plant?

Key Questions

What do plants need to survive?

How did plants adapt to life on land?

What feature defines most plant life cycles?

BUILD Understanding

Preview Visuals Before reading the lesson, look at the figure that lists the five main groups of plants. List anything that you already know about each group of plants.

In Your Workbook Go to your workbook to learn more about previewing visuals. Complete the chart for Lesson 22.1.

Characteristics of Plants

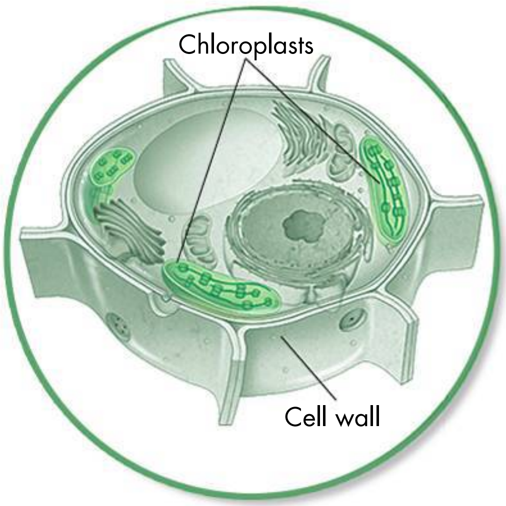
What color is life? Living things can be just about any color, of course. But imagine a place where living things are so plentiful that they block out the sun. Now, what color do you see?

If you've imagined a thick forest or a jungle, the color that you see is green. Green is the color of plants. Plants have adapted well to many environments. Therefore, plants dominate much of the surface of our planet. What are plants? Of course, trees, shrubs, flowers, and grasses are plants. Mosses and ferns are also plants. Biologists classify green algae as plants, too. What do all of these organisms have in common?

Cell Structure Plants are eukaryotes—their cells have nuclei and other organelles. The cell walls of all plants contain cellulose.

Getting Energy Most plants are autotrophs that make their own food by photosynthesis. Photosynthesis takes place in chloroplasts. During photosynthesis, the green pigments chlorophyll *a* and *b* capture energy from sunlight.

A few plants are heterotrophs. Instead of carrying out photosynthesis, these plants get their energy from other sources. Some plants are parasites. Others get their energy from the remains of dead organisms.



Plant Cells Plant leaves are green because of the pigments chlorophyll *a* and *b*. These pigments are found in chloroplasts. Plant cells also have cell walls containing cellulose.

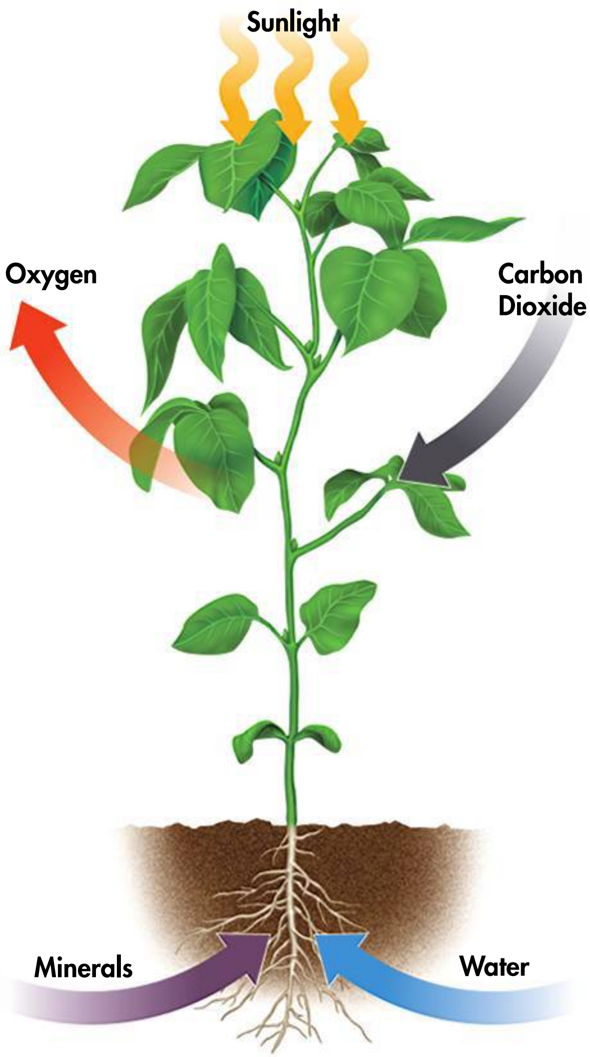
What Plants Need To survive, plants need to get energy from sunlight. They also need to take in carbon dioxide and release oxygen into the air. Plants also need water and minerals. Unlike animals, plants cannot move from place to place. But as you will see, plants have a number of adaptations that help them succeed without moving.

▶ ***Sunlight*** To carry out photosynthesis, plants need sunlight. Plants have many adaptations that help them gather sunlight. Leaves are often broad and flat, which lets them catch the sunlight. Stems hold leaves above the ground, exposing them to more light.

▶ ***Gas Exchange*** Plants need carbon dioxide for photosynthesis and oxygen for cellular respiration. Plants also need to release the extra oxygen produced during photosynthesis. They exchange these gases with the air and the soil.

▶ ***Water and Minerals*** Plants need water for photosynthesis. They also need water to help move nutrients throughout their bodies.

Land plants usually get water from the soil. As plants absorb water from the soil, they also absorb minerals. Minerals are nutrients needed for plant growth. Some plants rely on the process of diffusion to move water and nutrients throughout their bodies. Most plants have specialized tissues that carry water, minerals, and food.



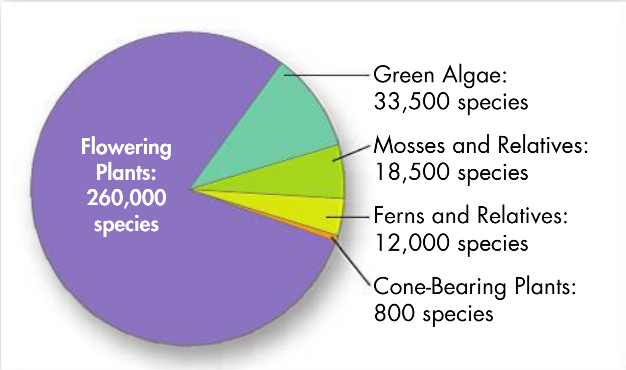
Basic Needs of a Plant All plants have the same basic needs: sunlight, water, minerals, and a way to exchange gases with the air.

Key Question What do plants need to survive?
Plants need sunlight, they need to exchange gases with the air, and they need water and minerals.

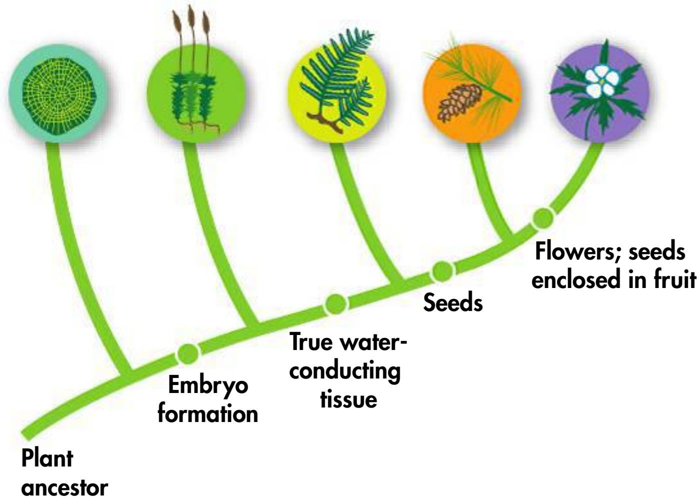
The Evolution of Plants

For most of Earth's history, there were no plants on land. Fossils show that the ancestors of land plants lived in water. These early organisms were similar to the green algae of today. Most of these green algae were single-celled organisms. A few had many cells.

The First Land Plants Fossils of spores from land plants date back as far as 475 million years ago. The oldest fossils of plants themselves date back to about 425 million years ago. These early plants were small and did not have leaves or roots. To get water, they grew close to the ground in damp areas. Fossils also suggest that the first land plants needed water to reproduce.



Five Groups of Plants Today, biologists classify plants into five major groups.



For more on the diversity of plants, go to the Visual Guide. **pp. DOL 20–29.**

BUILD Vocabulary

alternation of generations
a life cycle that has two alternating phases—a haploid (N) phase and a diploid (2N) phase

sporophyte
a spore-producing plant; the multicellular diploid phase of a plant life cycle

gametophyte
a gamete-producing plant; the multicellular haploid phase of a plant life cycle

SUFFIXES
The suffix *-phyte* comes from a Greek word that means "plant." Spoross*phytes*are plants that produce spores. Gameto*phytes* are plants that produce gametes.

Plants on Land Evolve Over time, adaptations arose that made plants more successful on land. These adaptations helped plants survive the drying rays of the sun. They also prevented the loss of water. Eventually, plants that did not need water to reproduce evolved. These plants could live in even the driest environments.

Several groups of plants evolved from the first land plants. One group developed into mosses. Another group gave rise to ferns, cone-bearing plants, and flowering plants. All of these groups are successful today. But they have very different adaptations.

The evolution of land plants changed the environments on Earth. As land plants grew, they formed the basis for new ecosystems. Plants also affected the evolution of other organisms, such as insects and birds.

An Overview of the Plant Kingdom Biologists divide the plant kingdom into five main groups, as shown in the pie graph above. This classification is based on four key features: the formation of embryos, specialized water-conducting tissues, seeds, and flowers. Plants that form embryos are called "land plants," even though some live in water.

Key Question How did plants adapt to life on land?
Evolution favored plants with adaptations that helped them survive the drying rays of the sun, prevented the loss of water, and allowed them to reproduce without water.

The Plant Life Cycle

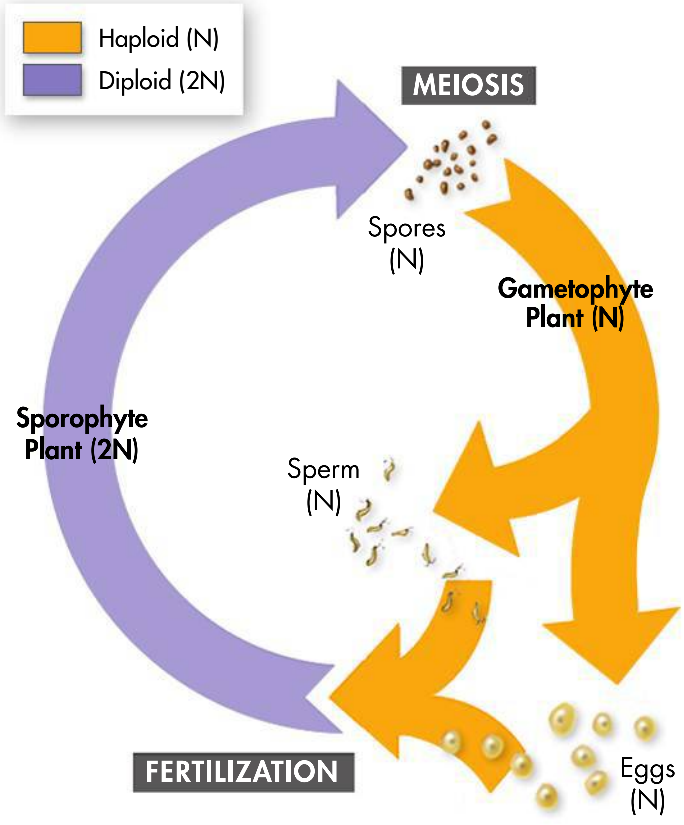
Plants have a life cycle that sets them apart from most other organisms. This life cycle changes between two phases: a diploid (2N) phase and a haploid (N) phase. (Haploid organisms have one set of chromosomes in their cell nuclei. Diploid organisms have two sets of chromosomes.) The shift between phases is called **alternation of generations.**

Two Plants The multicellular diploid (2N) phase is known as the **sporophyte** (SPOH ruh fyt), or spore-producing plant. The multicellular haploid (N) phase is the **gametophyte** (guh MEET uh fyt), or gamete-producing plant.

Steps of the Life Cycle The plant life cycle has several basic steps. A sporophyte plant produces haploid spores. Spores are usually single-celled. These spores grow into gametophytes. Gametophytes have many cells. Each gametophyte produces reproductive cells called gametes—sperm cells and egg cells. During fertilization, a sperm and egg come together, producing a diploid zygote. The zygote develops into a new sporophyte, and the cycle begins again.

In many plants, the gametophyte is the largest stage of the life cycle. However, as vascular and seed plants evolved, their sporophyte stages became much larger. Modern seed plants have a tiny gametophyte that is contained within the sporophyte.

Key Question What feature defines most plant life cycles? **Plants have life cycles with two phases, or alternation of generations. These phases are a diploid (2N) sporophyte phase and a haploid (N) gametophyte phase.**



Plant Life Cycle Most plants have a two-phase life cycle: the haploid gametophyte phase and the diploid sporophyte phase.

CHECK Understanding

Apply Vocabulary

1. During the plant life cycle, the ______ phase produces egg and sperm cells.

2. During the ______ phase of the plant life cycle, the plant produces spores.

3. A life cycle that switches between haploid and diploid phases is called ______.

Critical Thinking

4. Interpret Visuals List four basic needs of a plant. Then, explain how the plant in the art on page 529 meets those basic needs.

5. Explain How did the dry environment on land affect the evolution of plants?

6. Compare and Contrast Compare the gametophyte and sporophyte stages of the plant life cycle. Which is haploid? Which is diploid?

7. Write to Learn Answer the first clue of the mystery. Use the words *chloroplast*, *chlorophyll*, and *photosynthesis* in your answer.

MYSTERY CLUE

Scientists extracted large amounts of chlorophyll from maple leaves found with Iceman. How could this information be used to determine the season when he died? (Hint: See p. 528.)

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22.2 Seedless Plants

Key Questions

What are the characteristics of green algae?

What factor limits the size of bryophytes?

How is vascular tissue important?

BUILD Understanding

Venn Diagram Make a Venn diagram to describe the similarities and differences among the three groups of seedless plants. Fill in your Venn diagram as you read the lesson.

In Your Workbook Go to your workbook to learn more about Venn diagrams. Complete the Venn diagram for Lesson 22.2.

Green Algae

Most algae are classified as protists. But green algae are classified as plants. Why? Because green algae share many characteristics with the land plants. Like land plants, the cells of green algae have cell walls with cellulose. Their chloroplasts have chlorophyll *a* and *b*. Finally, biologists have found that the genes of green algae and land plants are similar.

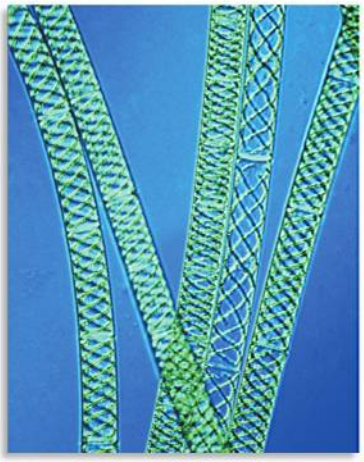
Most green algae live in fresh water or salt water. Some green algae live in moist areas on land. They absorb moisture and nutrients directly from their surroundings. Green algae lack the specialized tissues found in other plants.

Life Cycles of Green Algae Like other plants, many green algae show alternation of generations in their life cycles. Some live as haploid cells most of the time. They reproduce asexually by mitosis. Then, when living conditions become unfavorable, they reproduce sexually. To do this, they first produce haploid gametes. These gametes then fuse to form a diploid zygote. The zygote may remain inactive for many weeks or months. When conditions are favorable, the zygote enters meiosis and produces haploid cells. This begins the life cycle all over again.

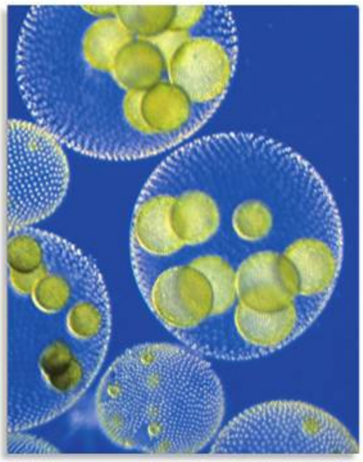
Multicellular Green Algae Many kinds of green algae form colonies. Some form long chains of cells. Others, like the ball-shaped colonies of *Volvox*, are more complex. In a *Volvox* colony, some cells are specialized for reproduction. Colonial algae may provide a clue about how multicellular plants arose.

Key Question What are the characteristics of green algae? **Green algae live mostly in fresh water or salt water; some live in moist areas on land. Some green algae are multicellular.**

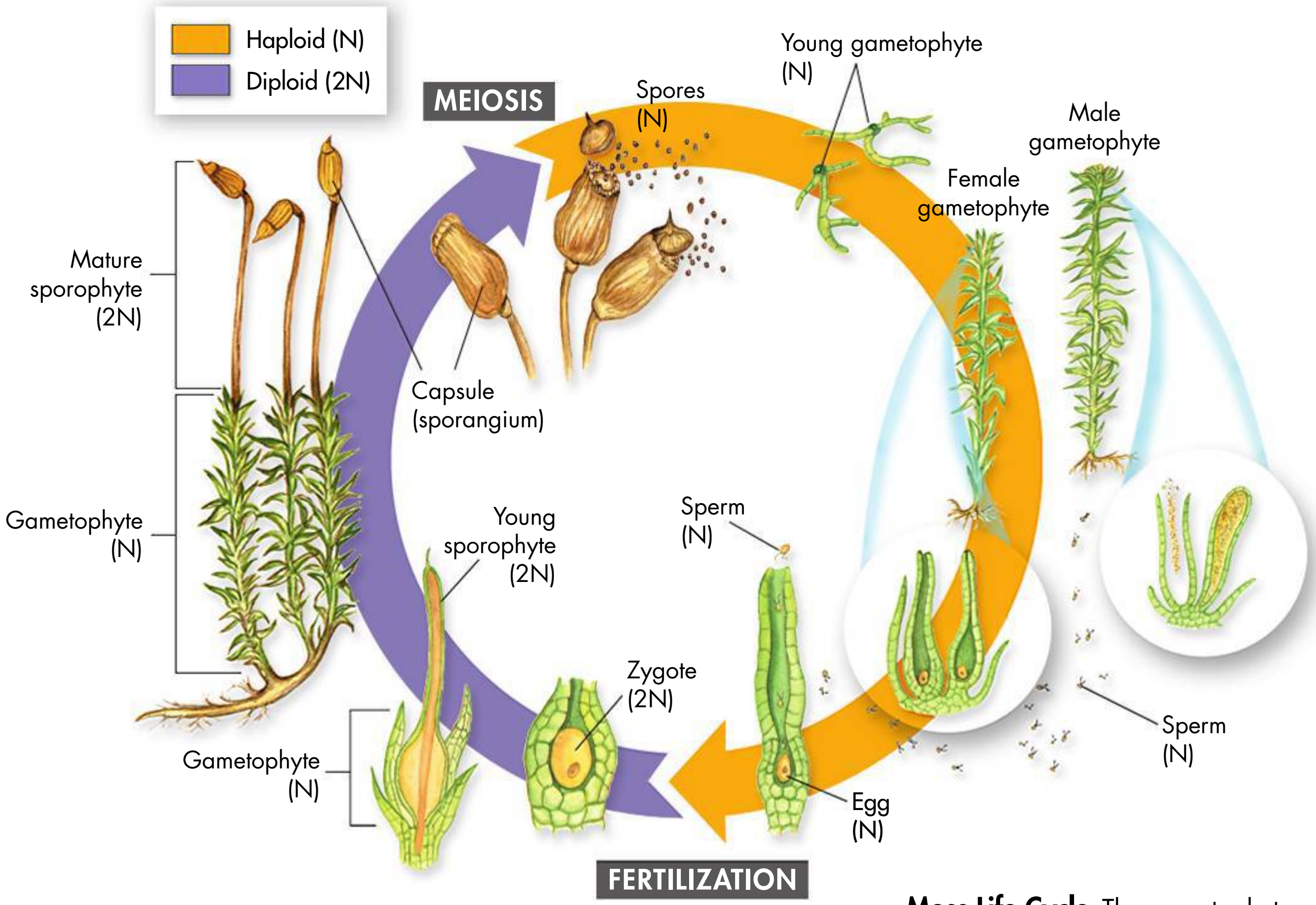
Spirogyra *(LM 140×)*



Volvox *(LM 50×)*



Multicellular Green Algae Some green algae live in colonies. *Spirogyra* colonies are made of long strands of cells. *Volvox* colonies form hollow balls, made of 500 to 50,000 cells.



Moss Life Cycle The gametophyte is the dominant stage of the moss life cycle. Specialized structures in the male and female gametophytes produce sperm and eggs.

Bryophytes

Imagine a forest floor. The moist ground is covered with a soft green carpet made of mosses. Mosses are the most common members of a group of plants called **bryophytes** (BRY oh fyts). Unlike algae, bryophytes are multicellular plants that have specialized structures. Mosses lack true leaves, stems, and roots. Rootlike filaments called rhizoids (RY zoydz) hold mosses in place. Rhizoids also absorb water and minerals. Mosses have a thin, waxy coating that prevents them from drying out.

Why Bryophytes Are Small Most land plants carry water and nutrients in specialized tissue called **vascular tissue.** Vascular tissue contains long tubes with very hard cell walls. Bryophytes do not have vascular tissue. Instead, they absorb water from their surroundings by osmosis. Because they lack vascular tissue, bryophytes can draw up water no higher than a meter above the ground. This limits the height of bryophytes. As a result, most bryophytes are small plants that grow only in damp soil.

Key Question What factor limits the size of bryophytes? **Bryophytes are small because they lack vascular tissue.**

Life Cycle The gametophyte is the dominant stage in the moss life cycle. The smaller sporophyte depends on the gametophyte for water and nutrients. Bryophytes produce sperm cells that swim using flagella. Sperm cells must swim through water to reach egg cells. Therefore, bryophytes must live in habitats that have open water for at least part of the year.

BUILD Vocabulary

bryophyte
a group of plants that have specialized reproductive organs but lack vascular tissue

vascular tissue
a specialized tissue in plants that carries water and nutrients

WORD ORIGINS
The word *vascular* comes from the Latin word *vas*, meaning "a vessel," or a container used to carry liquids. Vascular tissues carry liquids through a plant.

BUILD Vocabulary

xylem
a vascular tissue that carries water upward from the roots to every part of the plant

phloem
a vascular tissue that transports solutions of nutrients and carbohydrates produced by photosynthesis through the plant

WORD ORIGINS

The word *phloem* comes from the Greek word *phloios,* which means "bark." In many plants, such as trees, the inner layer of bark includes phloem.

Vascular Plants

For millions of years, only small plants, like mosses, grew on land. Then, about 420 million years ago, something remarkable happened. Suddenly, low-growing plants were joined by much taller plants and even trees. What happened? Fossils show that these new plants had vascular tissue. With the evolution of vascular tissues, plants were able to grow high above the ground.

Two Kinds of Vascular Tissue Vascular tissues allow fluids to travel through a plant body against the force of gravity. The vascular tissue that carries water from the roots to every part of a plant is **xylem** (ZY lum). Xylem is made up of hollow, tubelike cells called *tracheids* (TRAY kee idz). Tracheids are connected end to end. They have thick cell walls containing lignin. Lignin is a compound that toughens cell walls, making them strong enough to support the weight of the plant.

Vascular plants also have a second vascular tissue that is called phloem. **Phloem** (FLOH um) carries solutions of nutrients and food produced by photosynthesis. Like xylem, the cells of phloem are long and specialized to move fluids.

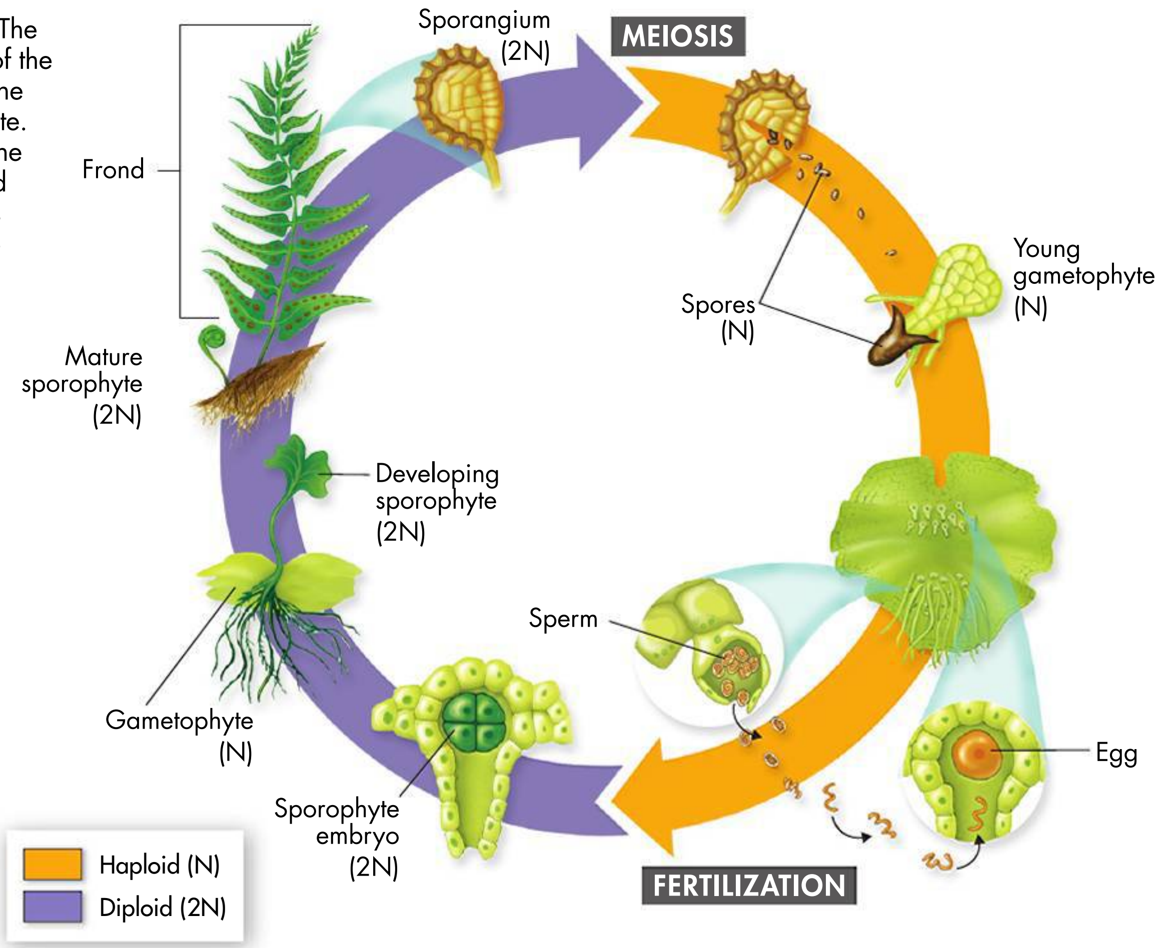
Key Question How is vascular tissue important?
Vascular tissue allows the movement of fluids throughout the body of a plant against the force of gravity.

Seedless Vascular Plants Today there are three groups of vascular plants that do not have seeds: club mosses, horsetails, and ferns. Ferns are the most common seedless vascular plants. They have strong roots and underground stems called rhizomes (RY zohmz). Their large leaves are called fronds. Ferns can live in areas with little light. They commonly grow in habitats that are wet.

Fern Life Cycle The large plant you recognize as a fern is the sporophyte phase of the fern's life cycle. As the fern matures, haploid spores develop on the undersides of its fronds. The spores grow into tiny, heart-shaped gametophytes. The gametophyte stage lives independently of the sporophyte. The gametophyte produces sperm and eggs. For fertilization to take place, the sperm must have water in order to swim to the eggs. The diploid zygote grows into a sporophyte.

Vascular Tissue Horsetails are seedless vascular plants. The micrograph shows a magnified view of the vascular tissue, which is reinforced by rings of lignin. Lignin helps support the plant.

Fern Life Cycle The dominant stage of the fern life cycle is the diploid sporophyte. In the diagram, the tiny, heart-shaped gametophyte has been enlarged to show the details.



CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The evolution of _______ made it possible for land plants to grow larger.

2. _______ carries nutrients and food throughout the body of the plant.

3. _______ is made up of tracheids, specialized cells that form water-conducting tubes.

Critical Thinking

4. Compare and Contrast List four ways that green algae are similar to other plants. How are they different from land plants?

5. Relate Cause and Effect Why are ferns able to grow so much taller than bryophytes?

6. Interpret Visuals Study the art of the life cycles of the moss and the fern. Identify which phase is dominant in each of these life cycles.

7. Write to Learn Answer the next clue of the mystery. Include the words *bryophyte* and *vascular tissue* in your answer.

MYSTERY CLUE

When studying the stomach contents of Iceman, scientists found a piece of moss. They concluded that Iceman ate the moss by accident. What does the moss indicate about the area in which Iceman lived? (Hint: See p. 533.)

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22.3 Seed Plants

Key Questions

What adaptations allow seed plants to reproduce without open water?

How does fertilization take place in gymnosperms without open water?

BUILD Understanding

Preview Visuals Look at the figure describing the pine life cycle. Write down your first impressions about how it differs from the fern life cycle.

In Your Workbook Go to your workbook to learn more about previewing visuals. Complete the activity for Lesson 22.3.

BUILD Vocabulary

seed a plant embryo and a food supply inside a protective covering

gymnosperm a group of seed plants that bear their seeds directly on the scales of cones

angiosperm a group of seed plants that bear their seeds within a layer of tissue that protects the seed; also called flowering plants

pollen grain in seed plants, the structure that contains the entire male gametophyte

The Importance of Seeds

Acorns, pine nuts, dandelion seeds, corn kernels, beans—seeds can be found nearly everywhere. What are seeds? Are they gametes? Reproductive structures? Do they contain egg and sperm? The answer is none of the above.

A **seed** is made up of a plant embryo and a food supply surrounded by a protective covering. Every seed holds a living plant, ready to sprout and grow when the conditions are right! Seeds allow plants to grow even in some of the driest places on Earth.

The First Seed Plants The earliest fossils of plants with seeds are about 360 million years old. These ancestors of today's seed plants had several adaptations that made them successful. Unlike mosses and ferns, seed plants do not need open water for the fertilization of gametes. Adaptations that allow seed plants to reproduce without open water include cones or flowers, the transfer of sperm by pollination, and the protection of embryos in seeds.

Cones and Flowers In seed plants, the dominant phase of the life cycle is the sporophyte. Male and female gametophytes grow and mature within the sporophyte. Gametophytes usually develop in reproductive structures known as cones or flowers. In fact, seed plants are divided into two groups based on which of these structures they have. Nearly all **gymnosperms** (JIM noh spurmz) bear their seeds directly on the scales of cones. Flowering plants, or **angiosperms** (AN jee oh spurmz), bear their seeds inside a layer of tissue that protects the seed.

Pollen In seed plants, the entire male gametophyte is contained in a tiny structure called a **pollen grain.** The pollen grain produces sperm. Sperm produced in a pollen grain do not swim through water to fertilize eggs. Instead, pollen grains are carried to the female reproductive structure in various ways. In some plant species, pollen grains are carried by wind. In other species, animals such as insects carry pollen grains to the female reproductive structure. The transfer of pollen from the male reproductive structure to the female reproductive structure of a plant is called **pollination.**

Seeds After fertilization, the zygote in a seed grows into a tiny plant—the embryo. The embryo is diploid. It is the early developmental stage of the plant's sporophyte. The embryo often stops growing while it is still small and contained in the seed. The embryo can remain in this state for weeks, months, or even years.

A tough **seed coat** surrounds and protects the embryo. The seed coat keeps the contents of the seed, including the embryo, from drying out. Seeds can survive long periods of cold, heat, or drought. When conditions are once again favorable, the embryo inside the seed begins to grow. The embryo uses nutrients from the food supply in the seed until it can carry out photosynthesis on its own.

Key Question What adaptations allow seed plants to reproduce without standing water?
Cones and flowers, the transfer of sperm by pollination, and the protection of embryos in seeds make it possible for seed plants to reproduce without standing water.

BUILD Vocabulary

pollination the transfer of pollen from the male reproductive structure to the female reproductive structure

seed coat the tough covering that surrounds and protects the plant embryo and keeps the contents of the seed from drying out

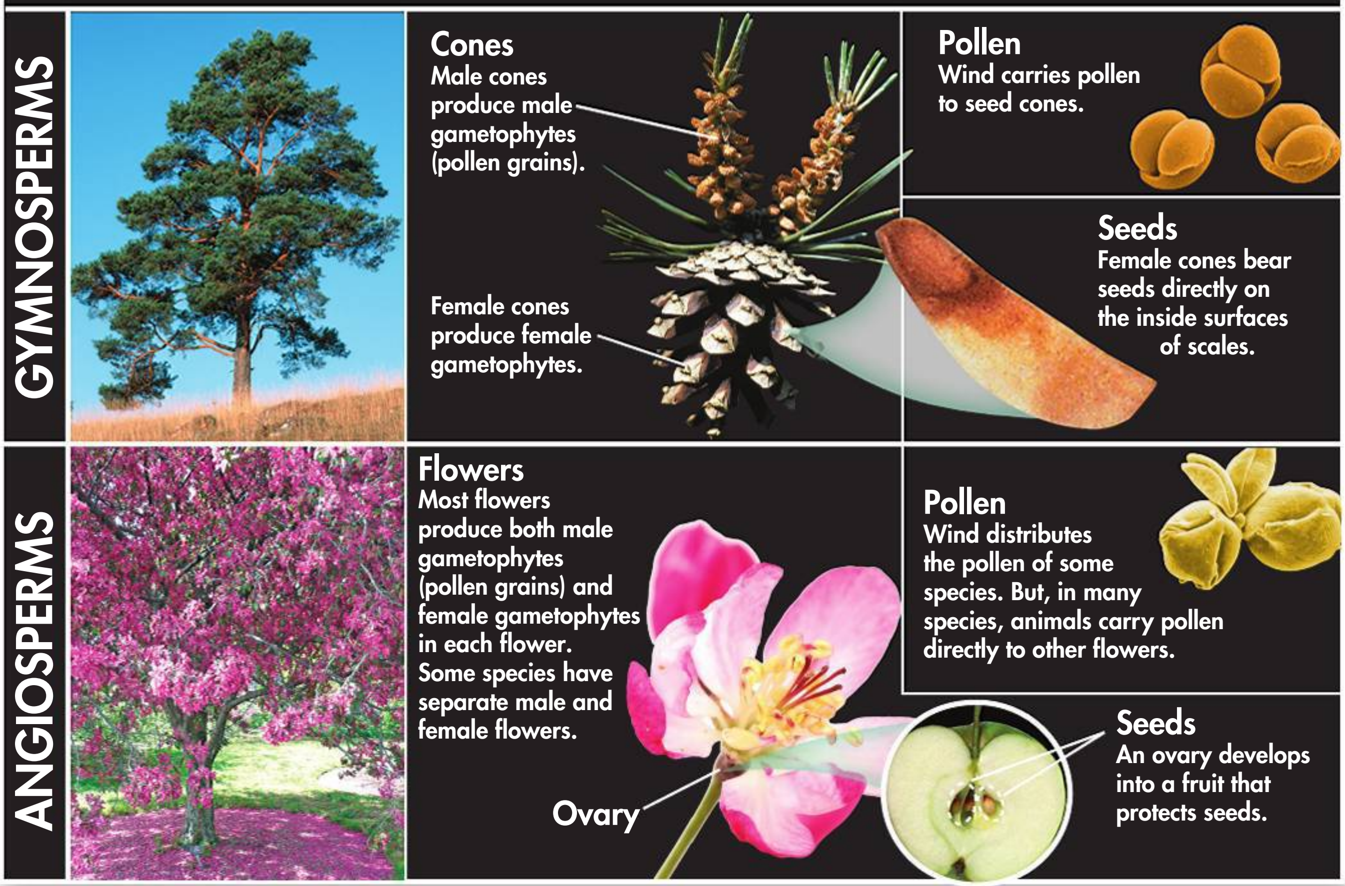
RELATED WORD FORMS

The verb *pollination* comes from the word *pollen*. Pollination occurs when pollen grains are carried to the female structures of a plant.

BUILD Connections

REPRODUCTION IN SEED PLANTS

The two types of seed plants can be identified by their reproductive structures.



The Life Cycle of a Gymnosperm

The word *gymnosperm* means "naked seed." The name comes from the fact that the seeds of gymnosperms are exposed on the scales in their cones. The most common gymnosperms are conifers, such as pine, spruce, cedar, and fir trees. Gymnosperms also include rare plants such as cycads and ginkgoes. The life cycle of a pine tree is shown on the next page.

Pollen Cone The pollen cone of a pine tree releases large amounts of pollen. Wind blows the pollen grains to the seed cones.

Pollen Cones and Seed Cones Gymnosperms have two kinds of cones: pollen cones and seed cones. Pollen cones, also called male cones, produce pollen grains. Each tiny pollen grain is a complete male gametophyte. One nucleus in the pollen grain divides, forming two sperm nuclei.

Female cones, or seed cones, are usually much larger than pollen cones. Near the base of each scale of a seed cone are two ovules. **Ovules** (AHV yoolz) are the structures in which the female gametophytes develop. In the ovules, meiosis produces haploid cells. The haploid cells grow and divide to form female gametophytes. Female gametophytes may have thousands of cells. When fully grown, a female gametophyte has only a few large egg cells. Each of these egg cells is ready to be fertilized.

Pollination The life cycle of a conifer begins when male cones release large numbers of pollen grains. These pollen grains are carried away by the wind. Some of the pollen grains reach female cones. The scales of the female cone are sticky, and the pollen grains stick to them. These grains are pulled inside, toward the ovule.

Fertilization and Development If a pollen grain lands near an ovule, the grain splits open and begins to grow a **pollen tube.** The pollen tube contains two sperm nuclei. Once the pollen tube reaches the female gametophyte, one sperm nucleus fertilizes the egg. The other sperm breaks down.

Fertilization produces a zygote. The zygote grows into an embryo—the new sporophyte plant. The embryo is then surrounded by a seed coat, forming a seed. The seed then falls to the ground, or is carried away by wind, water, or animals. If it lands where conditions are right, the seed will grow into a new plant.

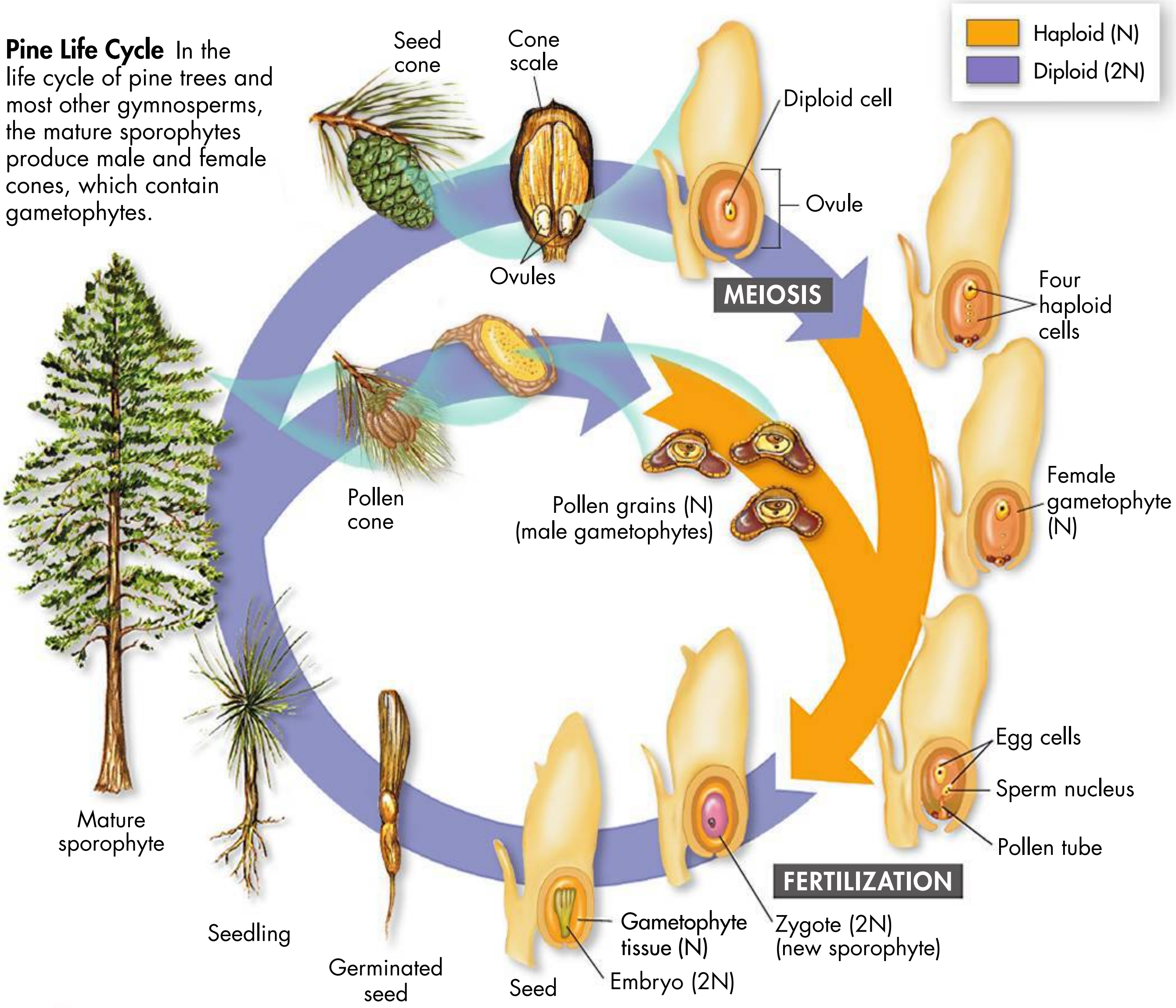
Key Question How does fertilization take place in gymnosperms without open water?
In gymnosperms, wind carries pollen grains to the female cone, where fertilization takes place.

BUILD Vocabulary

ovule
in seed plants, the structure in which the female gametophytes develop

pollen tube
the structure in a seed plant that contains two haploid sperm nuclei

WORD ORIGINS
The word *ovule* comes from the Latin word *ovum*, which means "egg." Ovules are the structures inside which female gametophytes develop and produce haploid gametes, or eggs.



Pine Life Cycle In the life cycle of pine trees and most other gymnosperms, the mature sporophytes produce male and female cones, which contain gametophytes.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. In seed plants, the male gametophyte is contained within a ________.

2. The young sporophyte embryo is protected within the seed by the ________.

3. ________ are seed plants that produce seeds in flowers.

Critical Thinking

4. Review List three adaptations of seed plants that allow them to reproduce without water.

5. Apply Concepts Classify the following structures of a pine tree as haploid or diploid: embryo, pollen grain, ovule, egg cell, sperm, zygote, seed cone, and seedling.

6. Write to Learn Answer the mystery clue. Use the word *conifer* in your answer.

MYSTERY CLUE

An unfinished bow made from conifer wood was found with Iceman. What does this indicate about what Iceman ate? Could the bow have been used for other purposes? Explain your answer. (Hint: See p. 538.)

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22.4 Flowering Plants

Key Questions

What are the key features of angiosperm reproduction?

How are angiosperms categorized?

BUILD Understanding

Compare/Contrast Table As you read, make a table to compare the three methods commonly used to put angiosperms into groups.

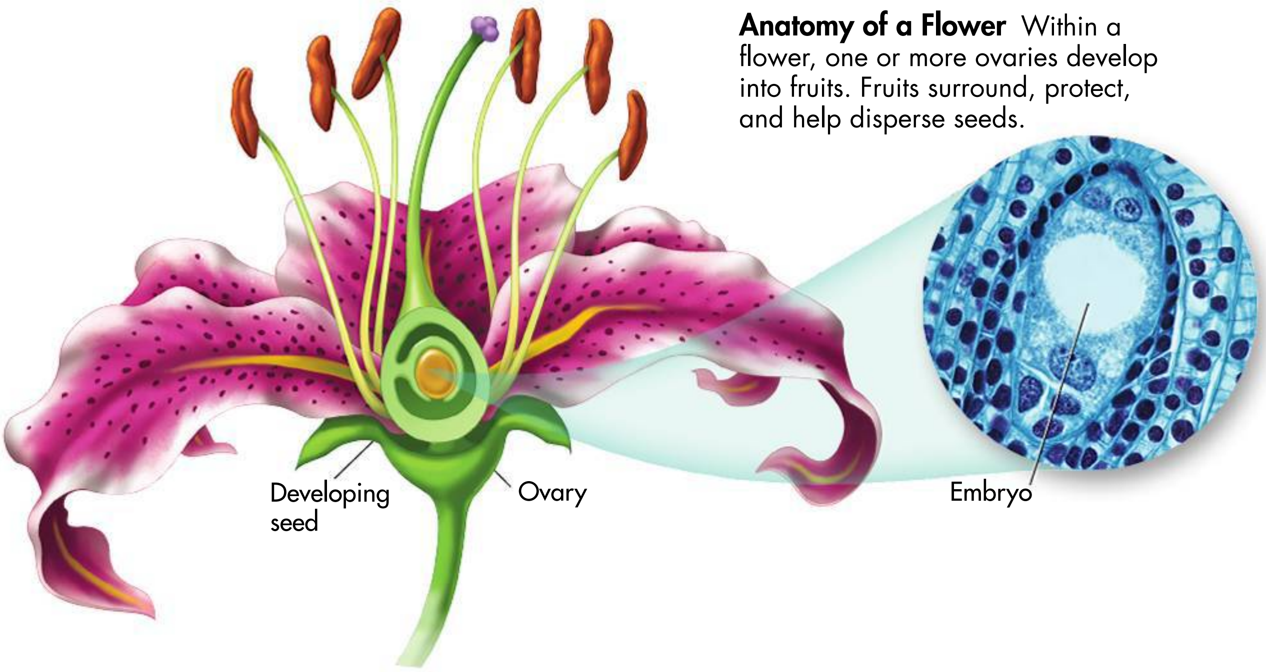
In Your Workbook Go to your workbook to learn more about using tables to compare and contrast characteristics. Complete the table for Lesson 22.4.

Flowers and Fruits

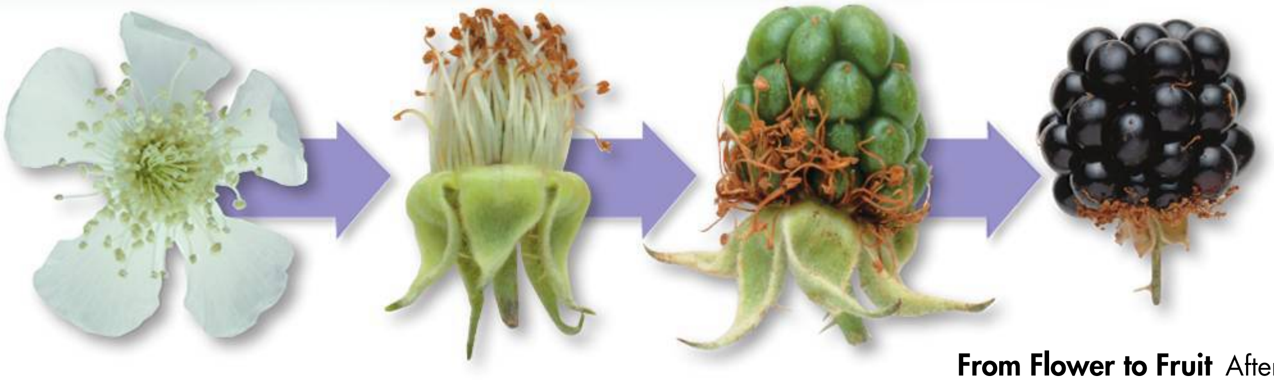
Flowering plants, or angiosperms, first appeared on land about 135 million years ago. They soon came to dominate the Earth. Today, angiosperms are the most abundant organisms in the plant kingdom. Why is this group of plants so successful?

Angiosperms have unique reproductive organs known as flowers. Flowers contain **ovaries,** which surround and protect seeds. The ovary gives angiosperms their name: *angiosperm* means "enclosed seed." After fertilization, ovaries develop into fruits. Fruits surround, protect, and help to spread the seeds.

Advantages of Flowers Most flowers attract animal pollinators, such as bees, moths, or hummingbirds. These animals are drawn by the color, scent, or shape of the flower. When they leave a flower, pollinators carry pollen with them. As they do this, the animals carry pollen to the next flower they visit. Pollination by animals is much more efficient than pollination by wind. Because they make pollination so efficient, flowers are a great evolutionary advantage to a plant.



Anatomy of a Flower Within a flower, one or more ovaries develop into fruits. Fruits surround, protect, and help disperse seeds.



From Flower to Fruit After fertilization, the many ovaries of a blackberry flower develop into a cluster of individual fruits.

Advantages of Fruits After pollination, the ovary develops into a fruit. A **fruit** is a structure that contains one or more seeds. Fruits play an important role in spreading seeds. Consider what happens when a bird eats a fruit, such as a berry. Seeds from the berry enter the bird's digestive system. The bird may fly far from the parent plant before dropping the seeds. In this way, seeds can be spread over large areas of land. Thus, fruits are another reason why angiosperms are so successful.

Key Question What are the key features of angiosperm reproduction? **Angiosperms reproduce sexually by means of flowers. After fertilization, the ovaries develop into fruits. Fruits surround, protect, and help to spread the seeds.**

INQUIRY into Scientific Thinking

What Forms Do Fruits Take?

Fruits vary widely. Some fruits, such as apples and pears, are fleshy. Other fruits, such as dandelion and maple fruits, have structures specialized for dispersal by wind. Some fruits, such as those of cocklebures, have structures that ensure the fruit is caught in the fur of a passing animal.

Procedure

1. Use a hand lens to examine different fruits. Write down your observations and make sketches of the fruits.

2. Place each fruit in a petri dish and use a scalpel to dissect it. **CAUTION:** Use care with sharp instruments.

3. Locate the seeds within each fruit. Write down your observations and make sketches of the dissected fruits.

Analyze and Conclude

1. **Compare and Contrast** Make a table that compares the characteristics of the fruits you observed.

2. **Infer** Fleshy fruits are often spread by animals. Dry fruits are often spread by the wind. For each of the fruits you examined, identify how the fruit is likely spread. Explain your answers.

In Your Workbook Get more help for this activity in your workbook.

BUILD Vocabulary

ovary a structure in flowering plants that surrounds and protects seeds

fruit a structure that contains one or more matured ovaries

cotyledon the first leaf or first pair of leaves produced by the embryo of a seed plant

monocot an angiosperm with one seed leaf in its ovary

dicot an angiosperm with two seed leaves in its ovary

PREFIXES

Mono- means "one," and *di-* means "two." Monocots have one seed leaf. Dicots have two seed leaves.

Angiosperm Diversity

Flowering plants range in size from tiny duckweed—a plant smaller than your fingernail—to giant trees. Angiosperms can be described by the structure of their stems, their length of life, or the number of their seed leaves.

Woody and Herbaceous Plants One of the easiest ways to describe a plant is by the characteristics of its stem. Woody plants, such as trees and shrubs, have stems that are hard and live from year to year. Herbaceous (hur BAY shus) plants do not form wood as they grow. Their stems are softer than the stems of woody plants. Dandelions, petunias, and sunflowers are herbaceous plants.

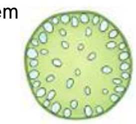
Annuals, Biennials, and Perennials Plants can also be described by their length of life. Flowering plants called annuals grow, flower, form seeds, and die in a single year. Cucumbers, pansies, and marigolds are annuals. Many other plants continue to grow from year to year. Biennials, such as foxgloves, grow for two years. Perennials, such as asparagus, can live for many years.

Monocots and Dicots Until recently, scientists classified flowering plants according to the number of seed leaves, or **cotyledons** (kaht uh LEED uns) in their embryos. Plants with one seed leaf were called **monocots.** Monocots included wheat, lilies, and palms. Plants with two seed leaves were called **dicots.** Dicots included roses, tomatoes, and oak trees. Monocots and dicots also differed in the structure of their leaves, stems, roots, and flowers.

Key Question How are angiosperms categorized?
Angiosperms are often grouped according to the characteristics of their stems, their life span, or the number of their seed leaves.

Comparing Monocots and Dicots This table compares the structure of monocots and dicots.

Characteristics of Monocots and Dicots

	Seeds	Leaves	Flowers	Stems	Roots
Monocots	Single cotyledon 	Parallel veins 	Floral parts often in multiples of 3 	Vascular bundles scattered throughout stem 	Fibrous roots 
Dicots	Two cotyledons 	Branched veins 	Floral parts often in multiples of 4 or 5 	Vascular bundles arranged in a ring 	Taproot 

Amborella Clade Only one species still exists in this oldest branch of angiosperms. Its floral parts have a spiral arrangement.

Water Lily Clade The water lilies are another very old group. Early water lily flowers may have been no more than 1 cm across. Today water lilies are large and showy.

Magnoliids This clade contains a wide range of flowers, from species that have small, plain flowers to the dinner-plate sized *Magnolia* flower shown here.

Monocots This clade contains about 20 percent of all angiosperms. Monocots include important crops, such as rice, corn, and wheat. They also include orchids, lilies, and irises.

Eudicots About 75 percent of angiosperms are eudicots. This clade is nearly as old as the angiosperms themselves. Eudicots diversified greatly several times in their history.

Angiosperm Clades Five major clades of angiosperms are shown here. Scientists are still working out how angiosperm clades are related.

Modern Classification Recall that biologists classify organisms according to their evolutionary relationships. Recent studies of fossils and plant genetics show that the history of angiosperms is very complicated. These discoveries are changing how biologists classify flowering plants. The art shows one modern view of how angiosperms could be classifed.

Biologists still classify the monocots in a single group. Dicots, however, have been divided into several different groups. Although it is no longer used in scientific classification, the term *dicot* is useful for describing plant structures. In the following chapters, the term is used for that purpose.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A plant that has leaves with parallel veins and flowers with six petals is a ______.

2. After pollination and fertilization, the ______ of a flower develops into a fruit.

3. A ______ has two cotyledons.

Critical Thinking

4. Review What reproductive structures are found only in angiosperms? Briefly describe the function of each.

5. Compare and Contrast List three common ways of describing or grouping flowering plants. How are these three methods different from scientific classification?

6. Write to Learn Answer the next clue of the mystery. Use the words *monocot* and *seed leaf* in your answer.

MYSTERY CLUE

Scientists found fragments of wheat in Iceman's digestive tract. Scientists also discovered that the wheat was planted and grown by people. How did scientists determine that the seed fragments came from a monocot? (Hint: See p. 542.)

BIOLOGY.com Search Lesson 22.4 GO • Lesson Assessment

Real-World Lab

OPEN-ENDED INQUIRY

Pre-Lab: Exploring Plant Diversity

Problem How many different kinds of plants are in a small ecosystem?

Materials notebook, protective work gloves, measuring tape, tweezers, scissors, small plastic bags, labels, hand lens, field guides for plants, camera (optional)

Lab Manual Chapter 22 Lab

Skills Focus Observe, Measure, Classify, Infer

Connect to the Big idea There are more than 290,000 known species of plants that exist on Earth—from tiny green algae to large-leaved ferns to imposing redwood trees. What do these species have in common? They all need light, carbon dioxide, oxygen, water, and minerals to survive. But plant species vary in the way they obtain and retain resources.

Plants have adaptations that allow them to succeed in different habitats. Thus, you will not find 290,000 species of plants in your community. But you should be able to find a variety of plants. In this lab, you will survey a small ecosystem and identify as many plant species as possible.

Background Questions

a. **Review** What are the features that botanists use to divide the plant kingdom into five major groups?

b. **Compare and Contrast** Compare abiotic and biotic factors in an ecosystem.

c. **Applying Concepts** Suppose an ecosystem includes a stream or pond. Would you include that part of the ecosystem in your plant survey? Explain your answer.

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Design an Experiment** What are some ways that you can make sure that you survey all the plants in your ecosystem?
2. **Classify** What should you do if you are not sure that an organism is a plant?
3. **Infer** Why might you want to use a regional field guide rather than a national field guide when identifying plants?

BIOLOGY.com Search Chapter 22 GO

Visit Chapter 22 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video The Untamed Science biologists interview plant experts to learn about healing chemicals manufactured by plants.

Tutor Tube Is this plant a girl? Compare animals and plants to understand plant reproduction.

Art Review See how well you can distinguish monocots and dicots.

InterActive Art Review and compare life cycles of vascular and nonvascular plants.

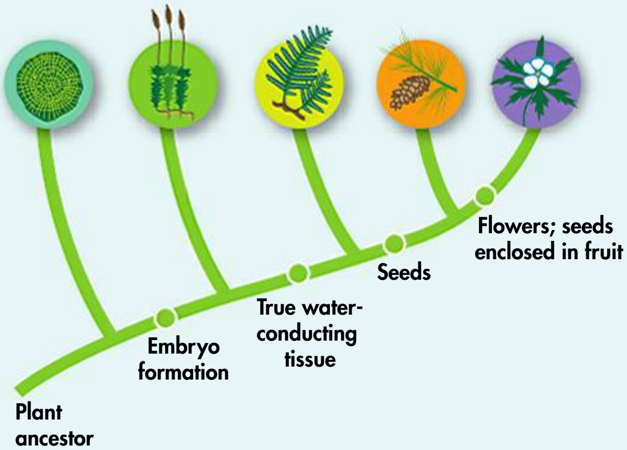
Art in Motion Follow the process of pollination and fertilization in a pine to see how a plant embryo is formed.

22 CHAPTER Summary

22.1 What Is a Plant?

- To survive, plants need sunlight, water, and minerals. They also need to exchange gases with the air.
- Over time, life on land favored the evolution of plants with adaptations that helped them survive the drying rays of the sun, prevented the loss of water, and allowed them to reproduce without water.
- Plants have alternation of generations, or life cycles with two phases. The two phases are a diploid (2N) sporophyte phase and a haploid (N) gametophyte phase.

alternation of generations (p. 530)
sporophyte (p. 530)
gametophyte (p. 530)



22.2 Seedless Plants

- Green algae live mostly in fresh water or salt water; some live in moist areas on land. Some green algae are multicellular.
- Bryophytes are small because they lack vascular tissue.
- Vascular tissues—xylem and phloem—allow the movement of fluids through the body of a plant against the force of gravity.

bryophyte (p. 533)
vascular tissue (p. 533)
xylem (p. 534)
phloem (p. 534)

22.3 Seed Plants

- Adaptations that allow seed plants to reproduce without open water include cones or flowers, the transfer of sperm by pollination, and the protection of embryos in seeds.
- Gymnosperms do not need open water for reproduction, because wind carries pollen grains to female cones, where fertilization takes place.

seed (p. 536)
gymnosperm (p. 536)
angiosperm (p. 536)
pollen grain (p. 536)
pollination (p. 536)
seed coat (p. 537)
ovule (p. 538)
pollen tube (p. 538)

22.4 Flowering Plants

- Angiosperms reproduce sexually by means of flowers. After fertilization, ovaries within flowers develop into fruits. Fruits surround, protect, and help to spread the seeds.
- Angiosperms are often grouped according to the characteristics of their stems, their life span, or the number of seed leaves.

ovary (p. 540)
fruit (p. 541)
cotyledon (p. 542)
monocot (p. 542)
dicot (p. 542)

22 CHECK Understanding

Assess the Big idea

Unity and Diversity of Life

Write an answer to the question below.

Q: What are the five main groups of plants, and how have four of these groups adapted to life on land?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each question should be one or two paragraphs long. To help you begin, read the **Hints** below the questions.

1. **How did the evolution of vascular tissue affect the structure of land plants?**

   Hint Vascular tissue carries water and nutrients throughout the bodies of plants.

   Hint Mosses and other bryophytes do not have vascular tissue.

2. **Choose a group of seedless vascular plants and a group of seed plants. Then, compare the process of reproduction in these two groups.**

   Hint Ferns are seedless vascular plants. Conifers and flowering plants are seed plants.

   Hint Seeds have three parts: the embryo, the seed coat, and a supply of food. Each has an important role in protecting the young plant.

3. **Why are flowering plants the most numerous group of plants alive today?**

   Hint Angiosperms have two unique structures, flowers and fruits.

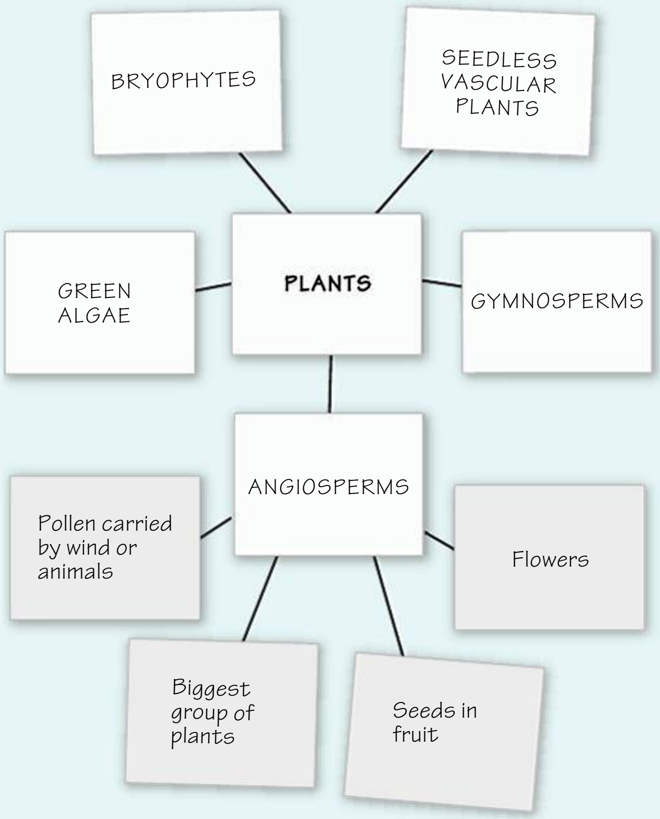
   Hint Animals play an important role in two parts of the plant life cycle.

Foundations for Learning Wrap-Up

Use the index cards you prepared when reading the chapter to help you organize your thoughts about the five types of plants.

Activity 1 Work with a partner to quiz each other on what you know about the five groups of plants. Shuffle your index cards and take turns sorting the cards based on whether each card describes green algae, bryophytes, seedless vascular plants, gymnosperms, or angiosperms.

Activity 2 Add one card to your deck and write Plants on it. Starting with the card labeled Plants, lay your cards on the table. Use pieces of yarn to create a cluster diagram that describes the five groups of plants.



22.1 What Is a Plant?

Understand Key Concepts

1. Which of the following is NOT a characteristic of plants?
   a. eukaryotic cell
   b. multicellular structure
   c. cell walls containing chitin
   d. chlorophyll

Test-Taking Tip

Process of Elimination When answering multiple-choice questions, identify answers that you know are wrong. In question 1, you know that all plants are eukaryotes and have chlorophyll. You know that plants have many cells. Therefore, the answer must be **c,** cell walls containing chitin.

2. Two gases that plants must exchange with the air are
   a. oxygen and nitrogen.
   b. oxygen and carbon dioxide.
   c. carbon dioxide and nitrogen.
   d. carbon dioxide and carbon monoxide.

3. Land plants likely evolved from organisms that are similar to which modern group of plants?
   a. green algae
   b. angiosperms
   c. gymnosperms
   d. seedless plants

4. List the two phases of the plant life cycle.

Think Critically

5. **Sequence** Four characteristics that biologists use to distinguish the major groups of plants are flowers, embryos, seeds, and vascular tissue. List these characteristics in the order they arose.

22.2 Seedless Plants

Understand Key Concepts

6. In vascular plants, water is carried from the roots to the body of the plant by
   a. xylem. **c.** cell walls.
   b. phloem. **d.** chloroplasts.

7. In ferns, underground stems are called
   a. fronds. **c.** rhizomes.
   b. rhizoids. **d.** vascular tissues.

8. Why are green algae classified as plants and not as protists?

9. What do seedless plants need for fertilization to occur?

Think Critically

10. **Explain** How does the structure of cells in vascular tissue play a role in the function of vascular tissue?

22.3 Seed Plants

Understand Key Concepts

11. The male gametophyte of seed plants is found in
    a. sperm. **c.** ovaries.
    b. ovules. **d.** pollen grains.

12. Which of the following is NOT part of a seed?
    a. ovule **c.** stored food
    b. seed coat **d.** young plant

13. Describe pollination in gymnosperms such as conifers.

14. What is the function of the seed coat?

Think Critically

15. **Compare and Contrast** Describe how gymnosperms and angiosperms are similar. Then, describe how they differ.

22 CHECK Understanding

22.4 Flowering Plants

Understand Key Concepts

16. In angiosperms, seeds are surrounded and protected by

a. cones. **c.** flowers.
b. fruits. **d.** seed leaves.

17. What kind of plants have life cycles that last several years?

a. dicots
b. annuals
c. monocots
d. perennials

18. How do woody plants differ from herbaceous plants?

19. How do fruits help spread seeds?

Think Critically

20. **Infer** Some fruits have adaptations that enable the seeds to be spread by wind. How might the structure of these fruits differ from the structure of fruits for seeds that are spread by animals?

21. **Compare and Contrast** Compare the size and function of the gametophyte in mosses, ferns, and seed plants.

Connecting Concepts

Use Science Graphics

Use the photograph to answer questions 22 and 23.

22. **Classify** Study the photograph of the flower above. Is this plant a monocot or dicot? Explain your answer.

23. **Infer** Would you expect the leaves of this plant to have parallel or branched veins? Would you expect the root system to have a taproot? Explain your reasoning.

solve the CHAPTER MYSTERY

STONE AGE STORYTELLERS

Scientists learn more about Iceman as they study the plant materials found with him. The large amount of chlorophyll in the maple leaves is common in spring and summer. Pollen is usually produced in spring. The leaves and the pollen found in Iceman's digestive tract suggest that he died in late spring.

The unfinished bow suggests that Iceman's trip into the mountains was not planned. He may have been running away from an enemy. Scientists later learned that a stone arrowhead was lodged beneath Iceman's left shoulder blade. The arrowhead cut a major blood vessel.

How did Iceman and his people live? The wheat in his digestive tract and other grains found on his clothes show that Iceman's society practiced an early form of farming.

1. **Apply Concepts** A clump of moss was also found with Iceman's possessions. Scientists hypothesize that Iceman used the moss the way that we use paper towels today. What property of moss makes this possible?

2. **Infer** Pollen and seeds are the most reliable plant-related evidence at archeological sites and at modern-day crime scenes because they are long lasting. Relate this quality to their structure and function.

UntamedScience **Never Stop Exploring Your World.** Iceman used plants in ways that made sense for the time he lived in. Take a video field trip with the ecogeeks of Untamed Science to see how far humans have come in realizing what plants have to offer.

Standardized Test Prep

Multiple Choice

1. Which of the following is a basic requirement of plants?
A sunlight
B carbon dioxide
C water
D all of the above

2. What stage in the alternation of generations is represented by fern fronds?
A sporophyte
B female gametophyte
C male gametophyte
D zygote

3. Which of the following is NOT a characteristic of dicots?
A branched veins
B taproot
C parallel veins
D two seed leaves

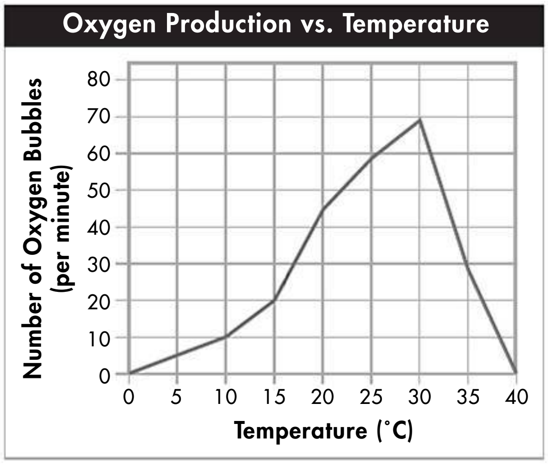
4. Which of the following is a structure associated with gymnosperms?
A flower
B cone
C fruit
D enclosed seed

5. In flowering plants, the mature plant ovary is also referred to as the
A gymnosperm.
B pollen grain.
C fruit.
D seed leaf.

6. Which is the largest group of plants?
A gymnosperms
B woody plants
C angiosperms
D bryophytes

Questions 7–9

A group of students placed a conifer sprig in a beaker of water. They measured the amount of oxygen given off during a set period of time to determine the rate of photosynthesis. They changed the temperature of the water in the beaker using an ice bucket and a hot plate. Their data are summarized in the graph below.



7. What is the independent variable?
A light intensity
B temperature
C oxygen bubbles
D photosynthesis rate

8. Which variable(s) should the students have held constant?
A plant type
B temperature
C light intensity
D plant type and light intensity

9. What can you conclude based on the data?
A The higher the temperature, the more oxygen bubbles are released.
B There is an optimum temperature for photosynthesis in this species of conifer.
C All plants are most efficient at 30°C.
D The lower the temperature, the more oxygen bubbles are released.

Open-Ended Response

10. Explain why seeds were an important adaptation for the success of plants on Earth.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	22.1	22.2	22.4	22.3	22.4	22.4	22.3	22.3	22.3	22.3

23 Plant Structure and Function

Big idea: Structure and Function

Q: How are cells, tissues, and organs organized into systems that carry out the basic functions of a seed plant?

BIOLOGY.com Search Chapter 23 GO • Flash Cards

INSIDE:

- 23.1 Specialized Tissues in Plants
- 23.2 Roots
- 23.3 Stems
- 23.4 Leaves
- 23.5 Transport in Plants

The leaves of this sundew plant are adapted to capture and digest live prey.

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

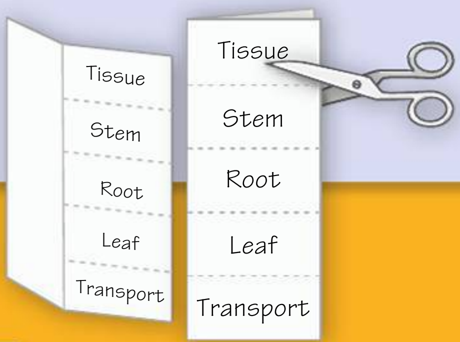
THE HOLLOW TREE

Imagine that you are hiking through a Central American rain forest on a hot afternoon. You see many unusual plants and animals. A monkey calls from a far-off tree, and a dense fog covers the landscape. Then, you stumble on a root and look up. You are standing in front of a huge tree. Its trunk seems to be made up of many tangled branches. Edging closer, you stick your head through a large opening between the branches. You look straight up. Inside, you find that the tree is hollow! This tree, a kind of fig, is indeed unusual.

Read for Mystery Clues What happened to the inside of the fig tree? And how did the tree grow so big if it has no center? As you read this chapter, look for clues that explain the structure of this strange plant.

FOUNDATIONS for Learning

Like many living things, plants have cells, tissues, and organs. Fold a sheet of paper in half lengthwise. Then, use a pair of scissors to make five flaps as shown below. On the flaps, write Tissue, Stem, Root, Leaf, and Transport. As you read each lesson, write what you learn beneath the appropriate flap. At the end of the chapter are two activities that will help answer the question: How are cells, tissues, and organs organized into systems that carry out the basic functions of a seed plant?



23.1 Specialized Tissues in Plants

Key Questions

- *What are the three main organs of seed plants?*
- *What are the functions of the main tissue systems of seed plants?*
- *How do meristems differ from other plant tissues?*

BUILD Understanding

Concept Map As you read, make a concept map to organize the information in this lesson.

In Your Workbook Go to your workbook to learn more about concept maps. Complete the concept map for Lesson 23.1.

Structure of Seed Plants

Have you ever wondered if plants are really alive? Compared to animals, plants don't seem to do much. But if you could see inside a plant, this impression would disappear. Like animals, plants move materials, grow, repair themselves, and respond to their environment. Although their pace may seem slow, plants are, indeed, living organisms.

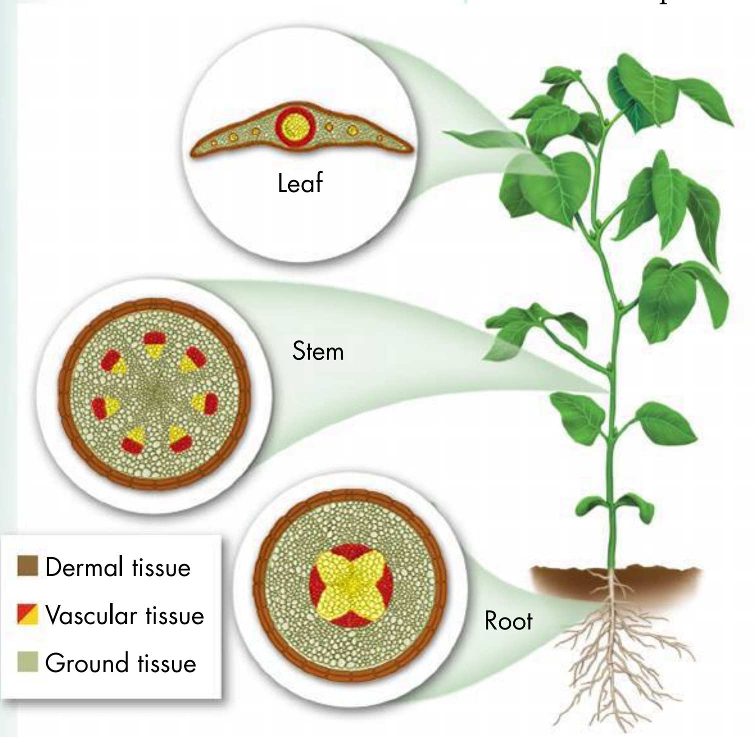
The cells of seed plants are organized into tissues, organs, and systems. The three main organs of seed plants are roots, stems, and leaves. Recall that an organ is a group of tissues that work together to carry out related functions.

Roots Roots hold plants in the ground and help hold the plant upright. Roots absorb water and nutrients from the soil. They then transport water and dissolved nutrients to the rest of the plant. Roots may also store food.

Stems Stems support the plant body. They contain vascular tissues that carry water and nutrients throughout the plant body. Stems help protect the plant against predators and disease. Stems also produce leaves and reproductive organs such as flowers.

Leaves Leaves are the plant's main photosynthetic organs. Oxygen and carbon dioxide move in and out of the leaf through tiny openings in the surface. Leaves also have adaptations that prevent water loss.

Key Question What are the three main organs of seed plants?
The three main organs of seed plants are roots, stems, and leaves.



Main Organs of Plants These cross sections of the main organs of plants show that all three organs contain dermal tissue, vascular tissue, and ground tissue.

INQUIRY into Scientific Thinking

What Parts of Plants Do We Eat?

When you eat your vegetables, you may be eating the leaves, stems, roots, or even flowers of a plant!

Procedure

1. Examine the outside of an onion, a sweet potato, a cabbage, and an artichoke. Write down your observations of each vegetable. Include a sketch of each vegetable. Label the parts that you see. **CAUTION:** *Do not eat the vegetables.*
2. Use a sharp knife or scalpel to cut each vegetable in half. Draw what you see inside. **CAUTION:** *Use care with sharp instruments.*
3. Use your observations to classify each vegetable as a root, stem, leaf, or other plant part.

Analyze and Conclude

1. Classify How did you classify the onion? What characteristics did you use to make this decision?

2. Infer How did you classify the sweet potato? How is its structure related to its function?

3. Infer How did you classify the cabbage? What does its color tell you about its function?

4. Infer How did you classify the artichoke? What does its inner structure tell you about its function?

In Your Workbook Get more help for this activity in your workbook.

Tissue Systems in Plants

Roots, stems, and leaves are linked together by systems that run the length of the plant. These systems produce, store, and carry nutrients. They also provide support and protection for the plant. Plants have three main tissue systems: dermal, ground, and vascular.

Dermal Tissue Dermal tissue covers a plant the way that skin covers your body. In young plants, dermal tissue is made of a single layer of cells called the **epidermis** (ep uh DUR mis). The epidermis is often covered with a thick, waxy cuticle. The cuticle prevents water loss. In older plants, dermal tissue may have many layers of cells. It may be covered with bark.

Ground Tissue Ground tissue makes and stores food. Ground tissue also helps support the plant. The edible parts of plants such as potatoes and squash are mostly ground tissue.

Most ground tissue is made of **parenchyma** (puh RENG kih muh) cells. Parenchyma cells have a thin cell wall and a large central vacuole. In leaves, these cells contain many chloroplasts and carry out most of a plant's photosynthesis.

Ground tissue may also contain two types of cells with thicker cell walls. **Collenchyma** (kuh LENG kih muh) cells have strong cell walls that can bend. These flexible cells help support large plants. Chains of collenchyma make up the "strings" in a stalk of celery. **Sclerenchyma** (sklih RENG kih muh) cells have very thick, hard cell walls. These cells make some ground tissue, such as seed coats, tough and strong.

BUILD Vocabulary

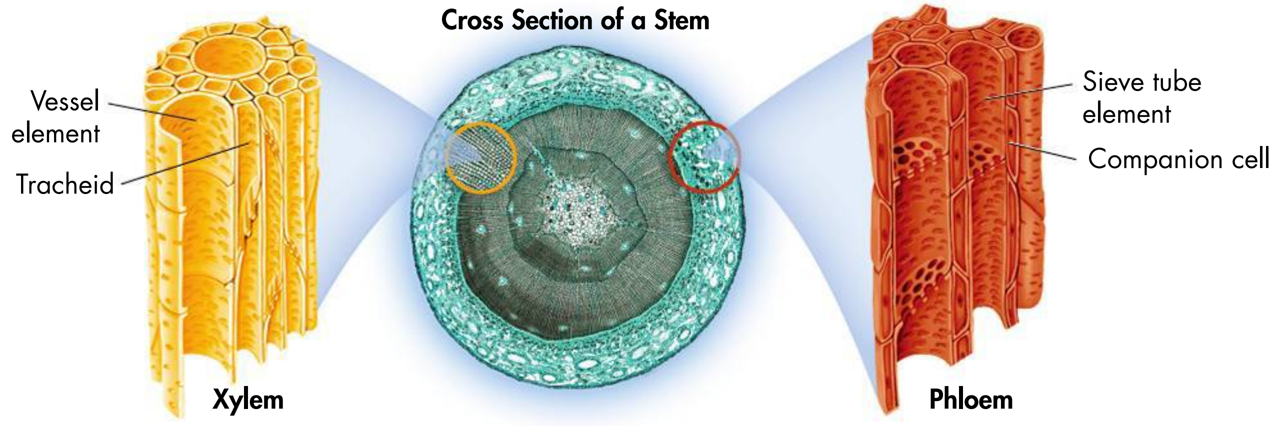
epidermis
the single layer of cells that makes up dermal tissue of plants

parenchyma
the main type of ground tissue; contains cells with thin cell walls and large central vacuoles.

collenchyma
a type of ground tissue that has strong, flexible cell walls; helps support larger plants

sclerenchyma
a type of ground tissue with extremely thick and rigid cell walls that make ground tissue tough and strong

WORD ORIGINS
The terms *epidermis* and *dermal* have a common word root: *derm*. This root comes from the Greek word *derma*, which means "skin." Both terms are used to describe an outer, protective covering.



Vascular Tissue Xylem and phloem move water and nutrients throughout a plant.

Vascular Tissue Vascular tissue supports the plant body. It transports water and nutrients throughout the plant. One kind of vascular tissue is xylem, which carries water. The other kind of vascular tissue is phloem, which carries dissolved nutrients. Both xylem and phloem cells are long and thin, almost like pipes.

▶ ***Xylem*** Seed plants have xylem cells called *tracheids*. Tracheids have tough cell walls that help support the plant. These cell walls contain the compound **lignin,** which makes them stiff and strong. As they mature, tracheids die, leaving only their cell walls. Openings in tracheid cell walls let water flow from cell to cell. Thinner areas of tracheid cell walls, known as pits, allow water to move into ground tissue.

Angiosperms have a second kind of xylem made up of cells known as *vessel elements*. Vessel elements are wider than tracheids. Like tracheids, vessel elements die as they mature.

▶ ***Phloem*** Unlike xylem cells, phloem cells are alive at maturity. The main phloem cells are *sieve tube elements*. These cells are arranged end to end. They form tubes through which dissolved nutrients move. *Companion cells* surround sieve tube elements. Companion cells support phloem cells. They aid in the movement of substances in and out of the phloem.

Key Question What are the functions of the main tissue systems of seed plants? **Dermal tissue protects the plant. Ground tissue makes and stores food and supports the plant body. Vascular tissue supports the plant body and transports water and nutrients.**

BUILD Vocabulary

lignin
a substance in vascular plants that makes cell walls rigid

meristem
an area of unspecialized cells responsible for continuing growth throughout a plant's lifetime

apical meristem
a group of unspecialized cells that divide to increase the length of stems and roots

RELATED WORD FORMS

Apex and *apical* are related words. *Apex* is a noun that refers to a narrowed or pointed end. *Apical* is an adjective that describes something related to an apex.

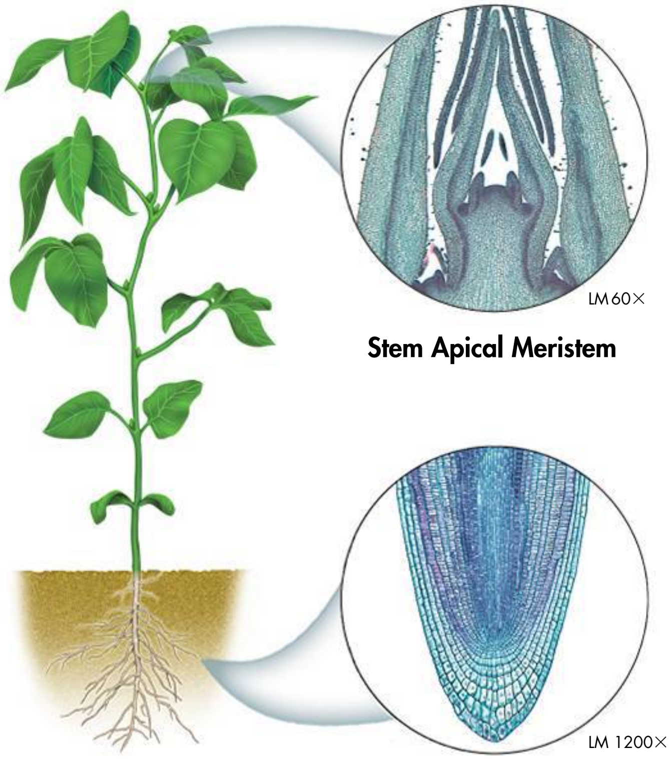
Plant Growth and Meristems

When most animals become adults, they stop growing larger. This is not true for most plants. Even the oldest trees produce new leaves and new reproductive organs every year. How do plants do it? How do plants stay "forever young"? The secret of plant growth is found in meristems. **Meristems** are areas of unspecialized cells that produce new cells. These new cells are produced by mitosis. Meristems are found in places where plants grow rapidly, such as the tips of stems and roots.

Apical Meristems Meristems in the tips of stems and roots are called **apical meristems.** Unspecialized cells produced in apical meristems divide rapidly, increasing the length of stems and roots. At first, the new, thin-walled cells look very much alike. Gradually, they develop into cells with specialized structures and functions. This development process is called differentiation. As cells differentiate, they produce dermal, vascular, and ground tissue.

Meristems and Flower Development The specialized cells of flowers and cones are also produced by meristems. The development of flowers and cones begins when genes cause changes in the apical meristem. In flowering plants, apical meristems are changed into floral meristems. Floral meristems then produce all the specialized tissues found in flowers.

Key Question How do meristems differ from other plant tissues?
Meristems are areas of undifferentiated cells that produce new cells by mitosis. These new cells can then differentiate into specialized cells.



Apical Meristems Apical meristems are found in the growing tips of stems and roots. Within apical meristems, unspecialized cells are produced by mitosis.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The ________ is dermal tissue that is made up of a single layer of cells.
2. The compound that makes the cell walls of seed plants stronger is called ______.
3. The region that is made up of cells that divide to increase the length of stems and roots is called ______.

Critical Thinking

4. **Review** What are the three main organs of seed plants?
5. **Interpret Diagrams** Review the art of the main organs of a plant on page 552. How are the three main organs similar in structure?
6. **Compare and Contrast** Compare apical and floral meristems. How are they similar? How are they different?
7. **Write to Learn** Answer the first clue of the mystery.

MYSTERY CLUE

The tangled branches seen in the mature figs are not stems. The seeds of the fig species sprout high up in the branches of other forest trees. These trees are called hosts. What are the "branches" that make up the trunks of these figs? How do they grow? (**Hint:** See p. 552.)

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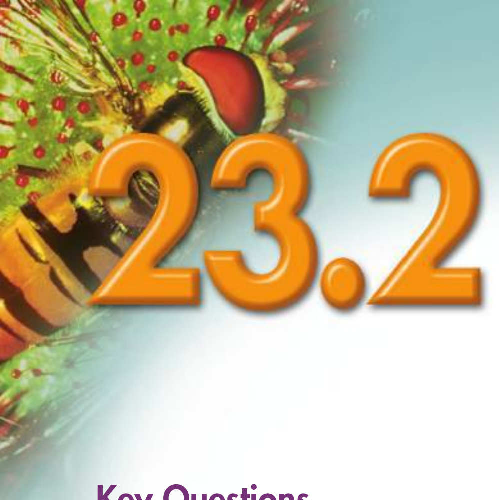


23.2 Roots

Key Questions

🔑 ***What are the main tissues in a mature root?***

🔑 ***What are the functions of roots?***

BUILD Understanding

Venn Diagram As you read, make a two-circle Venn diagram that compares the two types of root systems.

In Your Workbook Go to your workbook to learn more about Venn diagrams. Complete the Venn diagram for Lesson 23.2.

BUILD Vocabulary

root hairs small hairs on a root that produce a large surface area through which water and minerals can enter the root

cortex in plants, an area of ground tissue just inside the root through which water and minerals move

endodermis in plants, a layer of dermal tissue that completely surrounds the vascular cylinder

root cap the tough covering of the root tip that protects the meristem

PREFIXES

The prefix *endo-* means "inside." The endodermis is the inner layer of the cortex.

Root Structure and Growth

As soon as a seed begins to sprout, it puts out its first root. This root draws water and nutrients from the soil. Soon other roots branch out from the first root. These roots add length and surface area to the root system. Greater surface area lets the plant take in more water and nutrients. Rapid cell growth pushes the tips of the roots deeper into the soil. The new roots provide raw materials for the developing plant.

Types of Root Systems The two main types of root systems are taproots and fibrous roots. Taproot systems are found mainly in dicots. Fibrous root systems are found mainly in monocots. Recall from Chapter 22 that monocots and dicots are two groups of flowering plants.

▶ ***Taproot System*** In some plants, the main root grows long and thick. This root gives rise to much smaller branch roots. The main root is called a taproot. Taproots of oak and hickory trees grow so long that they can reach water several meters below the surface. Carrots, dandelions, radishes, and beets have short, thick taproots that store sugars and starches.

▶ ***Fibrous Root System*** In other plants, such as grasses, the root system begins with one root. This root is soon replaced by many other roots of about the same size. These roots grow separately from the base of the stem. They branch so much that no single root grows larger than the rest.

Two Root Systems Dandelions have a taproot system (left), while grasses have a fibrous root system (right).

Anatomy of a Root Roots contain the three tissue systems—dermal, ground, and vascular tissue. A mature root has an outside layer of dermal tissue, the epidermis. It also contains vascular tissue and a large area of ground tissue. The cells and tissues of a root are specialized to carry water and minerals.

▶ ***Dermal Tissue*** The epidermis protects the root. It also helps the root take in water and dissolved minerals. The cells of the epidermis project outward as long, thin **root hairs.** Root hairs reach into the spaces between soil particles. By increasing the surface area of the root that is in contact with the soil, root hairs help the root take in water and minerals.

▶ ***Ground Tissue*** Just inside the epidermis is an area of ground tissue called the **cortex.** After moving through the epidermis, water and minerals move through the cortex toward the center of the root. The cortex also stores the products of photosynthesis, such as starch.

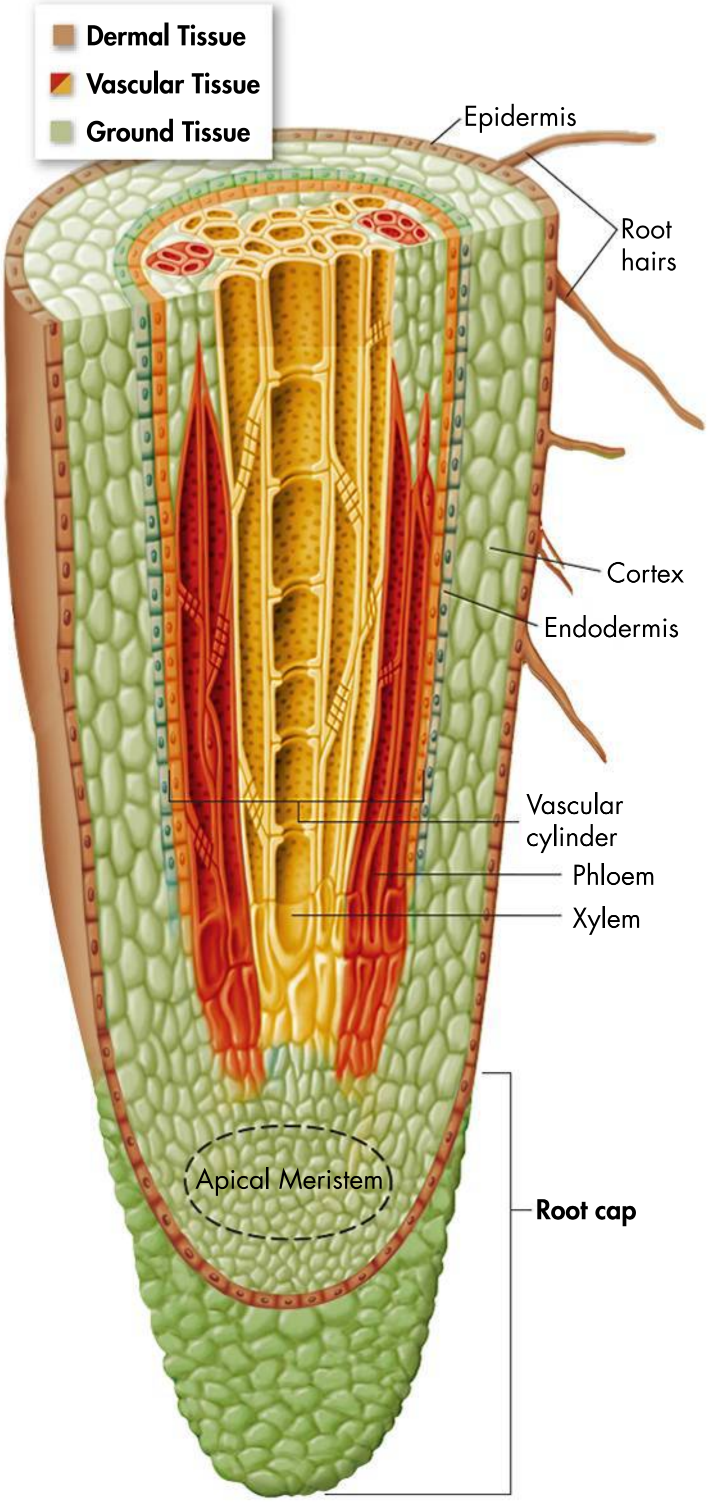
A layer of ground tissue known as the **endodermis** completely surrounds the vascular tissue. The endodermis plays a key role in the movement of water and minerals into the center of the root.

▶ ***Vascular Tissue*** At the center of the root, xylem and phloem make up an area called the *vascular cylinder*. Dicot roots like the one shown at right have a central column of xylem.

▶ ***Apical Meristem*** Roots grow longer as apical meristems near the root tip produce new cells. The root tip is covered by a tough **root cap.** The root cap protects the meristem as the root tip forces its way through the soil. The root cap also releases a slippery substance that helps the root grow through the soil. Cells at the tip of the root cap are always being scraped away. New root cap cells are added by the meristem.

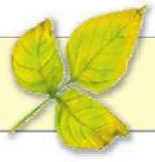
Key Question What are the main tissues in a mature root? **A mature root has an epidermis made up of dermal tissue. It contains ground tissue, which surrounds the vascular tissue.**

Anatomy of a Root A root has a central vascular cylinder that is surrounded by ground tissue and the epidermis.



Essential Plant Nutrients

Nutrient	Some Roles in Plant	Result of Deficiency
Nitrogen (N)	• Proper leaf growth and color • Synthesis of amino acids, proteins, nucleic acids, and chlorophyll	• Stunted plant growth • Pale yellow leaves ▶
Phosphorus (P)	• Synthesis of DNA • Development of roots, stems, flowers, and seeds	• Poor flowering • Stunted growth
Potassium (K)	• Synthesis of proteins and carbohydrates • Development of roots, stems, and flowers • Resistance to cold and disease	• Weak stems • Stunted roots • Edges of leaves turn brown ▶
Magnesium (Mg)	• Synthesis of chlorophyll	• Thin stems • Mottled, pale leaves
Calcium (Ca)	• Cell growth and division • Cell wall structure • Cellular transport • Enzyme action	• Stunted growth • Curled leaves ▶



Plant Nutrients Plants get many essential nutrients from soil.

Root Functions

Roots have several important functions. Roots support a plant and hold it in the ground. They store food. Roots take in water and nutrients from the soil. But materials do not just "soak" into the root. A plant must use energy to take in water and nutrients.

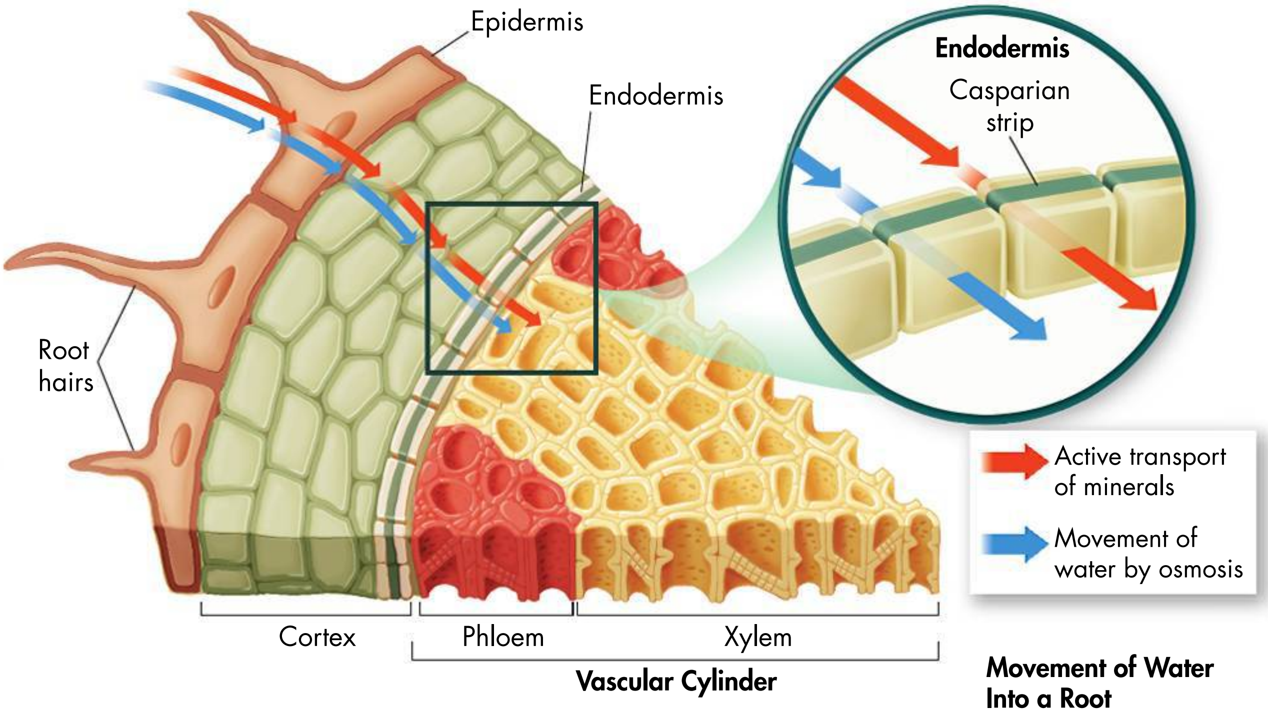
Uptake of Nutrients To grow, plants need several nutrients from the soil. Those needed in largest amounts are nitrogen, phosphorus, potassium, magnesium, and calcium. Plants also need small amounts of other nutrients, called trace elements. Trace elements include sulfur, iron, zinc, boron, copper, manganese, and chlorine.

Active Transport of Nutrients In the membranes of cells in the epidermis are proteins that can move ions by active transport. (Active transport uses energy to move materials across cell membranes.) These proteins use energy to move nutrients from the soil into the root. This action causes a high concentration of nutrient ions in the root cells.

Water Movement by Osmosis Water moves into the root by osmosis. In osmosis, water moves across a membrane to a place where the concentration of ions is higher. Water "follows" the ions that have been pumped into the root by active transport.

Movement Into the Vascular Cylinder Water moves from the epidermis, through the cortex, and into the vascular cylinder. The endodermis surrounds the vascular cylinder. Where these tissues meet, their cell walls form a waterproof zone called a *Casparian strip*. The Casparian strip forces water and nutrients to move through the cells of the endodermis. Water cannot pass between the cells. The endodermis filters and controls water and nutrients that enter the vascular cylinder.

Root Pressure The Casparian strip allows water and nutrients to move in only one direction—from the cortex into the vascular cylinder. Water and nutrients cannot move from the vascular cylinder back to the cortex.



Movement of Water Into a Root
A root absorbs water and dissolved nutrients from soil.

Why is this one-way system important? As nutrients are pumped into the vascular cylinder, more water follows by osmosis. This movement of water causes strong pressure in the vascular cylinder. That water has just one place to go—up. Root pressure forces water through the vascular cylinder and into the xylem. As more water moves from the cortex into the vascular cylinder, water in the xylem is pushed upward. Root pressure starts the movement of water through the whole plant.

Key Question What are the functions of roots? **Roots support and anchor the plant, store food, and absorb water and nutrients.**

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The tough cells of the ______ protect the apical meristem as the root grows through the soil.

2. The ______ surrounds the vascular cylinder.

3. Tiny projections from cells in the epidermis called ______ increase the surface area of a root.

Critical Thinking

4. Classify Roots contain dermal, vascular, and ground tissue. Name the tissue system to which each of these belongs: cortex, endodermis, epidermis, phloem, xylem.

5. Compare and Contrast Compare the role of active transport and the role of osmosis in taking in water and nutrients. How are these two processes connected?

6. Write to Learn Answer the mystery clue.

MYSTERY CLUE

The fig tree grows slowly until its roots reach the ground. Until its roots reach soil, how might the fig seedlings get nutrients?

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23.3 Stems

Key Questions

What are the three main functions of stems?

How do primary growth and secondary growth happen in stems?

BUILD Understanding

Preview Visuals Before you read, look at the figure that shows wood and bark formation. Define any familiar terms in your own words. List any terms you don't know. As you read, revise and add to your definitions.

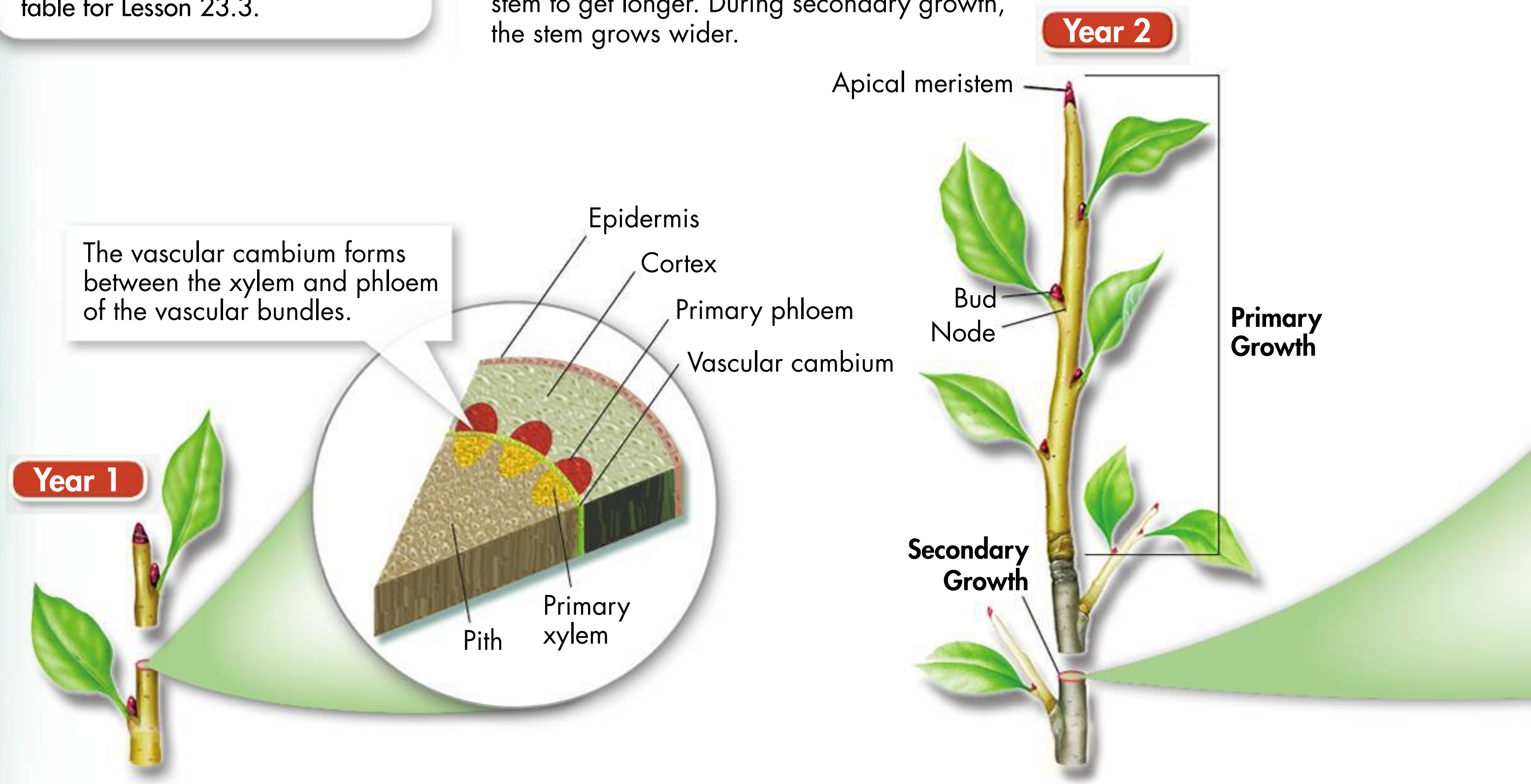
In Your Workbook Go to your workbook to learn more about previewing visuals. Complete the table for Lesson 23.3.

Structures and Function of Stems

Asparagus, water chestnuts, onions, and potatoes. What do these vegetables have in common? They are all stems! Stems vary in size and shape. Some grow underground. Others reach high into the air. But all stems have several important functions. Stems produce leaves, branches, and flowers. Stems hold leaves up to the sun. Stems move water and nutrients throughout the plant. Some stems carry out photosynthesis or store materials.

Anatomy of a Stem Stems are surrounded by a layer of epidermal cells. These cells have thick cell walls and a waxy cuticle. The areas where leaves grow out of the stem are called **nodes.** Small buds are found where leaves attach to the nodes. **Buds** contain apical meristems that can produce new stems and leaves. In larger plants, stems develop woody tissue.

Primary and Secondary Growth
During primary growth, the apical meristem produces new cells. These cells cause the stem to get longer. During secondary growth, the stem grows wider.



Vascular Bundle Patterns The arrangement of tissues in a stem differs among seed plants. In monocots, clusters of xylem and phloem tissue, called **vascular bundles,** are scattered throughout the stem. In most dicots and gymnosperms, vascular bundles form a ring.

Key Question What are three main functions of stems? **Stems produce leaves, branches, and flowers; they hold leaves up to the sun; and they carry water and nutrients throughout the plant.**

Growth of Stems

Plants grow in ways that are very different from the ways that animals grow. When animals grow, they have set characteristics. For example, cows have four legs, ants have six legs, and spiders have eight. But roses, tomatoes, and other plants don't have a set number of branches, roots, or leaves. Even so, plant growth is carefully controlled. Each species has a typical size and shape.

Primary Growth Apical meristems produce new cells throughout the plant's lifetime. These cells add length to the roots and stems. This growth, which happens at the tips of shoots and roots, is called primary growth. **Primary growth** occurs when cells produced in the apical meristem become longer. Primary growth takes place in the stems of all seed plants.

BUILD Vocabulary

node the part on a growing stem where a leaf is attached

bud a plant structure containing apical meristem tissue that can produce new stems and leaves

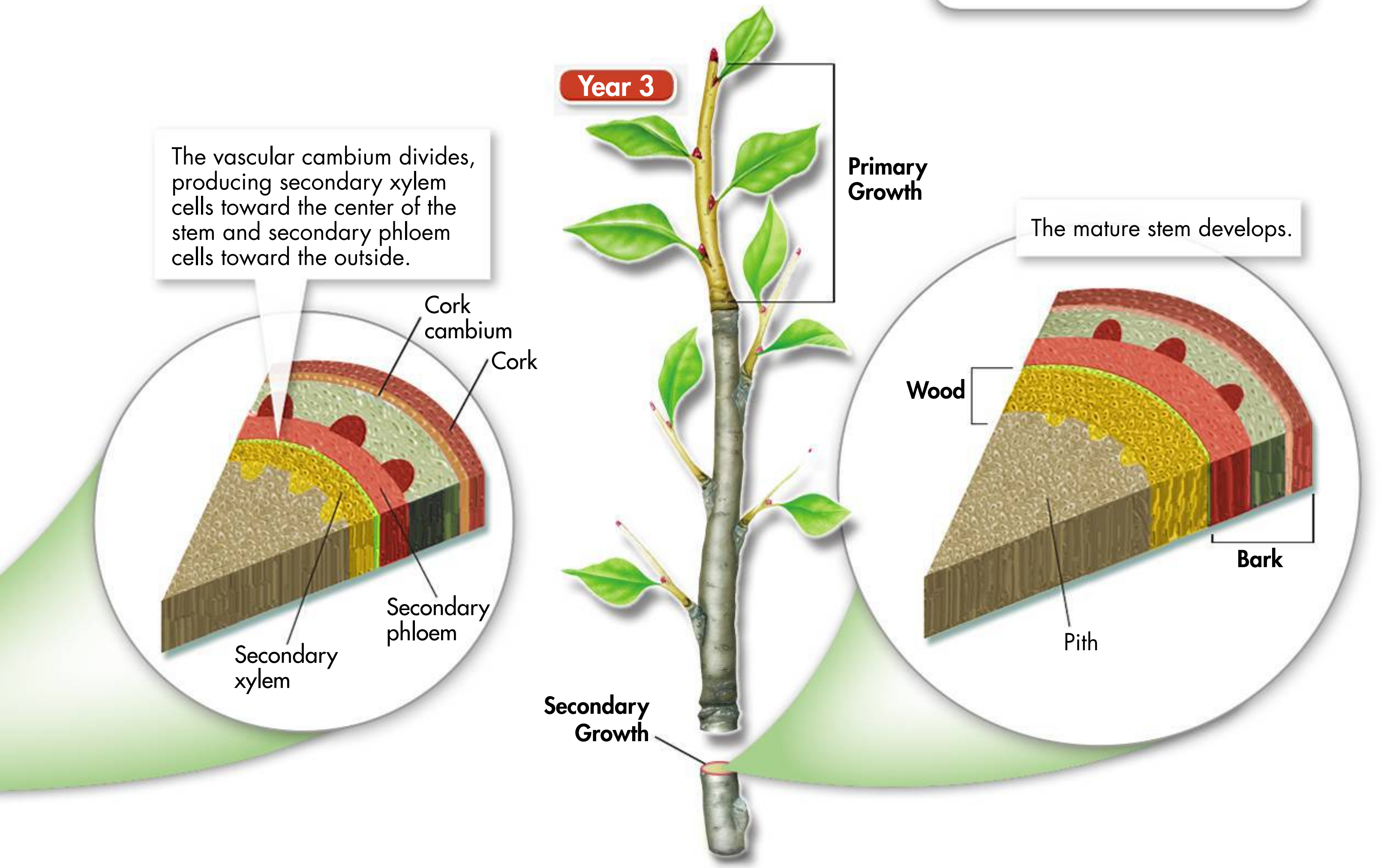
vascular bundle clusters of xylem and phloem tissue in stems

primary growth a pattern of growth that takes place at the tips and shoots of a plant

secondary growth the type of growth in which stems increase in thickness

ACADEMIC WORDS

Adjectives are words that describe nouns. Some describe order. *Primary* identifies something that comes first. *Secondary* identifies what happens next. Primary growth happens first. Secondary growth follows primary growth.



BUILD Vocabulary

vascular cambium a meristem that produces vascular tissues and increases the thickness of stems

cork cambium a meristem that produces the outer covering of stems during secondary growth

WORD ORIGIN

The word *cambium* comes from a Latin word that means "exchange." Both the vascular cambium and the cork cambium produce vascular tissue cells that will be involved in the exchange of materials within the plant.

Secondary Growth As a plant grows larger, the older stems and roots have more weight to support. They also need to move greater amounts of fluid through their vascular tissues. As a result, stems must increase in thickness as well as in length. The increase in thickness is known as **secondary growth.**

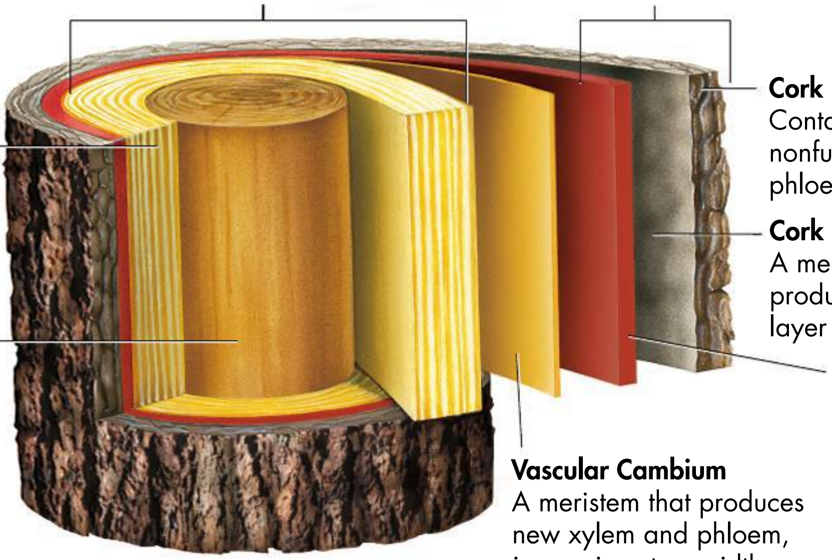
Secondary growth is common among dicots and conifers. These plants have meristems in their stems and roots that can produce secondary growth. Secondary growth lets shrubs and trees grow tall. The increase in stem width supports the extra weight. Secondary growth is rare in monocots. As a result, monocots are often limited in size.

In stems, secondary growth takes place in two tissues—vascular cambium and cork cambium. **Vascular cambium** is a meristem that produces vascular tissues. Another meristem, **cork cambium,** produces the outer covering of stems. Similar kinds of cambium tissue play a role in root growth. The addition of cells in the cambium layers increases the thickness of stems and roots.

Growth From the Vascular Cambium In the stem of a young dicot, vascular bundles are arranged in a ring. A thin layer of vascular cambium forms between the xylem and phloem of each vascular bundle. As cells in the vascular cambium divide, new layers of xylem and phloem form. This growth makes the stem get wider. Each year, the cambium makes new layers of vascular tissue. Over time, the stem grows thicker and thicker.

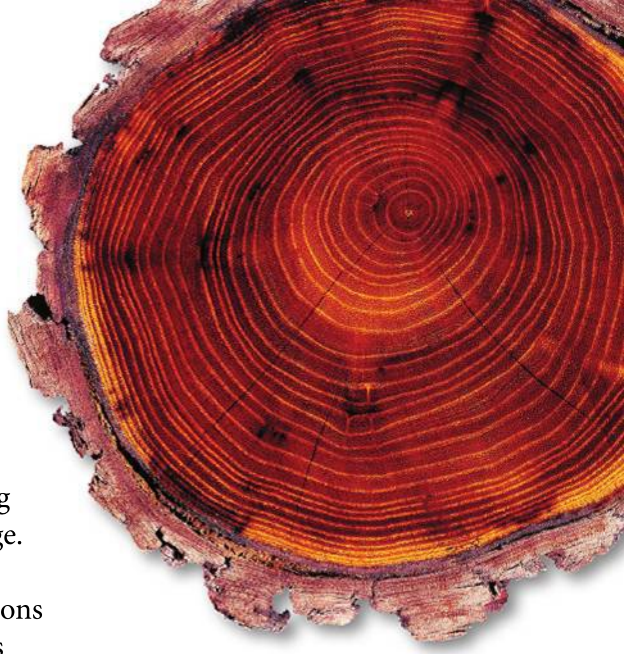
Formation of Wood Most wood is made up of layers of secondary xylem. The vascular cambium produces this xylem during secondary growth. The xylem builds up year after year. As woody stems grow thicker, the older xylem near the center of the stem no longer conducts water. Instead, it becomes what is known as *heartwood*. Heartwood usually darkens with age. Heartwood is surrounded by *sapwood*, which still conducts materials. Sapwood is usually a lighter color.

Formation of Wood and Bark This art shows the layers of wood and bark in a tree that has undergone several years of secondary growth.



Tree Rings In most of the temperate zone, tree growth is seasonal. When growth begins in the spring, the vascular cambium grows rapidly. Early growth produces large, light-colored xylem cells with thin cell walls. The result is a light-colored layer of wood. As the growing season continues, new cells become smaller and have thicker cell walls. As a result, a layer of darker wood forms. The alternation of light and dark wood produces tree rings. Little growth occurs during the winter or dry season, so there is usually a sharp boundary between rings.

Usually, each tree ring corresponds to a year of growth. By counting the rings in the cross section of a tree, you can estimate the tree's age. The size of the tree rings also provides information about weather conditions. For example, thick tree rings show that weather conditions were favorable for tree growth. There was plenty of rain. Thin rings show unfavorable conditions, such as a dry year.



Tree Rings A tree's age can be measured by counting its growth rings. The growing conditions for each year can be inferred by comparing the width and color of each ring.

Formation of Bark In a stem, all of the tissues found outside the vascular cambium make up the *bark*. Bark includes phloem, the cork cambium, and cork. During secondary growth, the vascular cambium adds secondary phloem to the bark.

Key Question How do primary growth and secondary growth happen in stems? **Primary growth is the result of the lengthening of cells produced in apical meristems. It takes place in all seed plants. Secondary growth increases the thickness of stems. It occurs in the vascular and cork cambiums of many dicots and conifers.**

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The part of a stem where a leaf is attached is a ______.
2. A structure that holds apical meristem tissues that can produce new stems and leaves is a ______.
3. The clusters of xylem and phloem tissues found in stems are called ______.

Critical Thinking

4. **Apply Concepts** How do stems support the functions of leaves and roots?
5. **Explain** Which meristem is involved in primary growth? Which two meristems are involved in secondary growth? Briefly describe the role of each.
6. **Write to Learn** Answer the mystery clue question. Use the words *primary growth* and *secondary growth* in your answer.

MYSTERY CLUE

As the fig grows, the roots grow in both length and thickness. The roots wrap around the host tree's trunk. How might this growth affect the host? (Hint: See p. 561.)

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23.4 Leaves

Key Questions

How is the structure of a leaf adapted to make photosynthesis more efficient?

What is the role of stomata in maintaining homeostasis?

BUILD Understanding

Preview Visuals Before you read, look at the figure of leaf anatomy. Find the three main tissue systems. After you read, identify which tissue system makes up leaf veins.

In Your Workbook Go to your workbook to learn more about previewing visuals.

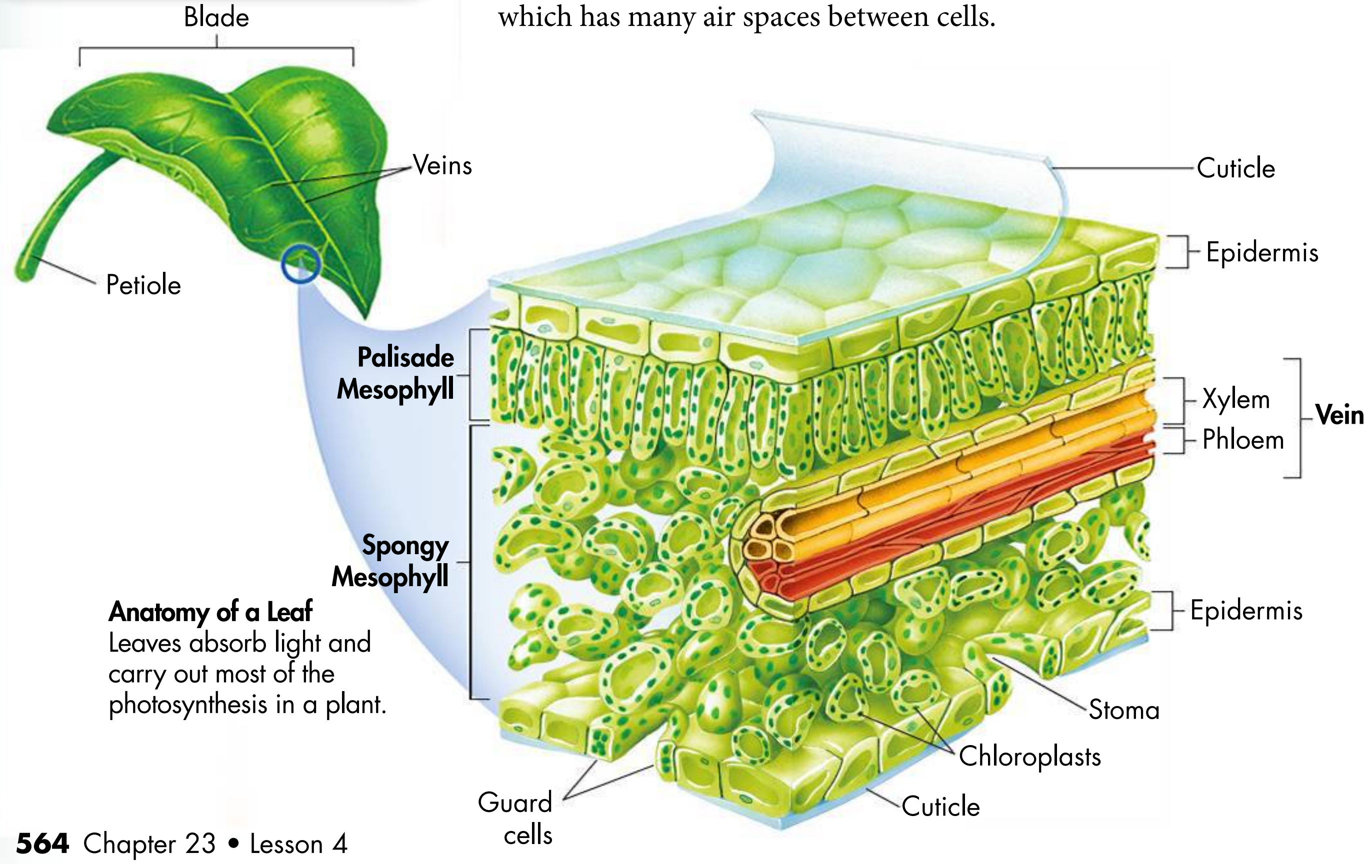
Structure and Function of Leaves

Leaves are the world's most important factories. Using the energy captured in photosynthesis, plants make the sugars, starches, and oils that feed nearly all land animals. In photosynthesis, plants use carbon dioxide and water to produce sugars and oxygen.

Anatomy of a Leaf The structure of a leaf is ideal for carrying out photosynthesis. To collect as much light as possible, most leaves are thin and flat.

▶ ***Epidermis*** A tough epidermis covers the top and bottom of most leaves. The epidermis is coated with a waxy cuticle that limits the loss of water. Small openings in the epidermis called **stomata** (singular: stoma) let gases move in and out of the leaf.

▶ ***Mesophyll*** Photosynthesis takes place in specialized ground tissue called **mesophyll** (MES uh fil). Beneath the upper epidermis is *palisade mesophyll*. Palisade mesophyll is made of closely packed cells that absorb light. Beneath the palisade mesophyll is *spongy mesophyll*, which has many air spaces between cells.



Anatomy of a Leaf Leaves absorb light and carry out most of the photosynthesis in a plant.

▶ ***Veins*** Veins of xylem and phloem run throughout the leaf and connect it to the stem. Xylem carries water from the roots into the leaf. Sugars produced in the leaf are moved into the veins. Then, phloem carries these sugars to the rest of the plant.

Key Question How is the structure of a leaf adapted to make photosynthesis more efficient? **The structure of a leaf allows the plant to collect light and carry out photosynthesis.**

Gas Exchange and Homeostasis

Plants need to exchange gases with the atmosphere. During photosynthesis, leaves take in carbon dioxide and give off oxygen. In respiration, plants take in oxygen and give off carbon dioxide.

The Role of Stomata Gases move in and out of the leaf through stomata. If stomata were open all the time, the plant would lose too much water. So, stomata are open long enough for photosynthesis to take place but not so long that the plant loses too much water. **Guard cells** are specialized cells that surround the stomata and control their opening and closing.

Changes in water pressure within the guard cells cause the stomata to open and close. When water is abundant, it flows into the leaf. This increases pressure in the guard cells. The stomata open. When water is scarce, water pressure within the guard cells decreases. Stomata close, reducing water loss by transpiration. Usually, stomata are open during the day, when photosynthesis takes place. They are closed at night. But if conditions are hot and dry, stomata may also close during the day.

Transpiration and Wilting The walls of mesophyll cells are moist, which allows gases to move in and out of the cells easily. Water evaporates from these surfaces and is lost to the atmosphere. **Transpiration** is the loss of water through leaves. Lost water may be replaced by water drawn into the leaf through xylem. If it is very hot or windy, water may be lost to transpiration faster than it is replaced. The plant may wilt.

Wilting is caused by the loss of water—and pressure—in a plant's cells. Normally, pressure in a plant's cells makes its leaves stiff. But if there is not enough water, the cell walls bend inward, and the plant wilts. When a leaf wilts, its stomata close. Transpiration slows down. Thus, wilting helps a plant save water.

Key Question What is the role of stomata in maintaining homeostasis? **Stomata are kept open long enough for photosynthesis to take place, but not so long that plants lose too much water.**

BUILD Vocabulary

stoma
(plural: stomata) a small opening in the epidermis of a plant that allows carbon dioxide, water, and oxygen to diffuse into and out of a leaf

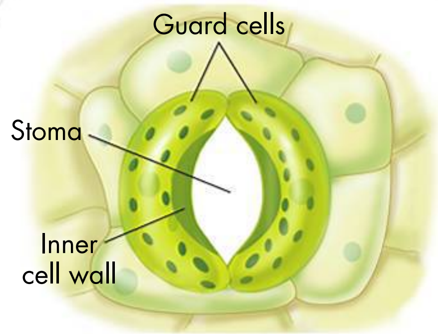
mesophyll specialized ground tissue found in leaves; performs most of a plant's photosynthesis

guard cell
a specialized cell in the epidermis of plants that controls the opening and closing of stomata

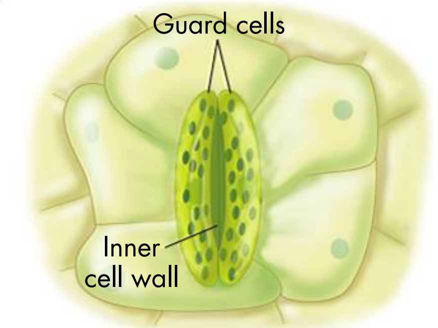
transpiration
the loss of water from a plant through its leaves

PREFIXES

The prefix *meso-* means "middle." Mesophyll tissue is in the middle of a leaf, inside the epidermis and around the veins.



Stoma Open



Stoma Closed

Guard Cell Function Stomata allow plants to balance the rate of photosynthesis and the loss of water.

Adaptations of Leaves

The leaves of the plants shown here have adaptations that help the plants live in various areas and conditions.

◀ **Pitcher Plant** The leaf of a pitcher plant is modified to attract and then digest insects and other small prey. Such plants typically live in nutrient-poor soils and rely on animal prey as their source of nitrogen.

Spruce The narrow leaves of a spruce tree contain a waxy epidermis as well as stomata that are sunken below the surface of the leaf. These adaptations reduce water loss from the leaves. ▶

Cactus Cactus leaves are actually nonphotosynthetic thorns that protect against herbivores. Most of the plant's photosynthesis is carried out in its stems. ▼

▼ **Living Stone** The two leaves of a living stone are adapted for hot, dry conditions. They are rounded, which minimizes the exposure of their surface to the air. They also have very few stomata.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The tissue in leaves that performs most of a plant's photosynthesis is ______.

2. Small openings in the epidermis of a plant that allow gases to diffuse in and out of a leaf are called ______.

3. During the process of ______, water is lost through openings in a plant's epidermis.

Critical Thinking

4. Explain To carry out photosynthesis, leaves need light, water, and carbon dioxide. Identify the tissues or structures of a leaf that provide each of these materials.

5. Apply Concepts Imagine a field. The day is hot and it has not rained for a few weeks. Will the stomata of plants in the field be open or closed? Explain your reasoning.

6. Write to Learn Answer the mystery clue question. Write a paragraph that describes how leaf structure plays a role in photosynthesis and how the fig's growth affects this function in the host plant.

MYSTERY CLUE

The mature fig plant blocks sunlight from the host tree. How might this affect photosynthesis in the host? (Hint: See p. 564.)

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23.5 Transport in Plants

Water Transport

Look at a tall tree. Maybe there's a tree outside your school that is 15 meters tall or more. Imagine carrying a bucket of water to the top of that tree. You would have to do a lot of work! Now think of a giant redwood, 100 meters high. How does water reach the top?

Active transport and root pressure move water from the soil into a plant's roots. Water entering the vascular cylinder of the root creates pressure. This pressure pushes water upward into the stem. But root pressure does not produce nearly enough force to lift water up into trees. Other forces play a larger role.

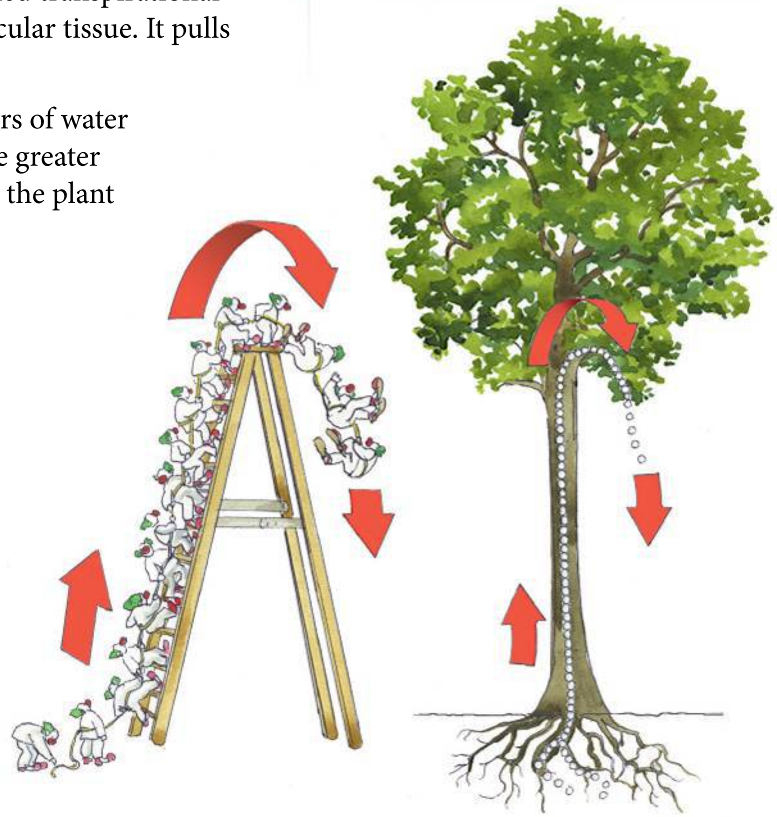
Transpiration The major force in water transport is produced by the evaporation of water from leaves during transpiration. As water evaporates through open stomata, cell walls within the leaf begin to dry out. Plant cell walls contain cellulose, a complex carbohydrate. Paper is also made of cellulose. As you know, dry paper towels strongly attract water. Like a paper towel, the dry cell walls pull water from cells deeper inside the leaf. This pull is called transpirational pull. Transpirational pull also takes place in vascular tissue. It pulls water from the roots up through the xylem.

On a hot day, even a small tree may lose 100 liters of water to transpiration. The hotter and drier the air, the greater the amount of water lost. As a result of this loss, the plant draws up even more water from its roots.

BUILD Connections

TRANSPIRATIONAL PULL

Imagine a chain of circus clowns. The clowns are tied together and climbing a tall ladder. When the first clown reaches the top, he falls off. He pulls the clowns behind him up and over the top of the ladder. Water molecules move through a plant this way. The chain of water molecules in a plant extends from the leaves down to the roots. As molecules exit the leaves through transpiration, they pull up the molecules behind them.



Key Questions

What are the major forces that transport water in a plant?

What drives the movement of fluid through phloem tissue in a plant?

BUILD Understanding

Compare/Contrast Table As you read, make a table in which you compare and contrast water transport and nutrient transport.

In Your Workbook Go to your workbook to learn more about comparing and contrasting. Complete the table for Lesson 23.5.

Capillary Action Capillary action causes water to move much higher in a narrow tube than in a wide tube.

BUILD Vocabulary

adhesion
a force of attraction between different kinds of molecules

capillary action
the tendency of water to rise in a thin tube

pressure-flow hypothesis
a hypothesis that explains how sap in phloem is transported through the plant from a sugar source to an area of lower sugar concentration

ACADEMIC WORDS
The word *hypothesis* means a possible answer to a scientific question. The pressure-flow hypothesis answers the question "What causes sap to flow within a plant?"

Pulling Water Upward To pull water upward, plants make use of water's physical properties. One of these properties is cohesion. Cohesion is the attraction among molecules of the same substance. Water molecules are strongly attracted to one another. The cohesion of water is strong because water molecules form hydrogen bonds with each other. Water molecules also form hydrogen bonds with other substances. This results from the force of adhesion. **Adhesion** is the attraction between molecules that are unlike each other.

You can observe adhesion and cohesion at work. Here is how. Place a thin, empty glass tube in a dish of water. Water will move up into the tube. Why? Water is attracted to the walls of the tube. Water molecules are also attracted to one another. This tendency of water to rise in a thin tube is called **capillary action.**

Putting It All Together What do transpirational pull and capillary action have to do with the movement of water through xylem? Recall that xylem is made of tracheids and vessel elements. These cells connect to form long, hollow tubes. The walls of these hollow tubes are made of cellulose. Water adheres to cellulose. As water is lost by transpiration, adhesion pulls water from the wet inside of the leaf. This pull is so powerful that it reaches through the xylem down to the tips of the roots. It even reaches into the water in the soil. Together, transpiration and capillary action provide the major force that moves water upward through a plant.

Key Question What are the major forces that transport water in a plant?
Transpirational pull and capillary action are the major forces that move water from soil and through the xylem tissue to the rest of the plant.

Nutrient Transport

How do sugars move in phloem? The leading explanation for transport in phloem is known as the **pressure-flow hypothesis.** Remember that unlike xylem cells, phloem cells are alive.

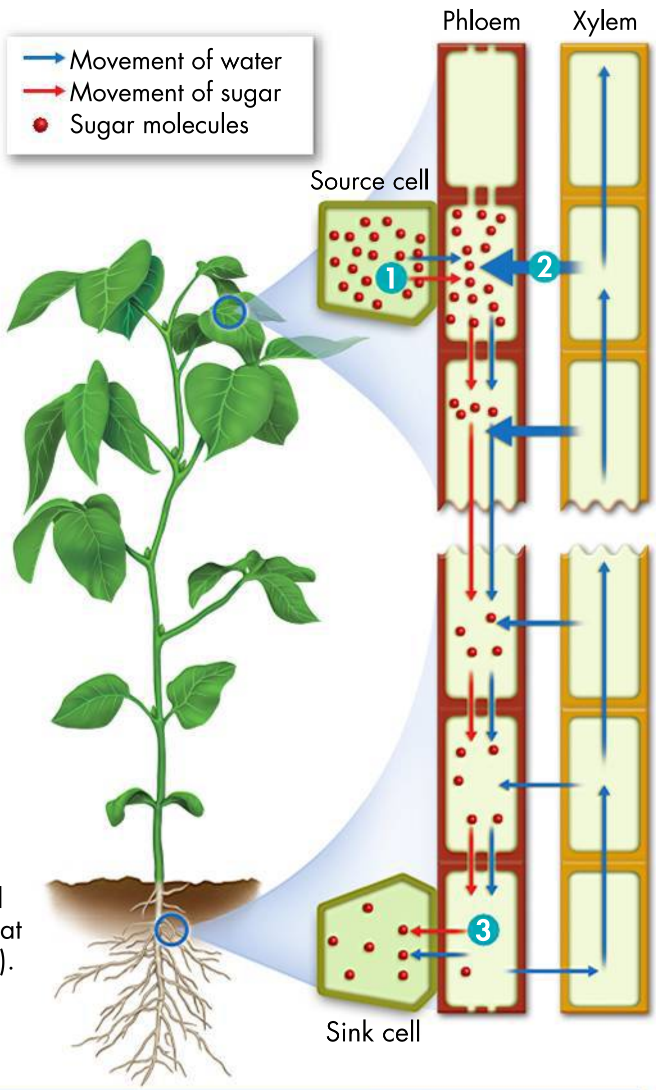
1. Active transport moves sugars into sieve tubes from the surrounding tissues.

2. Water follows the sugars into the sieve tubes by osmosis. This movement of water creates pressure in the sieve tube at the source of the sugars.

3. If sugars are needed in another area of the plant, they are pumped out of the sieve tube by active transport. Water then moves out of the sieve tube by osmosis. As the water leaves, it reduces the pressure in the tube at these areas.

Thus, pressure drives the flow of nutrient-rich fluid, or sap. Fluid moves from places where sugars are made to places where sugars are used or stored. Differences in nutrient concentration cause fluids to move in directions that meet the needs of the plant. The pressure-flow system helps plants respond to the seasons. During the growing season, sugars from the leaves are moved into ripening fruits or into roots for storage. As the growing season ends, the plant drops its fruits. Then nutrients are stored in the roots. As the growing season again approaches, chemical signals stimulate phloem cells in the roots. They pump sugars back into the phloem. Then, the pressure-flow system carries these sugars to the stems and leaves. This nutrient-rich fluid supports rapid growth.

Key Question What drives the movement of fluid through phloem tissue in a plant?
Changes in nutrient concentration cause the movement of fluid through phloem to meet the needs of the plant.



Pressure-Flow Hypothesis This diagram shows the movement of sugars as explained by the pressure-flow hypothesis. Fluid starts at places where sugars are made (source cells). The fluid moves to places where sugars are used or stored (sink cells).

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Water is attracted to cellulose by the force of ______.
2. ______ is the tendency of water to rise in a thin tube.
3. The ______ explains the movement of fluids through phloem.

Critical Thinking

4. **Relate Cause and Effect** On a hot, dry day, the stomata of a plant close. How could this affect the plant's rate of photosynthesis? Explain.
5. **Compare and Contrast** Compare the role of active transport with that of osmosis in the movement of materials through phloem.
6. **Write to Learn** Answer the mystery clue question. In your answer, use the words *xylem* and *cohesion*.

MYSTERY CLUE

Fig vines can grow to the top of very tall trees. How do the leaves at the top of the vine get the water they need for photosynthesis?
(Hint: See p. 567.)

BIOLOGY.com Search Lesson 23.5 GO • Lesson Assessment

Design Your Own Lab

GUIDED INQUIRY

Pre-Lab: Identifying Growth Zones in Roots

Problem Where does growth occur in plant roots?

Materials 150-mL beaker, paper towels, large bean seeds, petri dish, masking tape, metric ruler, fine-tip permanent marker

Lab Manual Chapter 23 Lab

Skills Focus Design an Experiment, Measure, Organize Data, Analyze Data

Connect to the Big idea A plant's root system absorbs nutrients, stores food, and provides support for the rest of the plant. As a plant grows, the root system must be able to absorb more nutrients, store more food, and provide more support. Thus, growth in the root system must keep pace with growth in the other parts of a plant. Where in a root does the growth occur that increases the root's length? In this lab, you will design an experiment to answer this question.

Background Questions

a. **Review** What are the three principal organs of seed plants?

b. **Compare and Contrast** What are the main functions of dermal tissue, vascular tissue, and ground tissue?

c. **Review** What are meristems?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Predict** A root is marked at two points along its length. What will happen to the distance between these marks if the root grows longer only near the tip? What will happen if growth occurs evenly along the entire length of the root?

2. **Design an Experiment** The procedure in Part A asks you to use four seeds. Why not use two seeds instead?

3. **Design an Experiment** How will you keep track of which seedling is which?

BIOLOGY.com Search Chapter 23 GO

Visit Chapter 23 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video The Untamed Science crew takes you to several exotic locations to see unique plant structures and adaptations.

Tutor Tube Tune in to Tutor Tube to see how new tissue growth makes plants taller.

Art Review Test your knowledge of leaf structures.

Art in Motion See how plant roots absorb nutrients and water molecules.

Visual Analogy Compare the motion of clowns climbing a ladder with water molecules being pulled up a tree.

23 CHAPTER Summary

23.1 Specialized Tissues in Plants

- The three main organs of seed plants are roots, stems, and leaves.
- Dermal tissue is the protective outer covering of a plant. Ground tissue produces and stores sugars and supports the plant. Vascular tissue supports the plant body and transports water and nutrients throughout the plant.
- Meristems are areas of unspecialized cells in which mitosis produces new cells that are ready for differentiation.

epidermis (p. 553)
parenchyma (p. 553)
collenchyma (p. 553)
sclerenchyma (p. 553)
lignin (p. 554)
meristem (p. 554)
apical meristem (p. 554)

23.2 Roots

- A mature root has an outside layer called the epidermis. A mature root also contains vascular tissue and a large area of ground tissue.
- Roots support a plant, hold the plant in the ground, store food, and absorb water and dissolved nutrients from the soil.

root hair (p. 557)
cortex (p. 557)
endodermis (p. 557)
root cap (p. 557)

23.3 Stems

- Stems produce leaves, branches, and flowers. Stems hold leaves up to the sun. Stems transport substances throughout the plant.
- Primary growth of stems is the result of elongation of cells produced in the apical meristem. It takes place in all seed plants.
- In the stems of conifers and dicots, secondary growth takes place in meristems called the vascular cambium and cork cambium.

node (p. 560)
bud (p. 560)
vascular bundle (p. 561)
primary growth (p. 561)
secondary growth (p. 562)
vascular cambium (p. 562)
cork cambium (p. 562)

23.4 Leaves

- The structure of a leaf helps the plant collect light and carry out photosynthesis.
- Plants maintain homeostasis by keeping stomata open long enough for photosynthesis to take place, but not so long that plants lose too much water.

stoma (p. 564)
mesophyll (p. 564)
guard cell (p. 565)
transpiration (p. 565)

23.5 Transport in Plants

- Transpirational pull and capillary action provide most of the force needed to move water from soil through the xylem tissues of a plant.
- Changes in nutrient concentration drive the movement of fluid through phloem to meet the needs of the plant.

adhesion (p. 568)
capillary action (p. 568)
pressure-flow hypothesis (p. 568)

23 CHECK Understanding

Assess the Big idea Structure and Function

Write an answer to the question below.

Q. How are cells, tissues, and organs organized into systems that carry out the basic functions of a seed plant?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each numbered question should be one or two paragraphs long. To help you begin, read the **Hints** below the question.

1. **Explain how the cells in the vascular tissue of a plant are specialized for transport of water and minerals.**

   Hint Use the words *tracheids*, *vessel elements*, *sieve tube elements*, and *companion cells* in your answer.

   Hint Review the information on Water Transport and Nutrient Transport in Lesson 23.5.

2. **How do the cells and tissues in the trunk of a tree help it support the weight of all of its branches and leaves?**

   Hint Trunks are stems that have undergone secondary growth.

   Hint Xylem contains tracheids and vessel elements.

3. **How do several different types of tissues in a leaf work together in the functioning of the leaf?**

   Hint The primary function of a leaf is to carry out photosynthesis.

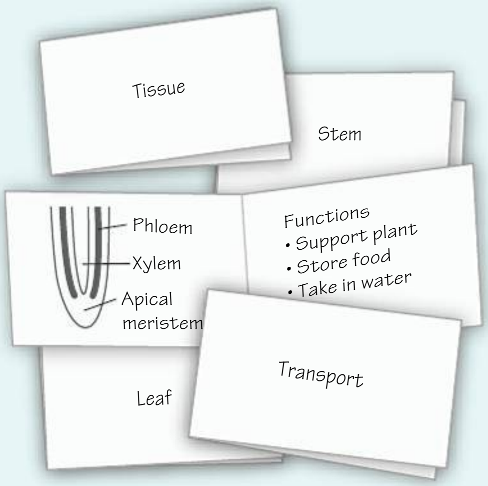
   Hint Leaves contain epidermis, mesophyll, and vascular tissue.

Foundations for Learning Wrap-Up

Use the folded page you prepared when reading the chapter to help you organize your thoughts about how cells, tissues, organs, and organ systems work together to help a plant survive.

Activity 1 Working with a partner or small group, discuss how each part of a plant works with another part of a plant. Use each tab of your folded paper to guide your discussion. For example, for the tabs labeled Leaves and Stems, identify how leaves work with stems to help the plant survive.

Activity 2 Complete each horizontal cut for each of the five topics to create five separate booklets. On the inside of each booklet, add a labeled sketch of the major structures in the lesson. Use the booklets to review the concepts from each lesson.



23.1 Specialized Tissues in Plants

Understand Key Concepts

1. The organ that supports the plant body and carries nutrients between different parts of the plant is the
   a. root. **c.** leaf.
   b. stem. **d.** flower.

2. Tracheids and vessel elements make up
   a. meristem. **c.** xylem.
   b. phloem. **d.** parenchyma.

3. What are the three main functions of ground tissue?

4. What is the main difference between mature xylem cells and mature phloem cells?

Think Critically

5. **Compare and Contrast** How are the epidermis of roots and leaves similar? How do they differ?

Test-Taking Tip

Using Lists It requires planning to answer an essay question. Before you start writing an answer, write a list of the points that you want to make. For a compare and contrast question, make two lists: one for similarities and one for differences.

23.2 Roots

Understand Key Concepts

6. Which of the following is a trace element that is absorbed by roots?
   a. nitrogen **c.** zinc
   b. phosphorus **d.** potassium

7. The waterproof barrier that separates the endodermis from the vascular cylinder is the
   a. guard cell. **c.** Casparian strip.
   b. phloem. **d.** cortex.

8. What are the two kinds of root systems?

9. How are root hairs important to plants?

Think Critically

10. **Explain** When you moved a plant to a large pot, you noticed that the plant's roots were very crowded in the old pot. After the plant was transplanted, it soon began to grow faster and looked healthier. Write a hypothesis that explains this observation.

23.3 Stems

Understand Key Concepts

11. A stem grows thicker when new tissue grows in
    a. vascular cambium. **c.** nodes.
    b. apical meristem. **d.** ground tissue.

12. Which of the following is part of the bark?
    a. heartwood **c.** xylem
    b. sapwood **d.** phloem

13. In stems, from what type of tissue does phloem develop?

14. What is the main difference between monocot and dicot stems?

Think Critically

15. **Infer** A plant undergoes only primary growth. Will it have a short life or a long life? Why?

23.4 Leaves

Understand Key Concepts

16. Most photosynthesis in a leaf takes place in the
    a. leaf vein. **c.** epidermis.
    b. mesophyll. **d.** cuticle.

17. Stomata open and close due to changes in the water pressure within
    a. phloem. **c.** guard cells.
    b. xylem. **d.** cell walls.

18. What is the function of the cuticle in a leaf?

Think Critically

19. **Infer** Cells in palisade mesophyll are closer together than cells in spongy mesophyll. How does this relate to the functions of these layers?

23 CHECK Understanding

23.5 Transport in Plants

Understand Key Concepts

20. Water molecules are attracted to each other by the force of

a. cohesion. **c.** transpiration.

b. adhesion. **d.** capillary action.

21. As water evaporates from a plant's leaves, it causes water to move through the plant by the force of

a. osmosis. **c.** capillary action.

b. active transport. **d.** transpirational pull.

22. What explains the movement of sugars and nutrients through phloem?

23. What happens to water when active transport moves sugars into phloem cells?

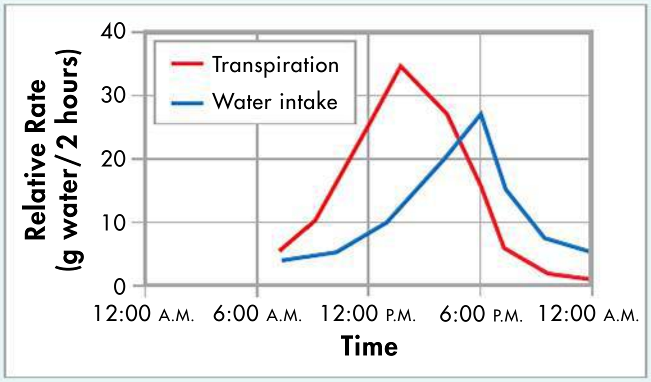
Think Critically

24. **Relate Cause and Effect** Would transpirational pull be stronger on a cold, rainy day or on a hot, dry day? Explain your answer.

Connecting Concepts

Use Science Graphics

Use the graph to answer questions 25–26.



25. **Analyze Data** When is the greatest amount of water lost through transpiration?

26. **Draw Conclusions** What is the relationship between transpiration and water intake?

solve the CHAPTER MYSTERY

THE HOLLOW TREE

The life of a strangler fig starts with a sticky seed. This seed is dropped on a high tree branch by an animal such as a bird, bat, or monkey. At first, the plant grows slowly. This slow growth happens because the roots take in the few dissolved nutrients found in the rainwater and the leaf litter that collects in the host tree's branches. Eventually, the first roots grow down the host's trunk and enter the ground. Then, the fig's growth rate increases rapidly. The fig sends down many more roots. These roots become tangled together. They crush the host tree's bark, including the phloem. As a result, fewer nutrients can move through the phloem.

The fig's stems and leaves eventually grow taller than the host tree. This shades the host from the sun. The host performs less photosynthesis. The fig's roots compete with the host's roots for limited nutrients in the soil.

This triple punch—strangulation, competition for light, and competition for nutrients—usually kills the host. An impressive "hollow" fig tree is left behind.

1. **Use Analogies** One scientist has described the strangler fig as a "vegetable octopus." Explain how this analogy relates to the habits of the strangler fig.

2. **Infer** Plants that sprout and grow on top of other plants are called epiphytes. In what biome do you think epiphytes are most common? Explain your reasoning.

UntamedScience™ **Never Stop Exploring Your World.** Finding the solution to The Hollow Tree mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Which of the following cell types is NOT found in a plant's vascular tissue?
   A tracheid
   B vessel element
   C guard cell
   D companion cell

2. Where in a plant does mitosis produce new cells?
   A meristems
   B chloroplasts
   C mesophyll
   D heartwood

3. Which tissues make up tree bark?
   A phloem
   B cork
   C cork cambium
   D all of the above

4. Which is NOT a factor in the movement of water through a plant's vascular tissues?
   A transpiration
   B capillary action
   C root pressure
   D meristems

5. All of the following conduct fluids in a plant EXCEPT
   A heartwood.
   B sapwood.
   C phloem.
   D xylem.

6. Where does most of the photosynthesis occur in a plant?
   A stomata
   B guard cells
   C vascular cambium
   D mesophyll tissue

7. Which of the following structures prevents the backflow of water into the root cortex?
   A palisade mesophyll
   B root cap
   C cambium
   D Casparian strip

8. Which of the following plants has a fibrous root system?
   A dandelion
   B beet
   C radish
   D grass

Questions 9–10

A student compared the average number of stomata on the top side and the underside of the leaves of different plants. Her data are summarized in the table below.

Average Number of Stomata (per square mm)

Plant	Top Surfaces of Leaves	Bottom Surfaces of Leaves
Pumpkin	29	275
Tomato	12	122
Bean	40	288

9. What generalization can be made based on the data?
   A All plants have more stomata on the top side of their leaves than on the bottom side.
   B Plants have fewer stomata on the top side of their leaves than on the bottom side.
   C Some plants have more stomata on the top side of their leaves than on the bottom side.
   D The number of stomata is the same from plant to plant.

10. Pumpkins, tomatoes, and beans all grow in direct sunlight. Assuming the plants receive plenty of water, stomata on the lower surface of their leaves
    A are always closed.
    B are usually clogged with dust.
    C are unlikely to close at night.
    D stay open during daylight hours.

Open-Ended Response

11. Contrast the functions of xylem and phloem.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10	11
See Lesson	23.1	23.1	23.3	23.5	23.3	23.4	23.2	23.2	23.4	23.4	23.5

24 Plant Reproduction and Response

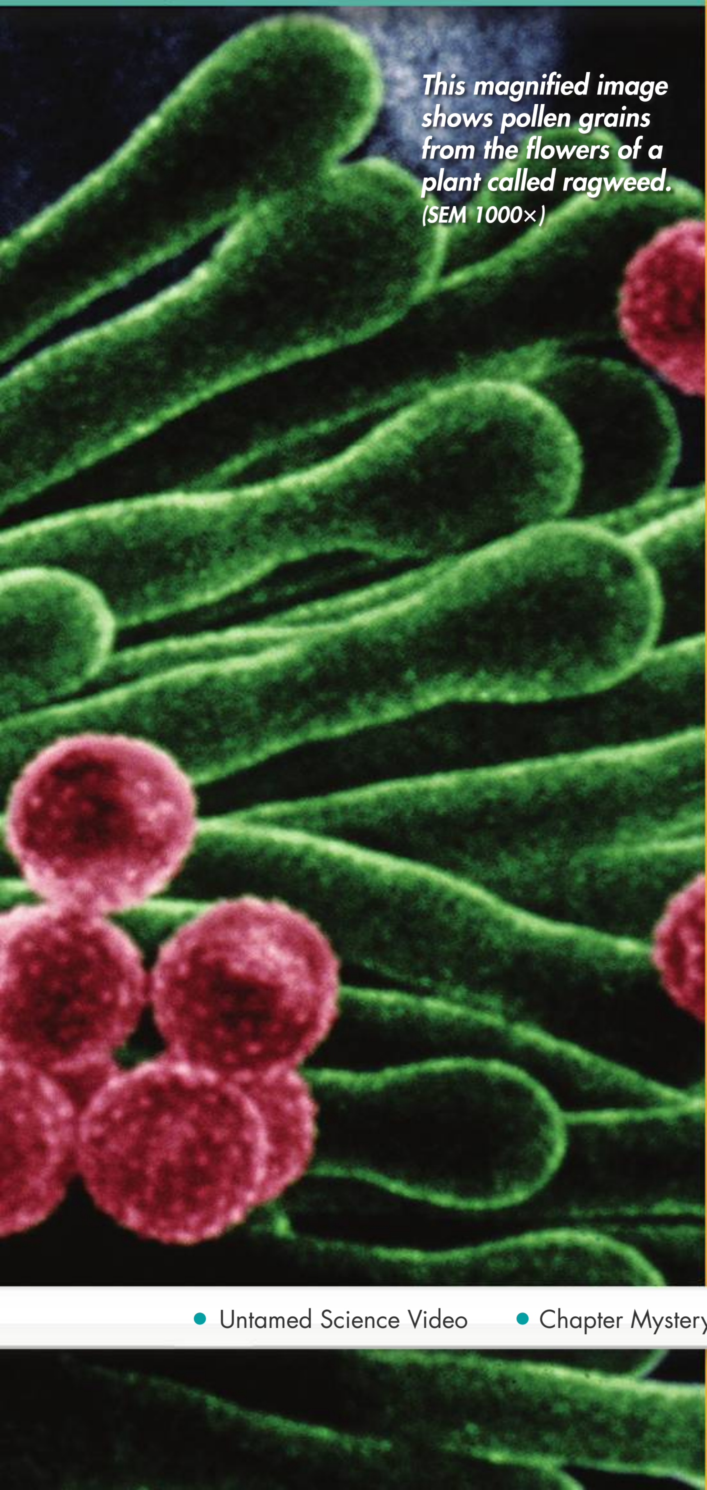
Big idea **Growth, Development, and Reproduction**

Q: How do changes in the environment affect the reproduction, development, and growth of plants?

BIOLOGY.com Search Chapter 24 GO • Flash Cards

INSIDE:

- 24.1 Reproduction in Flowering Plants
- 24.2 Fruits and Seeds
- 24.3 Plant Hormones
- 24.4 Plants and Humans



This magnified image shows pollen grains from the flowers of a plant called ragweed. *(SEM 1000×)*

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

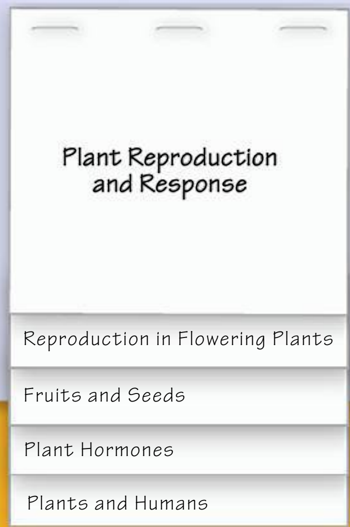
THE GREEN LEMONS

For years, a California warehouse stored freshly picked green lemons before they were shipped to market. The warehouse managers knew that the lemons would be a ripe yellow and ready to ship to market about five days after they arrived. Or so they thought. One year, for safety reasons, they replaced the warehouse's kerosene heaters with modern electric ones. Then, something surprising happened. When they began to pack their first shipment of five-day-old lemons, they had to call a halt. The lemons they expected to ship were still a bright, and very unripe, green.

Read for Mystery Clues What happened? Why didn't the lemons turn yellow? As you read this chapter, look for clues that explain why the lemons did not ripen.

FOUNDATIONS for Learning

As you read the chapter, make a layered book similar to the one shown below. On each flap, write down the name of the lesson. Then make notes about what you learn in each lesson. At the end of the chapter are two activities that use your layered book to help you to answer the question: How do changes in the environment affect the reproduction, development, and growth of plants?



24.1 Reproduction in Flowering Plants

Key Questions

What are flowers?

How does fertilization in angiosperms differ from fertilization in other plants?

What is vegetative reproduction?

BUILD Understanding

Two-Column Table Make a two-column table. Write the heading Male Gametophyte at the top of one column. Write the heading Female Gametophyte at the top of the second column. As you read, take notes about each gametophyte.

In Your Workbook Complete the table for Lesson 24.1.

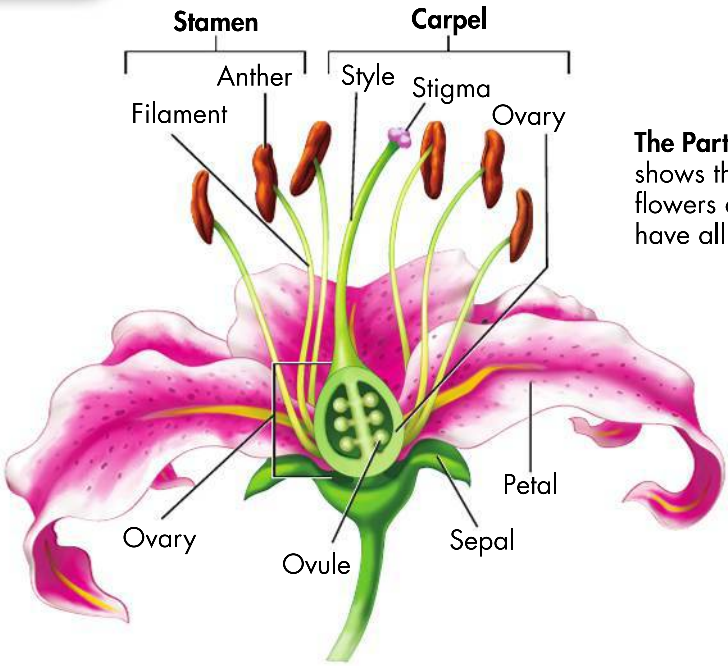
The Structure of Flowers

What makes a flower beautiful? Its color and shape? Of course, flowers vary greatly in color, size, and shape. But what is the point of a flower? To a plant, the whole point of a flower is sexual reproduction. Flowers help bring male and female gametes together and then protect the developing seeds.

Flowers are made up of four kinds of specialized leaves: sepals, petals, stamens, and carpels. The art below shows a typical flower with all of these structures.

Sepals and Petals The outermost flower parts are the sepals (SEE pulz). Often, sepals are green and look like leaves. Sepals surround and protect the flower bud as it develops. Inside the sepals are the petals. Petals, which are often brightly colored, attract pollinators to the flower.

Stamens and Carpels Within the petals are structures that produce gametophytes. Many flowering plants produce both male and female gametophytes. In other species, male and female gametophytes are produced on separate plants.



The Parts of a Flower This art shows the parts of a flower. The flowers of some species do not have all of the parts shown here.

BIOLOGY.com Search Lesson 24.1 GO • Art Review

INQUIRY into Scientific Thinking GUIDED INQUIRY

What Is the Structure of a Flower?

Procedure

1. Study a flower carefully. Use a hand lens if needed. Draw what you see, and label the parts of the flower.
2. Use forceps to remove an anther. Place the anther on a slide. Use a scalpel to cut one or more thin slices of the anther. **CAUTION:** *Be careful with sharp tools and slides. Place the slide on a flat surface before cutting.*
3. Lay the anther slices flat on the slide. Add a drop of water, and cover the anther slices with a coverslip. Use a microscope to look at the slices. Draw and label what you see.

Analyze and Conclude

1. **Apply Concepts** What structures did you find in the anthers? What is the function of these structures?
2. **Apply Concepts** What structures did you find in the ovaries? What is the function of these structures?
3. **Infer** Which parts of the flower will become seeds? Which parts will become fruit?

In Your Workbook Get more help for this activity in your workbook.

▶ ***Stamens*** **Stamens** are the male parts of a flower. Each stamen has a stalk called a filament. At the tips of filaments are **anthers.** Pollen grains, which are the male gametophytes, are produced in the anthers.

▶ ***Carpels*** The innermost parts of a flower are the carpels. **Carpels** produce and protect female gametophytes; later they produce seeds. Each carpel has a wide base called an ovary. The ovary contains one or more ovules. Female gametophytes grow inside the ovules. The carpel has a thin stalk called a style. At the top of the style is a sticky or feathery area known as the **stigma.** The stigma is specialized to capture pollen. Biologists sometimes call a single carpel or several carpels that are fused together a pistil.

Key Question What are flowers?
Flowers are reproductive organs that are made of four kinds of specialized leaves: sepals, petals, stamens, and carpels.

The Angiosperm Life Cycle

Like other plants, angiosperms have a life cycle with alternation of generations. The sporophyte phase is diploid (2N), and the gametophyte stage is haploid (1N). As with ferns and gymnosperms, the sporophyte of angiosperms is much larger than the gametophyte. In fact, the male and female gametophytes live within the tissues of the sporophyte.

BUILD Vocabulary

stamen the male part of the flower; includes an anther and a filament

anther a flower structure in which pollen grains are produced; part of the stamen

carpel the female part of the flower; the innermost part of a flower that produces and protects female gametophytes

stigma a sticky or feathery part of the carpel that is located at the top of a style; specialized to capture pollen

WORD ORIGINS
The word *carpel* comes from the Greek word *karpos*, which means "fruit." Carpels produce seeds and include the ovary, which develops into fruit.

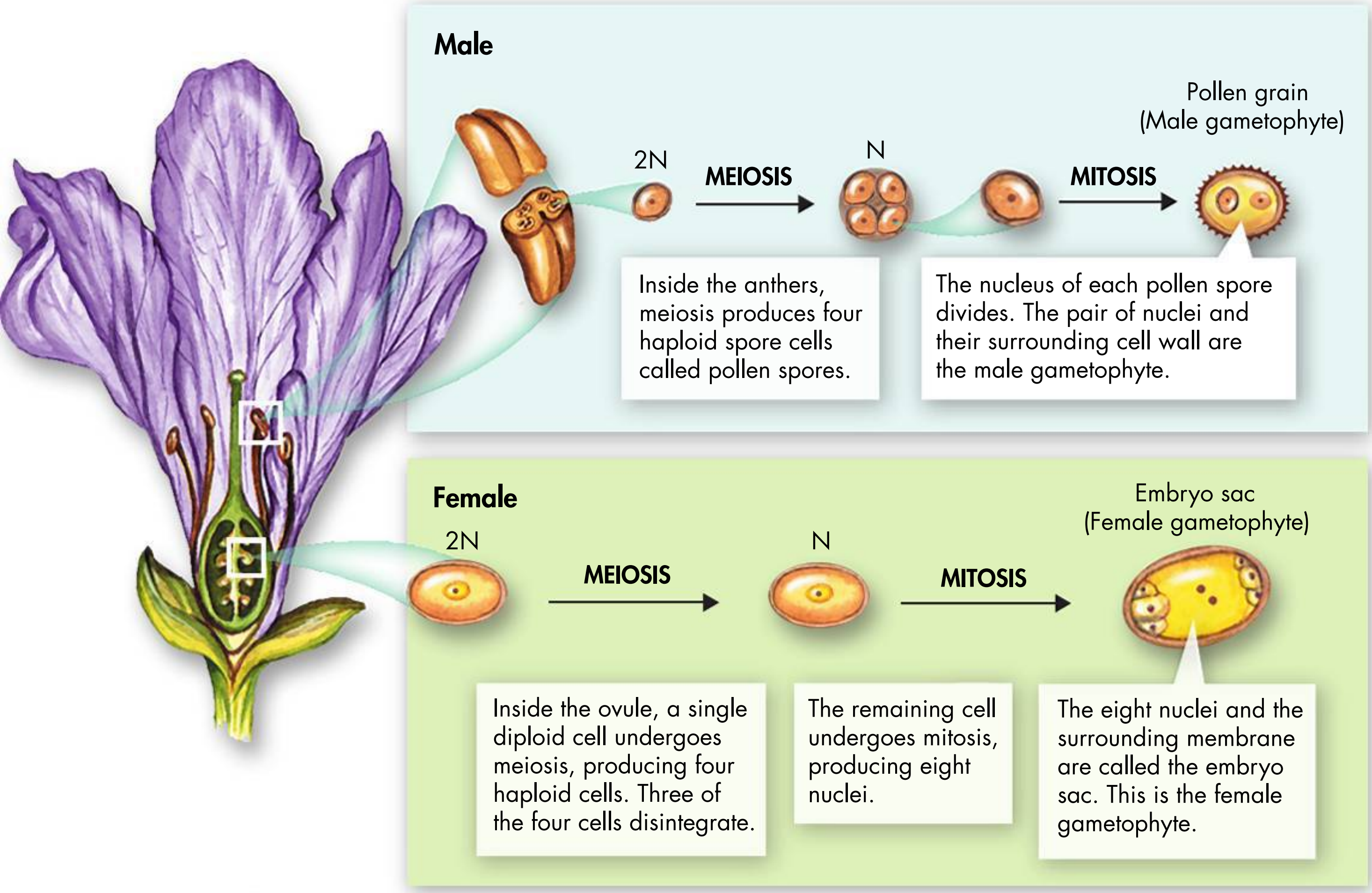
Development of Male Gametophytes Male gametophytes develop inside anthers. First, meiosis produces four haploid cells called pollen spores. Then each pollen spore divides by mitosis. This division forms two haploid nuclei. A thick wall surrounds the two nuclei. Together, the nuclei and wall form the male gametophyte, or pollen grain. The art below shows this process.

Development of Female Gametophytes Female gametophytes form in ovules at the bottom of the carpel. Each ovule is a future seed. The ovary, which surrounds and protects the ovules, is the future fruit.

The process starts when a diploid cell in an ovule divides by meiosis. This division forms four haploid cells. Three of these cells break down. The fourth cell divides by mitosis, producing eight nuclei. These eight nuclei and the surrounding membrane make up the **embryo sac.** The embryo sac is the female gametophyte. The embryo sac is contained within the ovule.

Cell walls form around six of the eight nuclei. One of the eight nuclei is the nucleus of the egg, or female gamete. If fertilization takes place, the egg will fuse with a male gamete, forming a zygote. The zygote will grow into a new sporophyte.

The Development of Gametophytes The male gametophyte develops inside an anther. The female gametophyte develops inside a single ovule.



Pollination The flowers of an oak tree (left) are pollinated by wind. They are small and not very showy. However, they produce large amounts of pollen. In contrast, flowers that are pollinated by animals (right) are often large and brightly colored.

Pollination Pollination is the transfer of pollen to the stigma of the flower. Most angiosperms are pollinated by animals, but some are pollinated by wind. Wind-pollinated flowers are usually small and not very colorful. Wind-pollinated plants rely on the production of huge numbers of pollen grains to carry pollen from one plant to another.

Animal pollinators, such as insects, birds, and bats, carry pollen from flower to flower. Flowers that are pollinated by animals have many adaptations that attract pollinators. These adaptations include bright colors, strong scents, and sweet nectar. Animal pollinators, in turn, have adaptations that help them get nectar from the flowers. Hummingbirds, for example, have long thin beaks that can reach the nectar deep inside tube-shaped flowers.

Flowering plants and their pollinators have a mutualistic relationship. The animals are rewarded by a source of food—pollen and nectar. The plants are helped because animals take pollen directly from flower to flower. The efficiency of animal pollination may be one of the main reasons why angiosperms have become the most successful group of plants.

Fertilization If a pollen grain lands on the stigma of a flower, the process of fertilization begins. One of the male gametophyte's nuclei forms a pollen tube. The pollen tube grows into the style. Eventually it reaches the ovary and enters an ovule. The other nucleus divides, forming two sperm cells. These sperm cells reach the egg through the pollen tube.

Inside the embryo sac, the two sperm fertilize different nuclei. This process is called **double fertilization.** First, one of the sperm nuclei fuses with the egg nucleus. A diploid (2N) zygote forms. The zygote will grow into the embryo. Next, the second sperm nucleus fuses with two other nuclei in the embryo sac to form a triploid (3N) cell. This 3N cell will grow into tissue known as **endosperm.** Endosperm contains a rich supply of food that will nourish the seedling as it grows.

BUILD Vocabulary

embryo sac
the female gametophyte within the ovule of a flowering plant

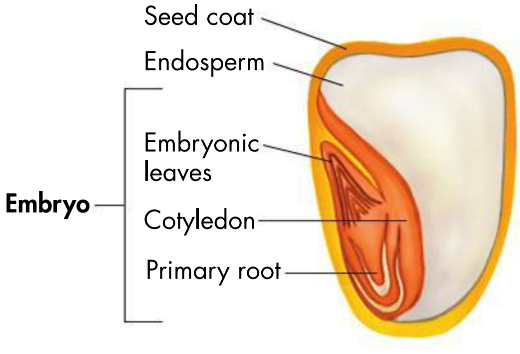
double fertilization
the process of fertilization in angiosperms, in which the first event produces the zygote, and the second event produces the endosperm within the seed

endosperm
the food-rich tissue that nourishes a seedling as it grows

PREFIXES

The prefix *endo-* means "within." Endosperm is located within a seed.

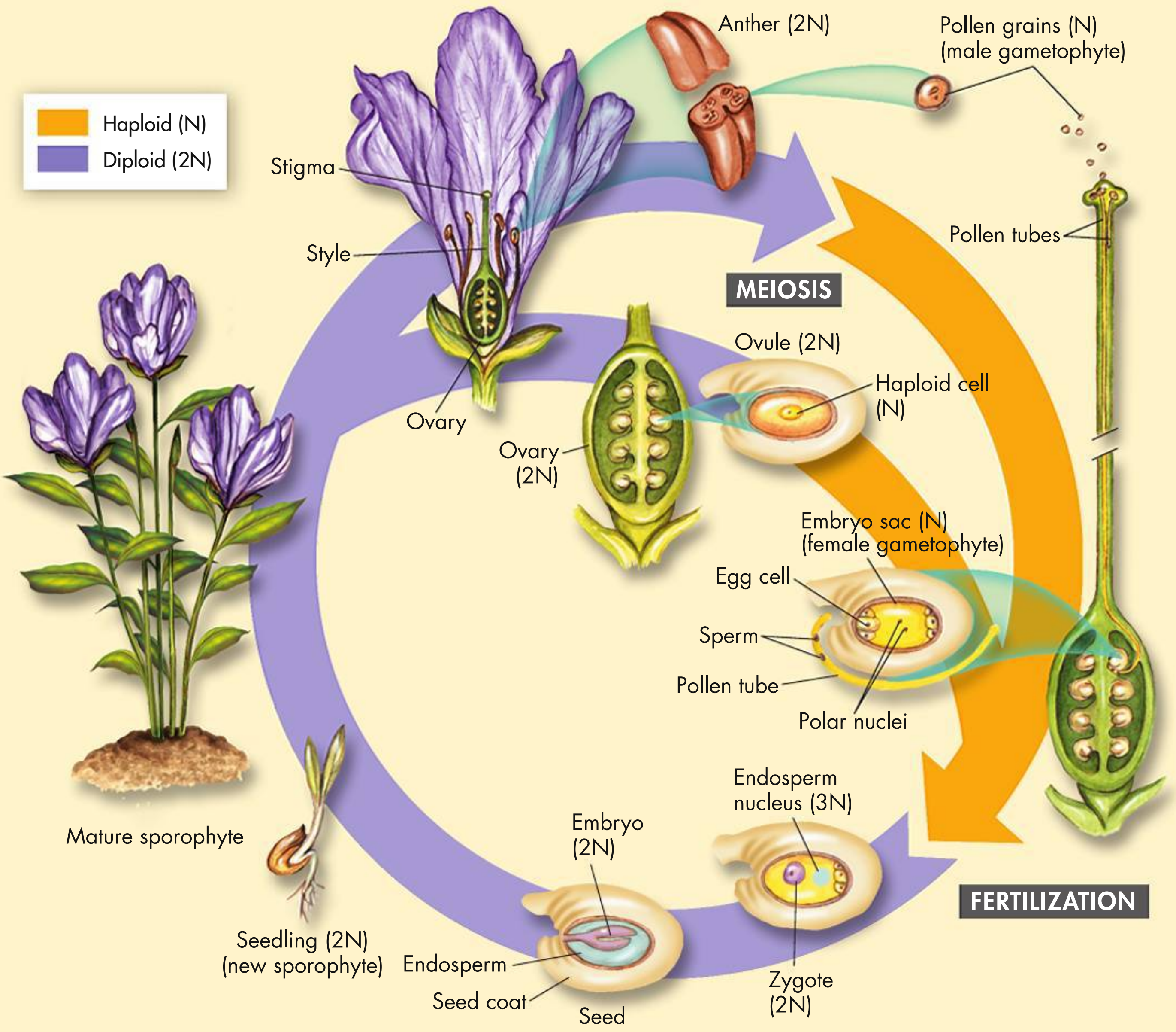
Inside a Corn Seed The endosperm and embryo of a corn seed result from double fertilization.



Double fertilization may be another reason why angiosperms are so successful. By using endosperm to store food, a plant spends very little energy on producing seeds from ovules until double fertilization has actually taken place. The energy saved can be used to make many more seeds.

Key Question How does fertilization in angiosperms differ from fertilization in other plants?
Angiosperms have two fertilization events. One produces a zygote. The other produces a tissue called endosperm.

Angiosperm Life Cycle In the life cycle of an angiosperm, the developing seeds are protected inside the ovary.



Vegetative Reproduction

Many flowering plants can reproduce asexually by **vegetative reproduction.** In vegetative reproduction, a single plant produces offspring that are genetically identical to itself. New plants are formed by mitosis. Vegetative reproduction does not require flowers, gametes, or fertilization.

Key Question What is vegetative reproduction?
Vegetative reproduction is the formation of new individuals by mitosis.

Types of Vegetative Reproduction Vegetative reproduction takes place naturally in many plants. New plants may grow from roots, leaves, or stems. Some species form plantlets, which are small plants that fall off the parent plant.

Vegetative reproduction does not involve pollination or seed formation. So, a single plant can reproduce quickly. If the parent plant is well adapted to an environment, its offspring can spread quickly. All of these offspring have exactly the same genes as the parent. One of the drawbacks of asexual reproduction is that it does not produce new combinations of genes. Genetic diversity helps a species survive if the environment changes.

BUILD Vocabulary

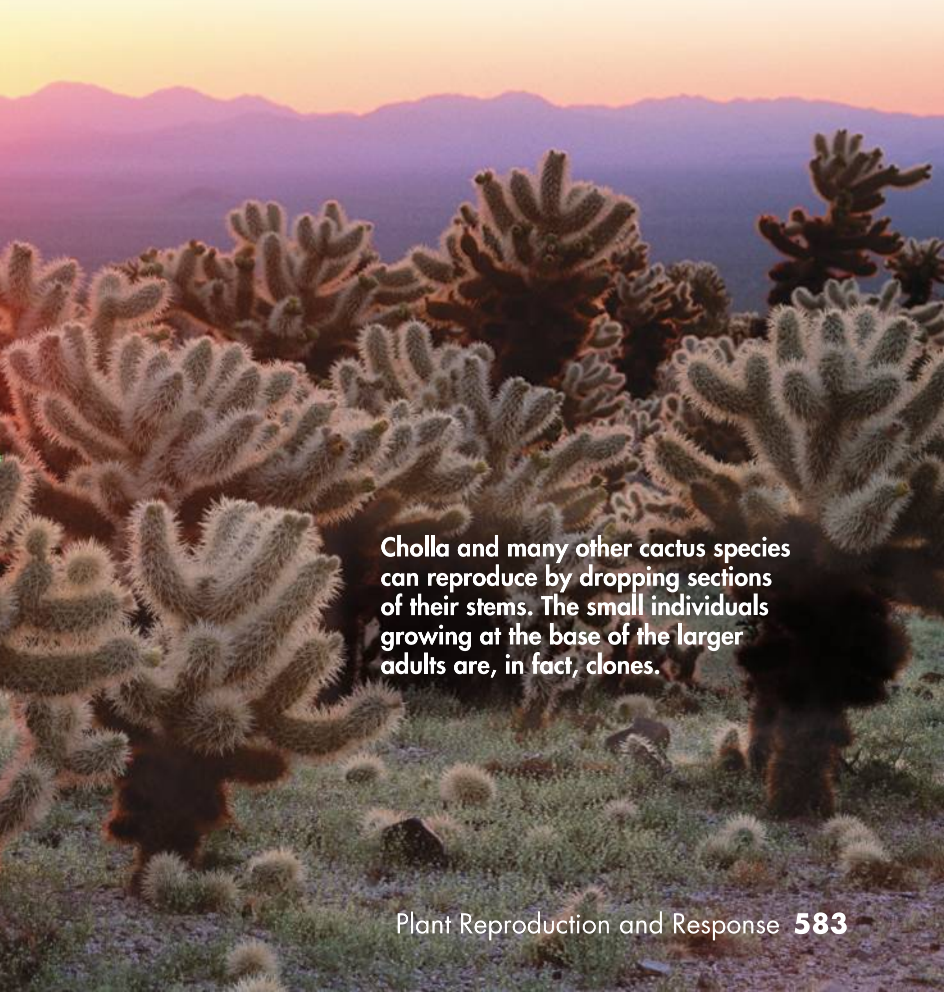
vegetative reproduction
a method of asexual reproduction in plants; the plant produces offspring that are genetically identical to itself

RELATED WORDS
The word *vegetative* comes from the Latin word *vegetus*, which means "to be lively, or alive." Words from this root usually refer to plants. For example, a *vegetable* is a plant that is grown for a part that can be eaten, such as its roots, stems, or leaves.

Examples of Vegetative Reproduction
Adaptations of the stem play a role in the vegetative reproduction of the plants shown here.

▲ A potato is an underground stem called a tuber that can grow whole new plants from buds called *eyes.*

▲ Strawberry plants send out long, trailing stems called stolons. Nodes that rest on the ground produce roots and upright stems and leaves.



Cholla and many other cactus species can reproduce by dropping sections of their stems. The small individuals growing at the base of the larger adults are, in fact, clones.

Grafting As it is just starting to bud, a branch from a lemon tree is grafted onto the branch of an established orange tree. Months later, the grafted branch bears lemons. This graft has formed a single plant bearing more than one species of fruit.

Plant Propagation People who grow, or propagate, plants often make use of vegetative reproduction. Two common ways of increasing the number of desirable plants are grafting and making cuttings.

To make a cutting, a grower cuts off a length of stem that has buds. (Remember that buds contain meristems.) The cut stem may then be partially buried in soil. Sometimes it is placed in a special mixture of nutrients that helps roots form.

Grafting is used to produce seedless plants and woody plants that cannot be grown from cuttings. In grafting, a bud or stem is cut from the parent plant. It is then attached to another plant. Grafting only works with plants that are closely related. A bud from a lemon tree can be grafted onto an orange tree, but not onto an oak tree.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. In seeds, the ________ nourishes the seedling as it grows.
2. Pollen grains form inside the ________.
3. The ________ is the female part of a flower.
4. In the process of ________, a plant reproduces asexually by mitosis.

Critical Thinking

5. **Explain** List and describe the four kinds of specialized leaves that make up a flower.
6. **Apply Concepts** Describe a feature of fertilization that happens only in angiosperms.
7. **Compare and Contrast** Compare the advantages and disadvantages of sexual reproduction with those of asexual reproduction in flowering plants.
8. **Write to Learn** Answer the first clue of the mystery.

MYSTERY CLUE

Whether the lemons grew on a grafted branch did not affect their ripening. Something changed after the lemons were picked. This change kept the lemons from ripening. What might it have been? (Hint: See above.)

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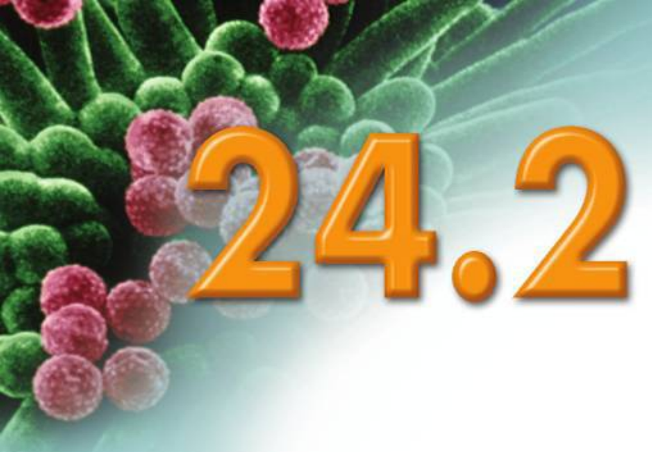


24.2 Fruits and Seeds

Seed and Fruit Development

What is a fruit? In everyday language, the word *fruit* describes sweet things, such as grapes or strawberries. But in biology, a fruit is a structure that surrounds and protects seeds. Therefore, many foods that we call vegetables, such as peas, corn, beans, cucumbers, and tomatoes, are also fruits.

Fruits develop from the ovary walls of a flower. After fertilization, nutrients from the plant flow into the flower tissues, feeding the developing seeds. As the seeds mature, the ovary walls around them thicken. A mature ovary wall may be fleshy, as in a tomato. Or it may be tough and dry, as in a peanut shell. (The peanuts themselves are seeds.)

Key Question How do fruits form?
As angiosperm seeds mature, the ovary walls thicken to form a fruit that surrounds the developing seeds.

Seed Dispersal

Fruits are rich in sugars and other nutrients. But fruits do not nourish seedlings. Seedlings get their food from endosperm. So why do angiosperms have seeds that are wrapped in another layer of nutrient-packed tissue? Think of wild blackberries. Each seed is enclosed in a sweet, juicy fruit. Blackberries are tasty treats for many animals that live in the forest. What good is a fruit if all it does is get eaten? Believe it or not, that's exactly the point! When an animal eats a fruit, it helps disperse, or scatter, the seeds.

Dispersal by Animals The seeds of many plants, especially those in fleshy fruits, are eaten by animals. These seeds have a tough coating that lets them pass through the animal's digestive system unharmed. Eventually, the seeds are deposited in the animal's droppings. Some dry fruits have burs that catch in an animal's fur. These fruits are then carried far away from the parent plant.

Key Questions

- *How do fruits form?*
- *How are seeds spread?*
- *What factors influence the dormancy and germination of seeds?*

BUILD Understanding

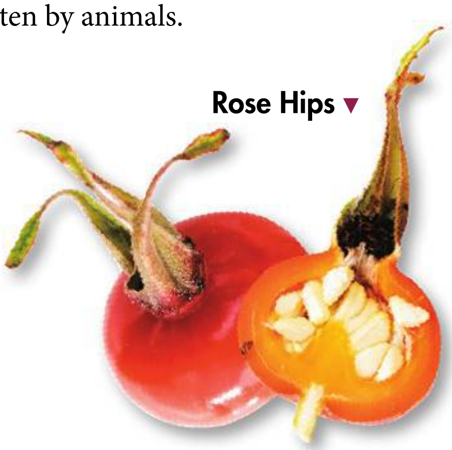
Flowchart Make a flowchart that shows the process of germination. Include the factors that affect germination. Indicate differences between monocots and dicots.

In Your Workbook Go to your workbook to learn more about flowcharts. Complete the flowchart for Lesson 24.2.

Variety Among Fruits Like the flowers from which they develop, fruits vary greatly in structure.

Strawberries ▼

Rose Hips ▼



Peanut Shell ▼

Dispersal of Seeds A bird called a Bohemian waxwing eats berries (left). Later, the bird will deposit the seeds in its droppings. Dandelion seeds (center) are spread by wind. The coconut fruit (right) can travel long distances by floating on water.

Dispersal by Wind and Water Some seeds are spread by wind. These seeds are usually contained in lightweight dry fruits. Consider a dandelion seed. It has a dry fruit that works like a parachute. Dandelion seeds can be blown far away from the parent plant. Other fruits travel by water. For example, coconut fruits can float long distances on seawater. That is why coconut trees can be found growing on islands that are far away from the mainland.

Key Question How are seeds spread?
Seeds in fleshy fruits are usually spread by animals. Seeds in dry fruits may be spread by animals, wind, or water.

Seed Dormancy and Germination

When they reach a good location, some seeds begin to grow right away. But many other seeds enter a period of **dormancy.** During dormancy, the embryo is alive, but it is not growing. The length of dormancy varies among species.

Germination Dormancy ends with **germination,** which is when the plant embryo grows again. Environmental factors such as temperature and moisture can cause germination. Before germinating, seeds absorb water. The seed swells, breaking open the seed coat. The root begins to grow. Then the shoot—the part of the plant that grows above ground—begins to sprout. The art on the next page compares the germination of a monocot with that of a dicot.

The Role of Cotyledons Cotyledons, or seed leaves, store nutrients that are used by the growing plant. Monocots have one seed leaf, which usually stays underground. A sheath protects the monocot shoot as it pushes through the soil.

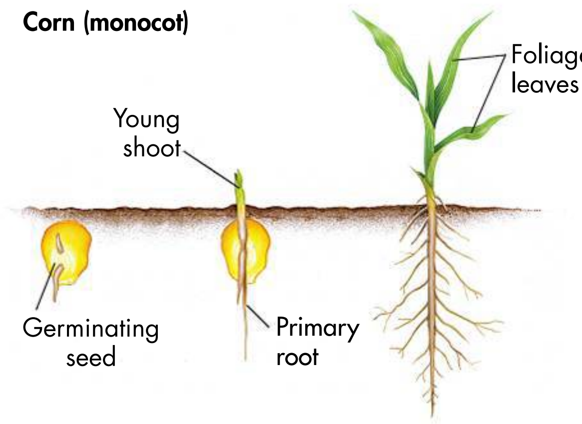
Dicots have two seed leaves. Dicots do not have a sheath to protect the shoot. Instead, the shoot bends to form a hook that forces its way through the soil. This protects the delicate tip of the plant. The shoot straightens as it grows out of the soil. In some dicots, the seed leaves appear above the ground. In other dicots, the seed leaves stay underground.

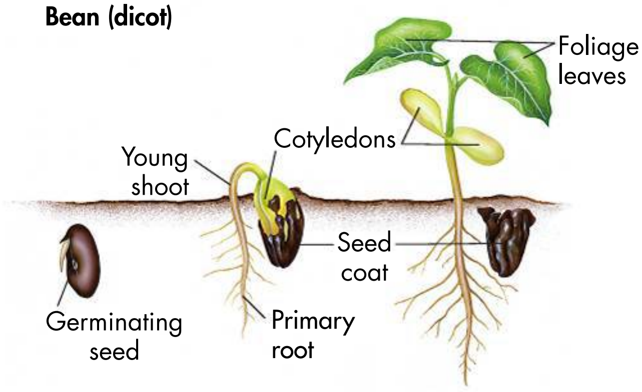
BUILD Vocabulary

dormancy
a period of time during which a plant embryo is alive but not growing

germination
the growth of the plant embryo following dormancy

WORD ORIGINS
The word *dormancy* comes from the Latin word *dormire*, which means "to sleep." While seeds don't sleep, dormancy is a period of inactivity. The embryo in a dormant seed is alive, but it is not growing.





Comparing Germination in Monocots and Dicots Corn is a monocot. A corn seedling (left) grows directly upward. It is protected by a sheath of tissue that surrounds the developing leaves. A bean is a dicot. A bean seedling (right) forms a hook in its stem. This hook gently pulls the new plant through the soil.

Advantages of Dormancy Dormancy makes it possible for seeds to be dispersed over long distances. It also lets seeds wait to germinate until conditions for growth are ideal. Plants that live in cold climates often have seeds that will not germinate until after a long period of cold. This dormancy stops their seeds from germinating until winter is over. Their seeds can survive freezing, but their seedlings cannot.

In some species, only extreme conditions will end dormancy. For example, the cones of some pine trees do not release their seeds until there is a forest fire. High temperatures cause the cones to open. Once the seeds are released, they germinate. This adaptation allows pine trees to quickly grow again after a fire.

Key Question What factors influence the dormancy and germination of seeds? **Temperature and moisture can cause a seed to end dormancy and germinate.**

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Some seeds undergo ________, so they do not grow right away.
2. The process in which the embryo in a seed starts to grow again is called ________.

Critical Thinking

3. **Explain** Describe how fruits form.
4. **Classify** Is a pumpkin a fruit? Why or why not?
5. **Explain** Describe two ways in which seeds are spread.
6. **Compare and Contrast** Compare the germination of a monocot with that of a dicot.
7. **Write to Learn** Answer the second clue of the mystery. Start a list of variables that affect seed development and fruit ripening. Add to your list as you continue reading the chapter.

MYSTERY CLUE

When the warehouse switched to electric heating, what might have changed in the lemons' environment? (Hint: See p. 586.)

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24.3 Plant Hormones

Key Questions

What roles do plant hormones play?

What are some examples of environmental stimuli to which plants respond?

How do plants respond to seasonal changes?

BUILD Understanding

Concept Map As you read, make a concept map that shows the effects of various hormones on plant growth.

In Your Workbook Go to your workbook to learn more about concept maps. Complete the concept map for Lesson 24.3.

Hormones

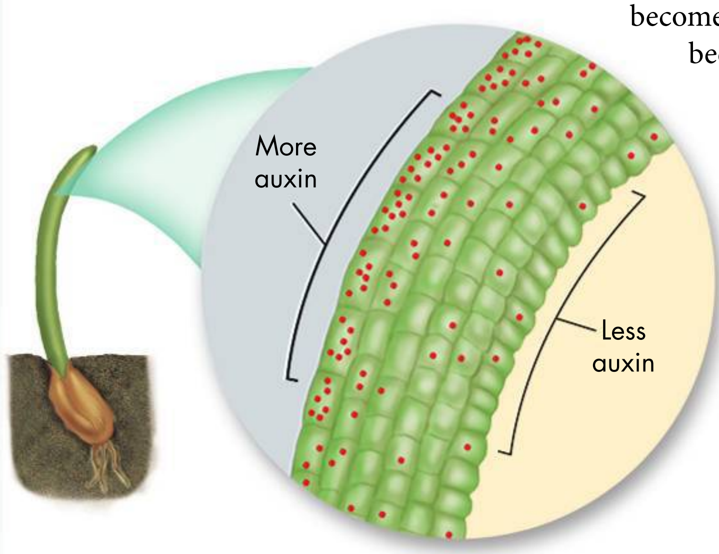
Plants grow in response to factors such as light, temperature, and moisture. But how do plant tissues "know" when to grow or reproduce? The actions of plant tissues and organs are controlled by hormones. **Hormones** are chemical signals that affect a plant's growth, activity, and development. Hormones also coordinate the way that a plant responds to its environment.

Cells in an organism affected by a particular hormone are called **target cells.** To respond to a hormone, a cell must have receptors. **Receptors** are usually proteins to which hormones bind. The way that a target cell responds depends on the kind of receptor. One kind of receptor might speed growth. Another might slow growth. As a result, a given hormone can affect roots differently from stems.

Auxins Hormones called auxins control cell elongation and the growth of new roots. Auxins are produced in apical meristems, then travel to the rest of the plant. Recall that apical meristems are found at the tips of stems.

Auxins control cell division in meristems. Apical meristems produce auxins that inhibit, or slow down, the growth of other buds on the same stem. The closer a bud is to the stem's tip, the more it is inhibited. This inhibition is called apical dominance. If you cut off the bud at the tip of a stem, the growth of the other buds on the stem is no longer inhibited. The other buds grow more quickly. The plant becomes bushier because the source of the auxins has been removed.

Auxins also explain why plants grow toward the light. When light hits one side of a shoot, auxins collect in the shaded areas. These cells grow longer. This causes the shoot to bend toward the light.



Auxins and Cell Elongation Cells grow longer on the shaded side of the shoot. This area has a higher concentration of auxins.

Cytokinins Cytokinins are hormones that are produced in growing roots, fruits, and seeds. Cytokinins cause cell division. They interact with auxins to control the growth of new organs in injured plants and to balance root and shoot growth. The effects of cytokinins often oppose those of auxins. Auxins cause the growth of new roots and inhibit the growth of shoot tips. Cytokinins do the opposite.

Gibberellins Hormones called gibberellins promote growth. These hormones can produce great increases in size, particularly in stems and fruits. Gibberellins also stimulate germination.

Abscisic Acid The hormone abscisic acid keeps cells from dividing, thereby stopping growth. Abscisic acid and gibberellins work together to control seed dormancy. When a seed is fully grown, abscisic acid stops the growth of the embryo. The embryo becomes dormant. The embryo rests until environmental conditions change the balance of hormones. For example, a heavy spring rain may wash away the abscisic acid. (Gibberellins do not wash away as easily as abscisic acid.) Then, gibberellins in the seed can start germination.

Ethylene One plant hormone—ethylene—is a gas. Fruit tissues release small amounts of ethylene, which helps fruits ripen. Ethylene also causes plants to drop organs that are no longer needed. For example, leaves drop in autumn, and fruits drop after they ripen. In each case, ethylene signals cells at the base of the structure to seal it off from the rest of the plant.

Key Question What roles do plant hormones play?
Plant hormones serve as signals that control development of cells, tissues, and organs. They also control responses to the environment. The opposing effects of plant hormones balance each other, contributing to a plant's homeostasis.

A Summary of Plant Hormones

Hormone	Some of the Effects	Where Found
Auxins	Promote cell elongation and apical dominance; stimulate growth of new roots	Produced in shoot apical meristem and transported elsewhere
Cytokinins	Stimulate cell division; affect root growth and differentiation; may work in opposition to auxins	Growing roots
Gibberellins	Stimulate growth; influence various developmental processes; promote germination	Meristems of shoot, root, and seed embryo
Abscisic acid	Inhibits cell division; promotes seed dormancy	Terminal buds; seeds
Ethylene	Stimulates fruits to ripen; causes plants to seal off and drop unnecessary organs, such as leaves in autumn	Fruit tissues; aging leaves and flowers

BUILD Vocabulary

hormone a chemical produced in one part of an organism that affects another part of the same organism

target cell a cell that has a receptor for a particular hormone

receptor a specific protein whose shape fits a specific hormone molecule

WORD ORIGINS

The word *hormone* comes from the Greek word *hormon*, which means "urge on." Hormones "urge" plants to grow or develop.

A Summary of Plant Hormones This table lists some of the effects of plant hormones and where the hormones can be found within the plant.

Three Plant Tropisms
Plants respond to light (left), gravity (middle), and touch (right).

Tropisms and Rapid Movements

Sometimes plants need to move in response to their environment. Many plant movements are slow. But some are so fast that even animals cannot keep up with them.

Tropisms Plants respond to environmental stimuli such as light, gravity, and touch. When plants sense these stimuli, they send signals to their roots and stems to change the direction of growth. These growth responses are called **tropisms.**

▶ ***Light*** The tendency of a plant to grow toward a light source is called **phototropism.** This response can be very quick. For example, young seedlings can bend toward a light source in just a few hours. Remember that changes in the concentration of auxin are responsible for phototropism. Experiments have shown that auxins move toward shaded tissue. This may be due to changes in membrane permeability caused by light.

▶ ***Gravity*** Auxins also affect **gravitropism,** the response of a plant to gravity. For reasons that are still not understood, auxins move to the lower sides of horizontal roots and stems. In stems, this movement causes the stem to bend upright. In roots, however, the movement of auxins causes roots to bend downward.

▶ ***Touch*** Some plants respond to touch, a process called **thigmotropism.** Vines and climbing plants show thigmotropism. When they encounter an object, they wrap around it. Other plants, such as grape vines, have tendrils. Tendrils grow from the base of the leaf and wrap tightly around any object they encounter.

Rapid Movements Some plant responses are surprisingly fast. One example of a plant that can respond rapidly is the carnivorous Venus' flytrap. When an insect lands on a flytrap's leaf, it triggers sensory cells on the leaf. Electrical signals are sent from cell to cell. Cell walls expand and osmotic pressure changes, causing the leaf to snap shut. The insect is trapped inside!

Key Question What are some examples of environmental stimuli to which plants respond?
Plants respond to environmental stimuli such as light, gravity, and touch.

BUILD Vocabulary

tropism
the movement of a plant toward or away from a stimulus

phototropism
the response of a plant to light

gravitropism
the response of a plant to the force of gravity

thigmotropism
the response of a plant to touch

photoperiod
the relative lengths of light and darkness that affect a plant's response

WORD ORIGINS
The word *tropism* comes from a Greek word that means "turning." During a tropism, a plant will "turn" toward or away from a stimulus.

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Response to Seasons

Year after year, some plants flower in the spring. Other plants flower in summer. Still other plants flower in the fall. Plants such as chrysanthemums flower when nights are long and days are short. These plants are called short-day plants. Plants such as spinach and irises flower when nights are short and days are long. These are called long-day plants.

Photoperiod and Flowering In the early 1920s, scientists discovered that the flowering of tobacco plants depends on the number of hours of darkness and light. Many other plants also respond to the relative lengths of darkness and light. This stimulus is called **photoperiod.**

Scientists have discovered that the pigment phytochrome (FYT oh krohm) plays a role in the way plants respond to photoperiod. Phytochrome absorbs red light. It also starts a number of signals within plant cells. These signals determine various plant responses, such as flowering and growth.

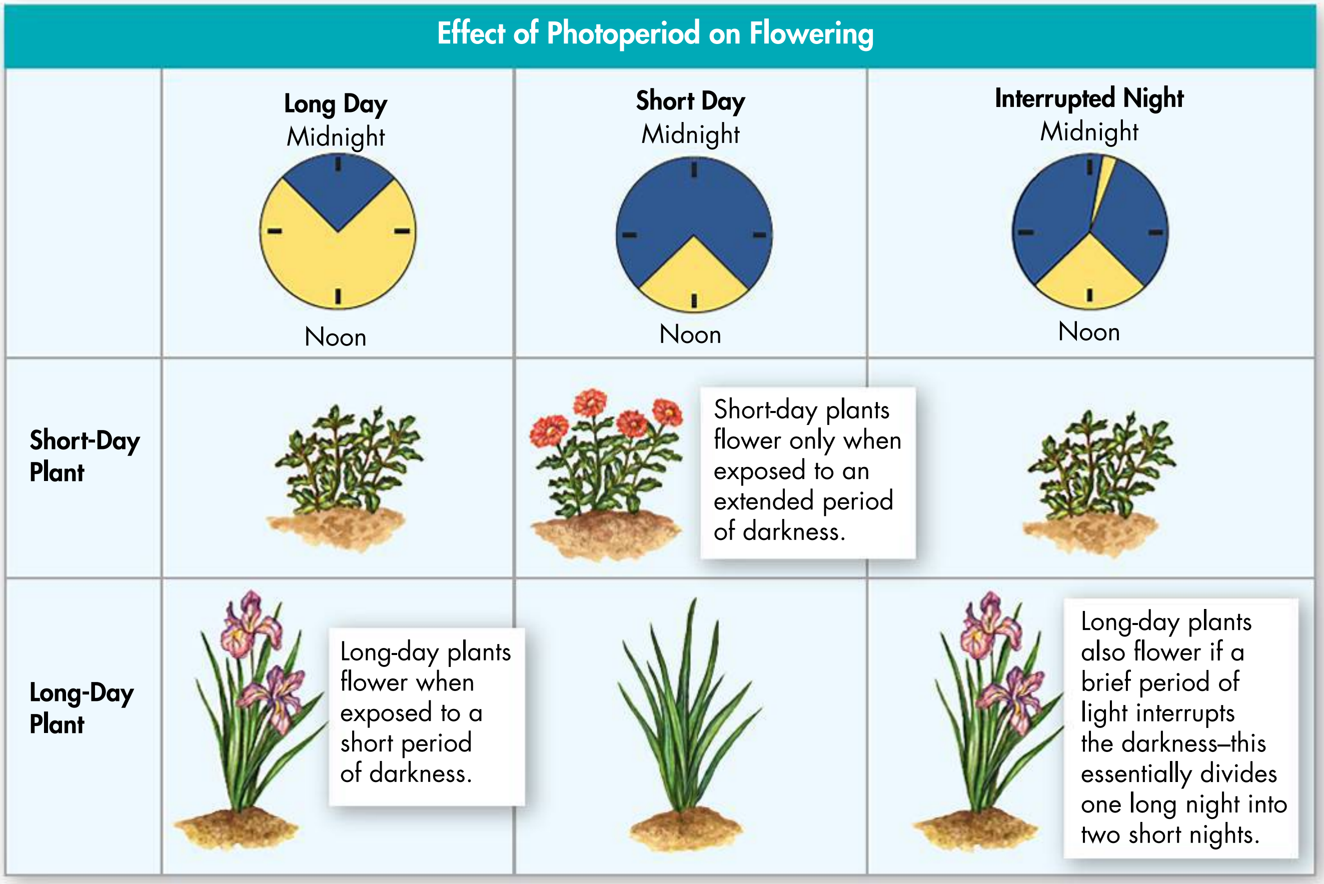
Key Question How do plants respond to changes in day length?
Photoperiod is a major factor in the timing of seasonal activities such as flowering and growth.

BUILD Connections

EFFECTS OF PHOTOPERIOD

How much light a plant receives and when it receives the light can affect when the plant flowers.

In Your Workbook Go to your workbook to learn more about the effect of photoperiod. Complete the table for Response to Seasons.



Adaptations for Winter In autumn, the leaves of deciduous trees stop photosynthesis and fall from the trees. The meristems at the tips of the branches produce thick, waxy scales. These scales cover and protect the new stem and leaf buds throughout the winter.

Winter Dormancy In winter, many plants become dormant. Phytochrome controls the many changes that prepare plants for winter dormancy. As cold weather approaches, deciduous plants move materials from leaves to roots. They stop photosynthesis and seal off leaves from the rest of the plant.

▶ ***Leaf Loss*** Many plants lose their leaves during the colder months. Because days are shorter in the fall, the phytochrome in leaves absorbs less light. The production of auxin drops, while the production of ethylene increases. The change in the relative amounts of these two hormones causes leaves to shut down. The pigment chlorophyll breaks down. Other pigments in the leaves, such as the bright yellow and orange carotenoids, can now be seen. Bright reds come from freshly made anthocyanins.

▶ ***Changes to Meristems*** Hormones also produce important changes in apical meristems. Meristems stop producing new leaves. Instead, they produce thick, waxy scales that protect leaf buds from the cold. Xylem and phloem tissues fill up with ions and organic compounds. This solution acts like antifreeze in a car: It keeps the tree's sap from freezing.

Key Question How do plants respond to cold winters? **As cold weather approaches, deciduous plants stop photosynthesis. They move materials from leaves to roots and seal off leaves from the rest of the plant.**

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The relative lengths of light and darkness produce a stimulus known as _______.

2. The growth of a plant toward a light source is called _______.

Critical Thinking

3. Explain What are the main roles of plant hormones?

4. Relate Cause and Effect Explain why a person who trims bushes should understand the effect of auxins on the growth of stems.

5. Apply Concepts Describe three examples of plant responses to external stimuli.

6. Write to Learn Answer the third clue of the mystery. Use the words *hormone*, *stimulus*, and *respond* in your answer.

MYSTERY CLUE

Kerosene heaters give off carbon dioxide and ethylene as they burn kerosene. Electric heaters do not give off these gases. Could this difference explain why the lemons didn't ripen? (Hint: See p. 589.)

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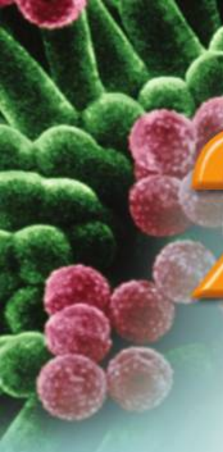


24.4 Plants and Humans

Agriculture

Walk through a grocery store and you will see products made from hundreds of different plants. Which plants are most important? Are there plants that humans can't live without?

Origin of Agriculture Agriculture, or farming, is the foundation of human society. Evidence suggests that agriculture developed separately in many parts of the world about 10,000 to 12,000 years ago. Once people learned how to grow plants for food, they tended to stay in one place. This led to the development of governments and other social institutions. Even today, more humans focus on agriculture than on any other activity.

Worldwide Patterns Thousands of different plants are raised for food. But for the bulk of their food, most people in the world rely on the seeds of four angiosperms—rice, wheat, corn, and soybeans. Three of these crops are grasses. In the United States, about 80 percent of cropland is used to grow wheat, corn, soybeans, and hay. These four crops are used for both humans and livestock. Of these crops, wheat, corn, and hay are grasses.

Key Question Which crops are the major food supply for humans? **Worldwide, most people depend on a few crops, including rice, wheat, soybeans, and corn, for the major part of their food.**

Key Questions

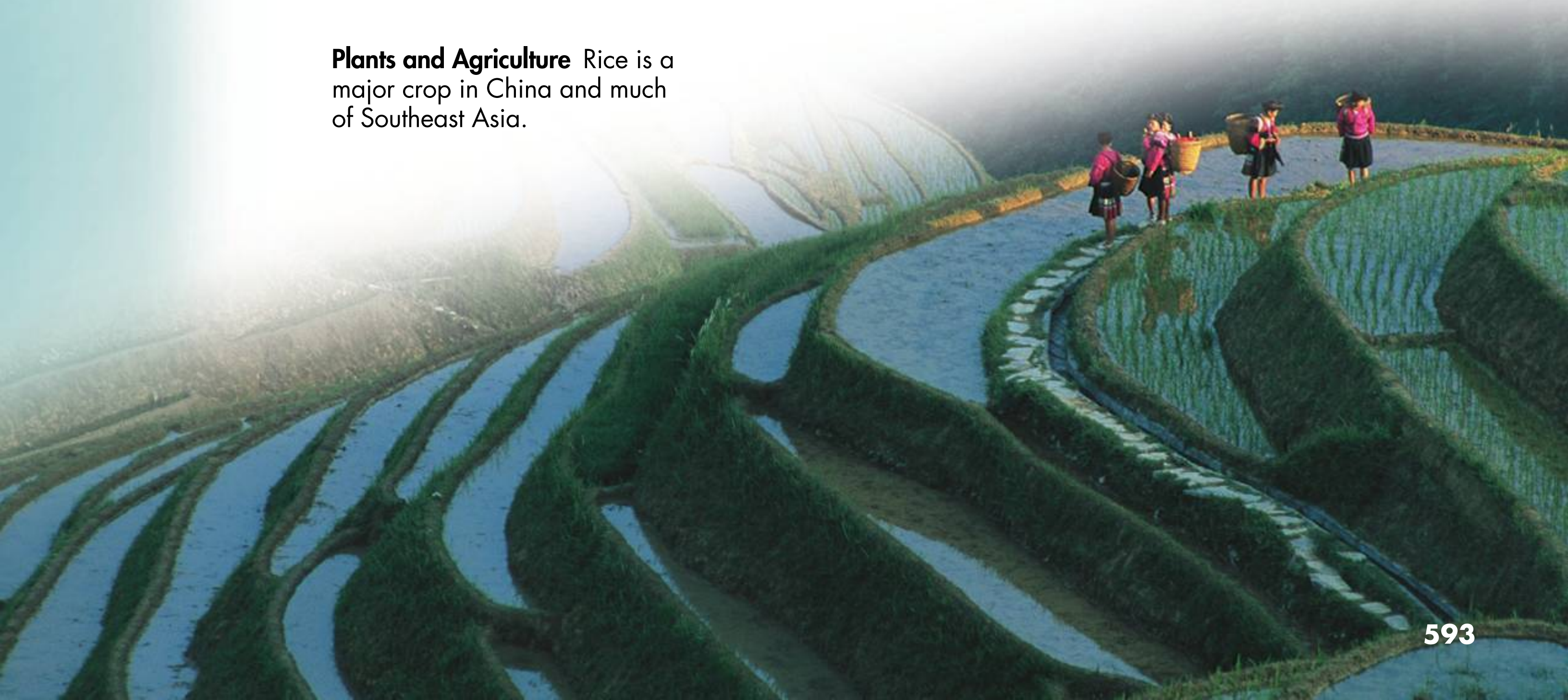
Which crops are the major food supply for humans?

In addition to food, what are some benefits that humans get from plants?

BUILD Understanding

Preview Visuals Look at the last picture in the lesson. Identify the plants that provided the raw materials for the products shown. Then, list other products that come from plants.

In Your Workbook Go to your workbook to learn more about previewing visuals. Complete the activity for Lesson 24.4.



Plants and Agriculture Rice is a major crop in China and much of Southeast Asia.

BUILD Vocabulary

green revolution
the development of highly productive crops and the use of modern agriculture to increase crop yields

ACADEMIC WORDS

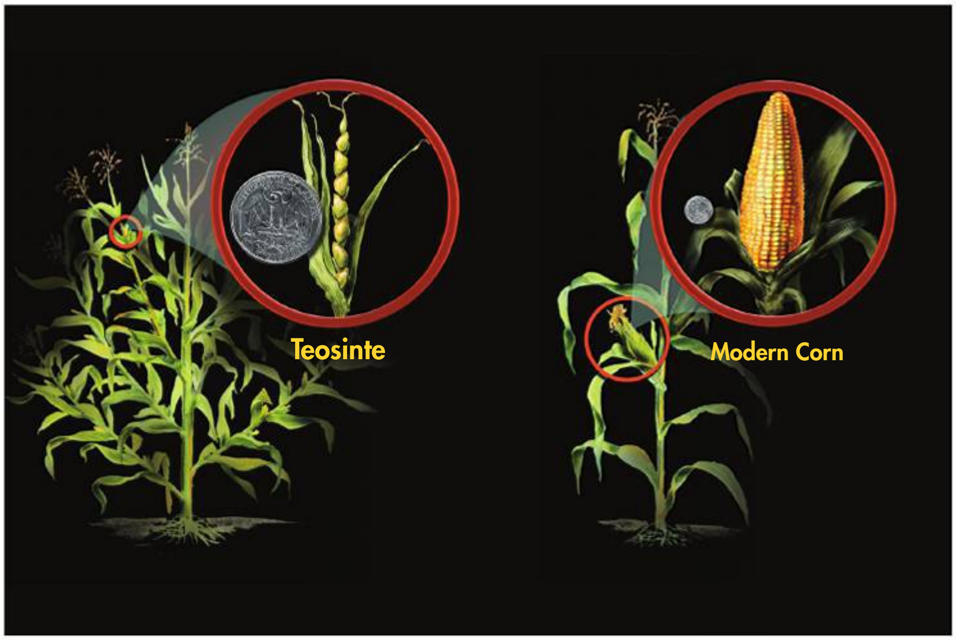
The word *revolution* is used to describe a major change in society. During the Industrial Revolution, for example, improvements in technology changed the way goods were manufactured. The green revolution changed methods of farming in many parts of the world.

New Plants The introduction of new crop plants has often changed human history. Four hundred years ago, plants such as corn and peanuts were unknown in Europe. The introduction of these plants from the Americas changed European agriculture. We may think of potatoes as a German or Irish food. But, originally, potatoes came from South America.

Agriculture has been improved through selective breeding. Recall that humans use selective breeding to produce crops and animals that have desirable traits. The corn grown by Native Americans was selectively bred. It was developed thousands of years ago from teosinte (tee oh SIN tee), a grass from Mexico. Most crops grown today are the result of selective breeding. For example, cabbage, broccoli, and cauliflower were all developed from a single species of wild mustard.

Changes in Agriculture Between 1950 and 1970, people began a worldwide effort to fight hunger by improving methods of farming. This effort, called the **green revolution,** greatly increased the world's food supply. The green revolution used new varieties of seeds and fertilizers. Fertilizers provide plants with nutrients such as nitrogen, phosphorus, and potassium. These nutrients make plants grow larger and produce more food. For thousands of years, farmers have provided crops with nutrients from natural sources, such as animal remains and manure. Today, many farmers use artificial fertilizers.

Fertilizers and pesticides must be used with great care. Too much fertilizer can kill plants. Fertilizer that washes off fields can contaminate the water. Pesticides are chemicals that are used to kill pests such as insects. Because pesticides are poisons, they can harm wildlife and humans if not used correctly.



From Wild Grass to Crop The selective breeding of teosinte (left) began about 8000 years ago. It led to the development of modern corn (right). As you can see from the image of the quarter, modern corn has much larger kernels compared to its ancestor teosinte.

Products From Plants Plants provide raw materials for many useful products.

◀ The succulent plant *Aloe vera* contains many chemicals that soothe and moisturize the skin. Extracts of this plant are used in many skin lotions as well as in burn and wound ointments.

Fiber, Wood, and Medicine

Some of the most important uses of plants have nothing to do with food. Plants produce materials that we use for homes and clothes. They also provide some of our most effective medicines. If you are reading this page in a printed book, you are looking at paper made from North American conifers. You may be sitting on a chair made from an oak tree. And you are probably wearing at least one piece of clothing made from the fibers of the cotton plant.

Key Question In addition to food, what are some benefits that humans get from plants? **Plants provide the raw materials for our homes and clothes, and some of our most effective medicines.**

The acoustical properties of Sitka spruce wood make it ideal for use in pianos, guitars, violins, and other musical instruments. ▼

Cotton is used in countless products including thread, fabrics, bandages, carpeting, and insulation. Cotton fibers are outgrowths of the seed coat epidermis. ▶

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The _______ led to the production of much larger amounts of food.

Critical Thinking

2. Review What four crops form the base of the world's food supply?

3. Explain In addition to providing food, why are plants important to human society? Give three examples.

4. Write to Learn What would life be like if humans had never developed agriculture? Write a short story that describes such a world.

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Real-World Lab

GUIDED INQUIRY

Pre-Lab: Plant Hormones and Leaves

Problem How does a plant hormone affect leaf loss?

Materials leafy plant, masking tape, permanent marker, scissors, string, toothpick, auxin paste, plastic container or tray

Lab Manual Chapter 24 Lab

Skills Focus Observe, Draw Conclusions, Apply Concepts

Connect to the Big idea A plant may flower in response to a change in the hours of daylight, or a plant may stop growing in response to colder temperatures. These responses to changes in the environment are coordinated by plant hormones, which regulate plant development. A hormone may stimulate roots to grow, seeds to germinate, or fruits to ripen. A hormone may inhibit cell division or promote dormancy of seeds or plants. In this lab, you will investigate the effect of a plant hormone on leaf loss.

Background Questions

a. **Explain** Do all plant cells respond to every plant hormone? Why or why not?

b. **Explain** What is photoperiod? What is dormancy? How are they related?

c. **Review** In the fall, what happens to the production of auxin and ethylene in the leaves of flowering plants?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Use Visuals** Draw a simple leaf. Label the blade and the petiole.
2. **Control Variables** What is the control in this experiment?
3. **Infer** How will auxins move from the paste to the base of the petiole?

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Visit Chapter 24 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Using time-lapse videography, the Untamed Science crew reveals how plants move in response to various stimuli.

Art in Motion Watch how meiosis and mitosis produce ova and pollen in an angiosperm.

Art Review Review the structures of a flower.

InterActive Art Change the length of day and see how it affects both short- and long-day plants.

24 CHAPTER Summary

24.1 Reproduction in Flowering Plants

- Flowers are reproductive organs that are made up of four kinds of specialized leaves: sepals, petals, stamens, and carpels.
- The process of fertilization in angiosperms differs from fertilization in other plants. In angiosperms, there are two fertilization events. One produces the zygote. The other produces a tissue called endosperm within the seed.
- Vegetative reproduction is the formation of new individuals by mitosis. Vegetative reproduction does not include gametes, flowers, or fertilization.

stamen (p. 579)
anther (p. 579)
carpel (p. 579)
stigma (p. 579)
embryo sac (p. 580)
double fertilization (p. 581)
endosperm (p. 581)
vegetative reproduction (p. 583)

24.2 Fruits and Seeds

- As angiosperm seeds mature, the ovary walls thicken to form a fruit. The fruit surrounds and protects the developing seeds.
- Seeds are spread by animals, wind, and water. Seeds in fleshy fruits are usually spread by animals. Seeds that are spread by wind or water usually have lightweight fruits that can be carried by wind or float on water.
- Environmental factors such as temperature and moisture can cause a seed to end dormancy and germinate.

dormancy (p. 586)
germination (p. 586)

24.3 Plant Hormones

- Plant hormones serve as signals that control the development of cells, tissues, and organs. They also coordinate a plant's responses to the environment.
- The opposing effects of plant hormones balance each other, contributing to a plant's homeostasis.
- Plants respond to environmental stimuli such as light, gravity, and touch.
- The relative length of darkness and light, or photoperiod, affects seasonal activities such as flowering and growth.
- As cold weather approaches, deciduous plants stop photosynthesis. They move materials from leaves to roots and seal off leaves from the rest of the plant.

hormone (p. 588)
target cell (p. 588)
receptor (p. 588)
tropism (p. 590)
phototropism (p. 590)
gravitropism (p. 590)
thigmotropism (p. 590)
photoperiod (p. 591)

24.4 Plants and Humans

- Worldwide, most people depend on a few crops, including rice, wheat, soybeans, and corn, for the major part of their food.
- Plants produce the raw materials for our homes and clothes. They also provide some of our most powerful and effective medicines.

green revolution (p. 594)

24 CHECK Understanding

Assess the Big idea

Growth, Development, and Reproduction

Write an answer to the question below.

Q. How do changes in the environment affect the reproduction, development, and growth of plants?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each numbered question should be one or two paragraphs long. To help get ideas, read the **Hints** below the question.

1. **How do animals in an ecosystem affect the reproduction of angiosperms?**

   Hint The key function of a flower is reproduction.

   Hint Fruits and seeds need to be dispersed.

2. **How do plants respond to light, gravity, and touch? Include the names of these three responses in your answer.**

   Hint Sometimes, a plant grows toward a stimulus. Sometimes, it grows away from a stimulus.

   Hint Sometimes, shoots and roots have different responses to the same stimulus.

3. **How does the interaction of hormones and the environment control the germination of seeds?**

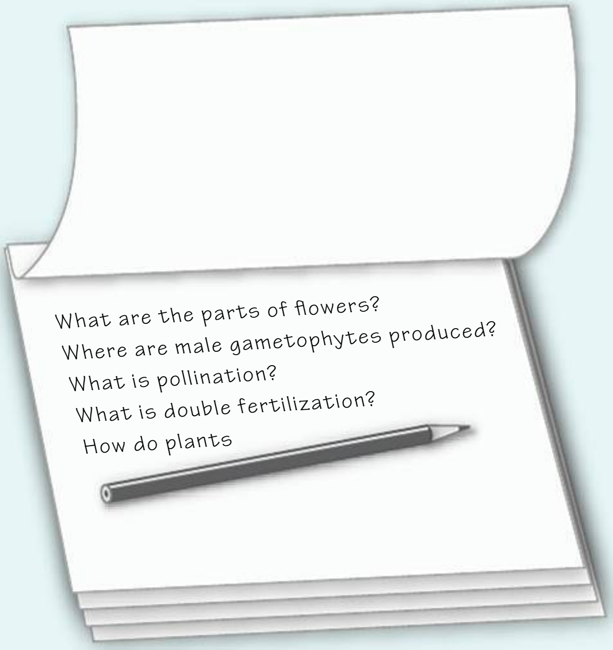
   Hint Dormancy can ensure that a plant germinates under ideal conditions.

Foundations for Learning Wrap-Up

Use the layered book that you made while reading the chapter to help you review concepts related to how angiosperms reproduce and respond to the environment.

Activity 1 Work with a small group to make an illustrated book that describes how plants reproduce and how they respond to changes in their environment. You can add illustrations to your layered book, or you can make a new book.

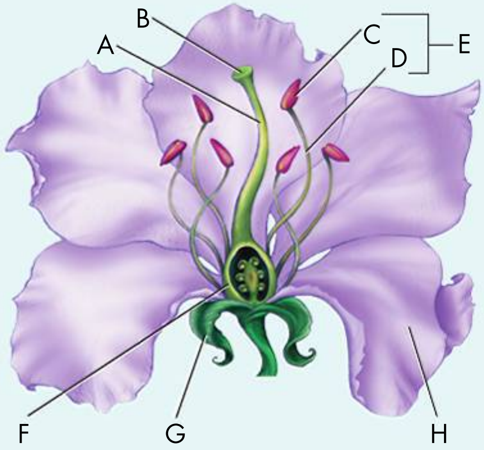
Activity 2 The last page of your layered book is blank. Use this page to write review questions as shown below. Use these questions to help you learn the concepts in the chapter. When you are stumped, flip to the other pages in your layered book to find help.



24.1 Reproduction in Flowering Plants

Understand Key Concepts

Use this art to answer questions 1–3.



1. Which structure produces the male gametophytes?
   a. A **c.** C
   b. B **d.** D

2. Pollination takes place when a pollen grain lands on
   a. B. **c.** F.
   b. C. **d.** G.

Test-Taking Tip

Read All Letters Carefully Sometimes the answers are letters only. Don't get confused by the capital letter and the lowercase letter. As you read each answer choice, circle the corresponding letter in the diagram. Then write the name of the part next to the answer choice. So, in question 2, look at answer **a.** It is B, so circle B in the diagram. What is it? Write "stigma" next to B. This way, you can read the words, not just the letters.

3. What is the name for the entire female structure of a flower? Which three structures in the diagram make up the female part of a flower? Name each of these parts.

Think Critically

4. **Infer** Bees are important pollinators. Recently, scientists have discovered that bee populations are getting smaller, but they don't know why. What might happen to angiosperms if bees disappear?

24.2 Fruits and Seeds

Understand Key Concepts

5. A period during which an embryo is alive but not growing is called
   a. dormancy. **c.** germination.
   b. fertilization. **d.** pollination.

6. In the carpel, the thickened ovary wall will eventually become the
   a. cotyledon. **c.** female gametophyte.
   b. endosperm. **d.** fruit.

7. What is the function of seed dormancy? Give two examples of when it is helpful to a plant.

Think Critically

8. **Infer** Some flowers have stamens but lack carpels. Can these flowers produce fruits? Explain your reasoning.

24.3 Plant Hormones

Understand Key Concepts

9. The hormone that stimulates cell division and causes seeds to germinate is
   a. auxin. **c.** ethylene.
   b. cytokinin. **d.** gibberellin.

Think Critically

10. **Form a Hypothesis** Form a hypothesis that describes how plants such as vines benefit from thigmotropism.

11. **Evaluate** Spinach is a long-day plant. It grows best when night length is 10 hours or less. Will spinach grow well near the equator? Explain your reasoning.

24 CHECK Understanding

24.4 Plants and Humans

Understand Key Concepts

12. Most human food comes from
a. angiosperms. **c.** gymnosperms.
b. conifers. **d.** trees.

Think Critically

13. Infer How is it possible that most of our food comes from seeds rather than the plant body?

Connecting Concepts

Use Science Graphics

Growth responses of plants to stimuli are called tropisms. *A tropism is positive if the affected plant part grows toward the stimulus. The response is negative if the plant part grows away from the stimulus. The experiment shown below tested the effect of gravitropism on plant growth. The conclusion drawn from the experiment was that the plant stems grow upward due to negative gravitropism. Use the diagram to answer questions 14–17.*

14. Interpret Visual Describe the three experimental setups and the result of each.

15. Form a Hypothesis What could be a probable hypothesis for this experiment?

16. Evaluate From the experimental setups shown, was the hypothesis successfully tested? Explain.

17. Evaluate What kinds of changes would you make to improve this experimental design?

solve the CHAPTER MYSTERY

THE GREEN LEMONS

The mystery of why the lemons didn't ripen was solved by a story from the nineteenth century. In those days, gas streetlights were commonly used in large cities. A few years after such streetlights were installed, people noticed a difference in nearby trees. The trees growing near the streetlights had developed short, thick stems. They also dropped their leaves much earlier than they should have. The hormone level in the trees had changed. This change happened because the streetlights released ethylene.

Remember that ethylene is a hormone that plays a role in the ripening of fruit. The source of the ethylene does not matter. The ethylene made by a plant is the same as the ethylene released by a kerosene heater. Because ethylene is a gas, it can diffuse through the air, cell walls, and membranes of a plant and its fruit. Replacing the kerosene heaters with electric heaters removed the source of ethylene in the warehouse. As a result, the lemons stayed green and did not ripen.

1. Relate Cause and Effect Tomatoes that are put in a paper bag with apples ripen much more quickly than those placed in open air. What would this suggest about the effects of ripe apples on unripe tomatoes?

2. Propose a Solution How could farmers, shippers, and grocers use the effects of ethylene to their advantage?

UntamedScience **Never Stop Exploring Your World.** Finding the solution to The Green Lemons mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

Standardized Test Prep

Multiple Choice

1. Where in a flower are pollen grains produced?
   A sepals
   B carpels
   C anthers
   D ovary

2. Which part of the flower develops into a fruit?
   A pollen tube
   B sepals
   C stigma
   D ovary

3. Which flower structure includes all the others?
   A style
   B carpel
   C stigma
   D ovary

4. The trumpet honeysuckle has long, red, narrow tubular flowers. What is the most likely means of pollination?
   A wind
   B water
   C bee
   D hummingbird

5. All of the following are fruits EXCEPT
   A tomato.
   B corn.
   C potato.
   D cucumber.

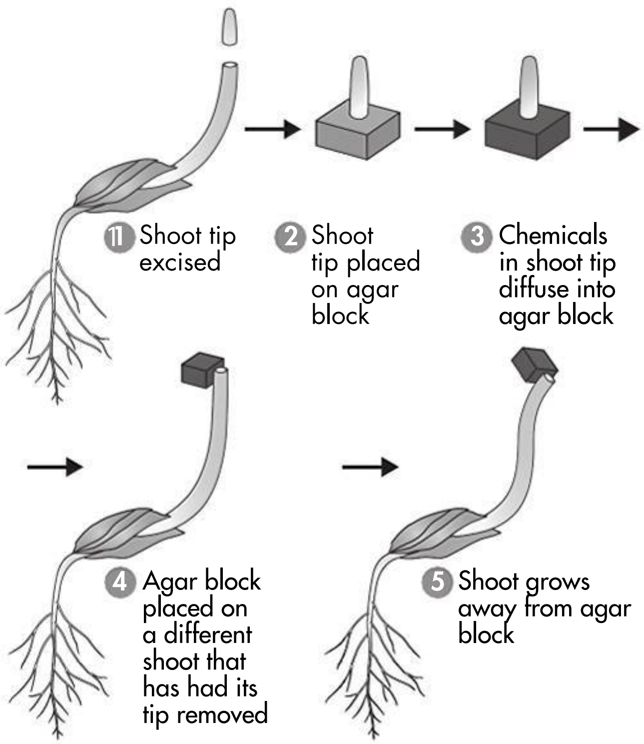
6. Seeds that are contained in large, fleshy fruits are usually dispersed by
   A animals.
   B water.
   C wind.
   D rotting.

7. Which of the following causes fruit to ripen?
   A auxin
   B cytokinin
   C ethylene
   D gibberellin

8. Which is an example of thigmotropism?
   A change in leaf color
   B climbing vines
   C blooming
   D photoperiod

Questions 9–10

The results of an experiment are summarized in the art below.



9. Which of the following can be concluded from the results of this experiment alone?
   A Hormones are produced in the growing tips of plant roots.
   B Plants grow toward the sun due to compounds produced in their stems.
   C Agar blocks contain a variety of plant compounds.
   D Compounds produced in shoot tips can cause stems to bend.

10. Applying your knowledge of specific plant hormones, explain the results.

Open-Ended Response

11. Describe why seed dormancy is a valuable adaptation that has helped explain the evolutionary success of seed plants.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10	11
See Lesson	24.1	24.2	24.1	24.1	24.2	24.2	24.3	24.3	24.3	24.3	24.2

Unit Project

Create a Board Game

Did you have any favorite board games as a kid? Remember how much fun they were to play? Now you get to relive that fun as an employee of an educational toy company! You have been asked to design a board game about the diversity of living things.

Your Task Create a board game based on the groups of living things discussed in this unit—bacteria, viruses, "protists," fungi, and plants. You will exchange games with classmates to test your knowledge and to evaluate the quality of their game.

Be sure to
- include a clever title and colorful, creative board.
- write clear "How to Play" instructions.
- write answerable game questions related to the groups of organisms you've learned about.
- design the game so that winning depends on mastery of the material.

Reflection Questions

1. **Score your game using the rubric below. What score did you give yourself?**
2. **What did you do well in this project?**
3. **What needs improvement?**
4. **What aspects of another group's game did you like? Why?**
5. **After playing the game, what topics did you do well with? What topics do you need to study more?**

Assessment Rubric

Score	Scientific Content	Quality of Game
4	Game includes challenging, but answerable, questions about all of the groups discussed in the unit. Winning the game depends on how well a player knows the material.	Game is very well designed and creative. "How to Play" instructions are clear and easy to follow.
3	Game includes answerable questions on all of the groups discussed in the unit. Winning the game depends on how well a player knows the material.	Game is designed effectively. "How to Play" instructions can be followed.
2	Game includes some answerable questions, but others are unclear or impossible to answer. Winning the game does not necessarily depend on how well a player knows the material.	Game design could use improvement. "How to Play" instructions are difficult to follow.
1	Many questions are vague and/or unanswerable. Winning the game does not depend on how well a player knows the material.	Game design shows little evidence of planning. "How to Play" instructions are impossible to follow.