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MINISTRY OF EDUCATION

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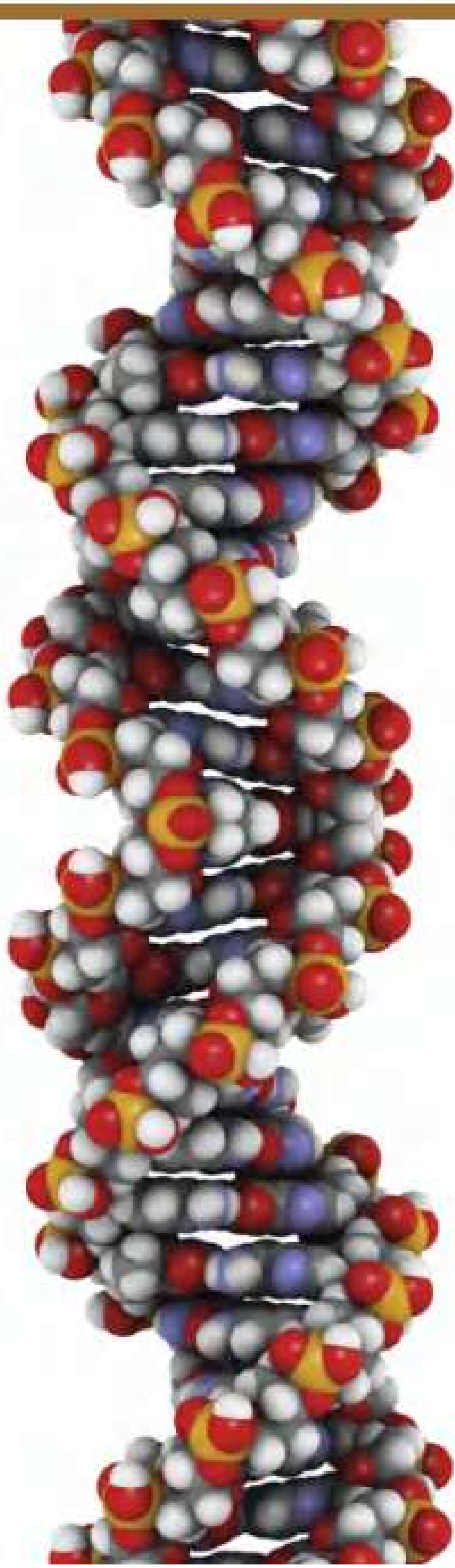
Inspire Biology

UAE Edition
Grade 11 Advanced
Student Edition



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Inspire Biology, Student Edition

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Contents

INTRODUCTION TO GENETICS AND PATTERNS OF INHERITANCE

ENCOUNTER THE PHENOMENON

Why are these siblings not identical?

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

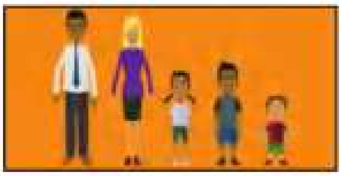
Make Your Claim Use your CER chart to make a claim about why these siblings are not identical. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 1: Explore & Explain: The Inheritance of Traits



LESSON 4: Explore & Explain: Pedigrees

LESSON 1

MENDELIAN GENETICS

FOCUS QUESTION

What is the significance of Mendel's experiments to the study of genetics?

How Genetics Began

In 1866, Gregor Mendel, an Austrian monk and a plant breeder, published his findings on the method of inheritance in garden pea plants. The passing of traits to the next generation is called inheritance, or heredity. Mendel, shown in **Figure 1**, was successful in sorting out the mystery of inheritance because of the organism he chose for his study—the pea plant. Pea plants are true-breeding, meaning that they consistently produce offspring with only one form of a trait.

Pea plants usually reproduce by self-fertilization. A common occurrence in many flowering plants, self-fertilization occurs when a male gamete within a flower combines with a female gamete in the same flower. Mendel also discovered that pea plants could easily be cross-pollinated by hand. Mendel performed cross-pollination by transferring a male gamete from the flower of one pea plant to the female reproductive organ in a flower of another pea plant.

HISTORY Connection Mendel rigorously followed various traits in the pea plants he bred. He analyzed the results of his experiments and formed hypotheses concerning how the traits were inherited. The study of **genetics**, which is the science of heredity, began with Mendel, who is regarded as the father of genetics.

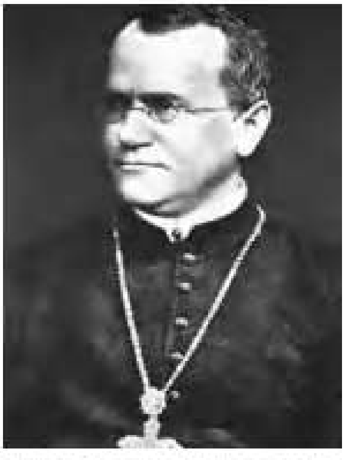


Figure 1 Gregor Mendel is known as the father of genetics.

Get It?

Infer why it is important that Mendel's experiments used a true-breeding plant.

3D THINKING — DCI Disciplinary Core Ideas — CCC Crosscutting Concepts — SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Applying Practices: Punnett Squares

HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

The Inheritance of Traits

Mendel noticed that certain varieties of garden pea plants produced specific forms of a trait, generation after generation. For instance, he noticed that some varieties always produced green seeds and others always produced yellow seeds. In order to understand how these traits are inherited, Mendel performed cross-pollination by transferring male gametes from the flower of a true-breeding green-seed plant to the female organ of a flower from a true-breeding yellow-seed plant. To prevent self-fertilization, Mendel removed the male organs from the flower of the yellow-seed plant. Mendel called the green-seed plant and the yellow-seed plant the parent generation—also known as the P generation.

F_1 and F_2 generations

When Mendel grew the seeds from the cross between the green-seed and yellow-seed plants, all of the resulting offspring had yellow seeds. The offspring of this P cross are called the first filial (F_1) generation. The green-seed trait seemed to have disappeared in the F_1 generation, and Mendel decided to investigate whether the trait was no longer present or whether it was hidden, or masked.

Mendel planted the F_1 generation of yellow seeds, allowed the plants to grow and self-fertilize, and then examined the seeds from this cross. The results of the second filial (F_2) generation—the offspring from the F_1 cross—are shown in **Figure 2**. Of the seeds Mendel collected, 6022 were yellow and 2001 were green; almost a perfect 3:1 ratio of yellow to green seeds. Mendel studied seven traits—seed or pea color, flower color, seed pod color, seed shape or texture, seed pod shape, stem length, and flower position—and found that the F_2 generation from these crosses also showed a 3:1 ratio.

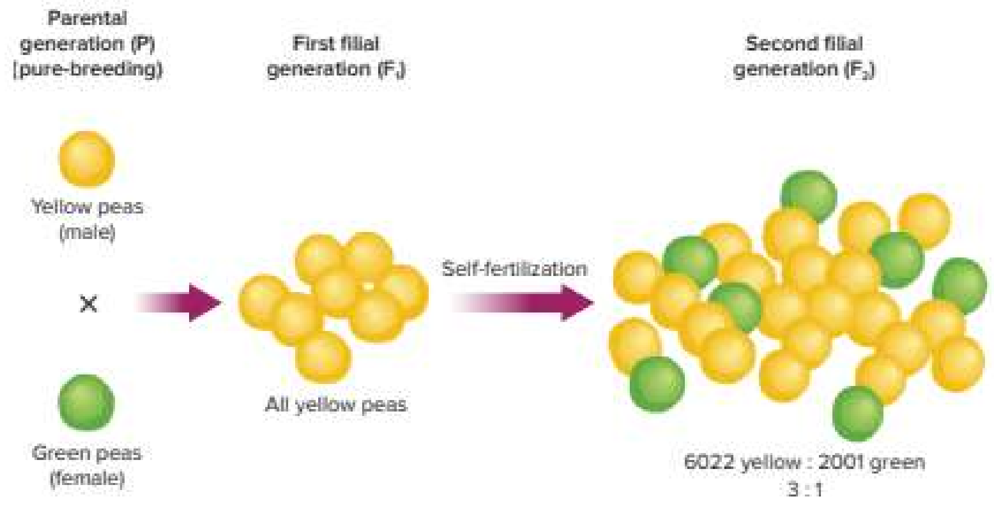


Figure 2 The results of Mendel's cross involving true-breeding pea plants with yellow seeds and green seeds are shown here.

Explain *why the seeds in the F_1 generation were all yellow.*

Genes in pairs

Mendel concluded that there must be two forms of the seed trait in the pea plants--yellow-seed and green-seed--and that each was controlled by a factor, which now is called an allele. An **allele** is defined as an alternative form of a single gene passed from generation to generation. Therefore, the gene for yellow seeds and the gene for green seeds are each different forms of a single gene. Mendel concluded that the 3:1 ratio could be explained if the alleles were paired. He called the form of the trait that appeared in the F_1 generation **dominant** and the form of the trait that was masked in the F_1 generation **recessive.** In the cross, the yellow seed was dominant and the green seed was recessive.

Dominance

When Mendel allowed the F_1 generation to self-fertilize, he showed that the recessive allele for green seeds had not disappeared. Mendel concluded that the green seed form of the trait did not show up in the F_1 generation because the yellow-seed form of the trait is dominant. When it is present, it masks the allele for the green-seed form.

When modeling inheritance, the dominant allele is represented by a capital letter, and the recessive allele is represented by a lowercase letter. An organism with two of the same alleles for a particular trait is **homozygous** (ho muh ZI gus) for that trait. Homozygous, yellow-seed plants are *YY* and green-seed plants are *yy*. An organism with two different alleles for a particular trait is **heterozygous** (heh tuh roh ZY gus) for that trait. A bean plant that is heterozygous for the trait of seed color is *Yy*. When alleles are present in the heterozygous state, the dominant trait will be observed. The recessive trait will be masked.

Genotype and phenotype

A yellow-seed plant could be homozygous or heterozygous. An organism's appearance does not always indicate which alleles are present. The observable characteristic or outward expression of an allele pair is called the **phenotype.** The phenotype of pea plants with the genotype *yy* will be green seeds. The organism's allele pairs are called its **genotype.** The genotype of yellow-seed plants could be *YY* or *Yy*. In plants with green seeds, the genotype is *yy*.

Get It?

Infer whether an individual with a recessive phenotype for a trait is heterozygous or homozygous for that trait.

WORD ORIGINS

homozygous
heterozygous
come from the Greek words *homos*, meaning *the same*; *hetero*, meaning *other* or *different*; and *zygon*, meaning *yoke*

STEM CAREER Connection

Genetic Counselor
Are you interested in genetics? Are you a good listener and a strong communicator? Genetic counselors use Mendelian principles and other genetic concepts to assess a person's risk for inheriting a genetic disorder. They provide information and educational support to patients as well as to medical professionals in places like hospitals and clinics.

Mendel's laws

Mendel used his results to develop the law of segregation and the law of independent assortment. These laws can be applied to analyze patterns of inheritance.

Law of segregation Mendel used homozygous yellow-seed and green-seed plants in his P cross. In **Figure 3(A),** the top drawing shows that each gamete from the yellow-seed plant contains one *Y*. Recall that the chromosome number is divided in half during meiosis. The gametes that are generated contain only one of the pair of seed-color alleles.

The bottom drawing in **Figure 3(A)** shows that each gamete from the green-seed plant contains one *y* allele. Mendel's **law of segregation** states that the two alleles for each trait separate during meiosis. During fertilization, two alleles for that trait unite.

The third drawing in **Figure 3(B)** shows the alleles uniting to produce the genotype *Yy* during fertilization. All resulting F_1 generation plants will have the genotype *Yy* and will have yellow seeds because yellow is dominant to green. These heterozygous organisms are called **hybrids.**

Get It?

Restate Mendel's law of segregation in your own words.

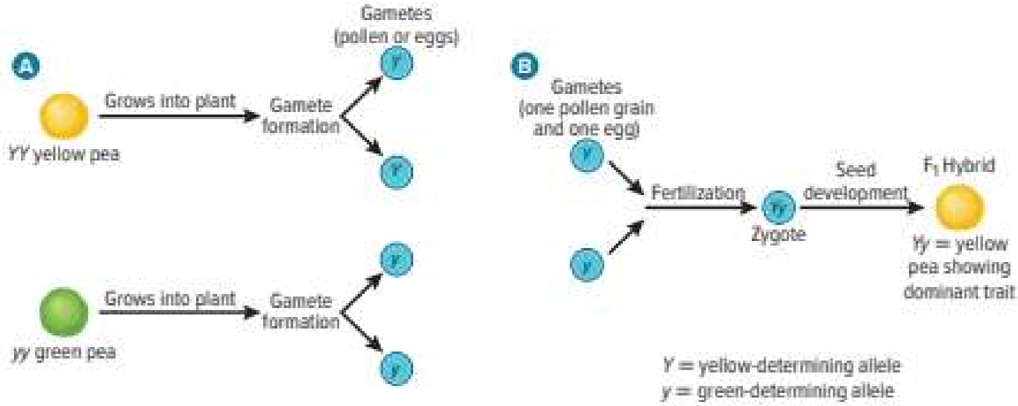


Figure 3 During gamete formation in the *YY* or *yy* plant, the two alleles separate, resulting in *Y* or *y* in the gametes. Gametes from each parent unite during fertilization.

Explain *how the zygote that results from fertilization has a different genotype than either parent plant.*

ACADEMIC VOCABULARY

generated
produced or created
The gametes that are generated during meiosis contain only one allele from each pair.

CCC CROSSCUTTING CONCEPTS

Cause and Effect Write an explanation about how how the law of segregation can be used to predict the alleles inherited by an individual. Cite evidence from the text and **Figure 3** in your explanation.

Law of independent assortment Mendel also experimented with the shape of the peas as well as the color. He noticed that smooth, round peas were expressed more than wrinkled peas. He noted the dominant, round peas to have an allele *R* and the recessive, wrinkled peas to have an allele *r*.

Mendel crossed two types of peas in the parental generation: a dominant round, yellow pea (*YYRR*) with a recessive wrinkled, green pea (*yyrr*). He found that all of the F_1 generation had the same phenotype: round, yellow peas, or the genotype *YyRr*.

Mendel allowed F_1 pea plants with the genotype *YyRr* to self-fertilize in a dihybrid cross. Mendel calculated the genotypic and phenotypic ratios of the offspring in both the F_1 and F_2 generations. From these results, he developed the **law of independent assortment,** which states that a random distribution of alleles occurs during gamete formation. Genes on separate chromosomes sort independently during meiosis, as shown in **Figure 4.**

The random assortment of alleles results in four possible gametes: *YR*, *Yr*, *yR* or *yr*, each of which is equally likely to occur. When a plant self-fertilizes, any of the four allele combinations could be present in the male gamete, and any of the four combinations could be present in the female gamete.

Get It?

Evaluate How can the random distribution of alleles result in a predictable ratio?

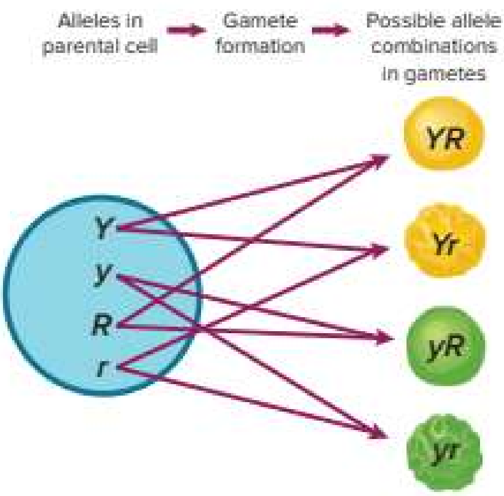


Figure 4 The law of independent assortment is demonstrated by the equal chance that each pair of alleles (*Yy* and *Rr*) can randomly combine with each other.

Predict *how many possible gamete types can be produced.*

Punnett Squares

In the early 1900s, Dr. Reginald Punnett developed what is known as a Punnett square to predict the possible offspring of a cross between two known genotypes. Punnett squares help keep track of the possible genotypes involved in a cross.

Monohybrid cross

The diagram in **Figure 5** shows how Mendel continued his experiments by allowing the *Yy* plants to self-fertilize. A cross such as this one that involves hybrids for a single trait is called a monohybrid cross. The *Yy* plants produce two types of gametes—male and female—each with either the Y or y allele. The combining of these gametes is a random event. This random fertilization of male and female gametes results in the following genotypes—*YY, Yy, Yy,* or *yy*, as shown in **Figure 5.** Notice that the dominant *Y* allele is always written first, whether it came from the male gamete or the female gamete. In Mendel's F_1 cross, there are three possible resulting genotypes: *YY, Yy,* and *yy*; and the genotypic ratio is 1:2:1. The phenotypic ratio is 3:1—yellow seeds to green seeds. The genotypic ratio and the phenotypic ratio differ, because two different genotypes—*YY and Yy* produce the same phenotype.

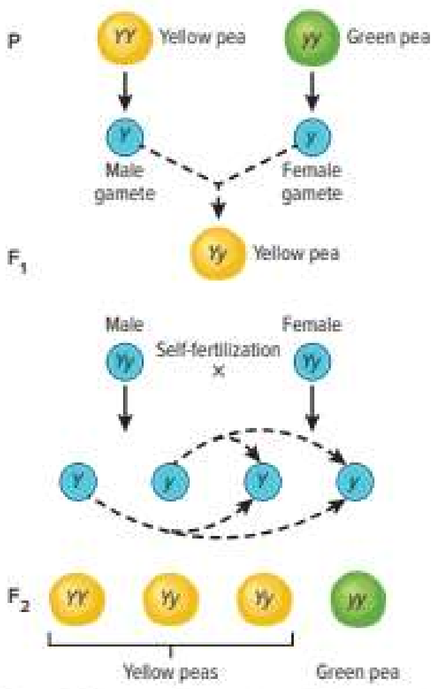


Figure 5 During the F_1 generation self-fertilization, the male gametes randomly fertilize the female gametes.

Do you have freckles like the boy in **Figure 6?** The appearance of freckles is a dominant trait that can be represented by (*F*). Suppose both of your parents have freckles and are heterozygous (*Ff*) for the trait. What possible phenotypes could you or your siblings have?

Figure 6 Freckles are a dominant trait.

Identify *the genotypes that can produce this phenotype.*

Examine the Punnett square in **Figure 7**. The number of squares is determined by the number of different types of alleles—*F* or *f*—produced by each parent. In this case, the square is 2 × 2 squares because each parent produces two different types of gametes. The male gametes are written across the horizontal side and the female gametes are written on the vertical side. The possible combinations of each male and female gamete are written on the inside of each corresponding square.

How many different genotypes are found in the Punnett square? One square has *FF*, two squares have *Ff*, and one square has *ff*. Therefore, the genotypic ratio of the possible offspring is 1:2:1. The phenotypic ratio of freckles to non freckles is 3:1.

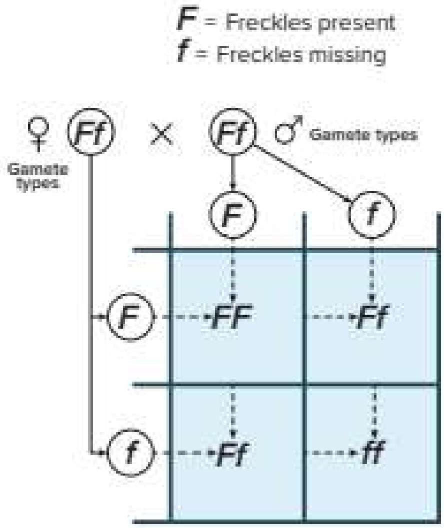
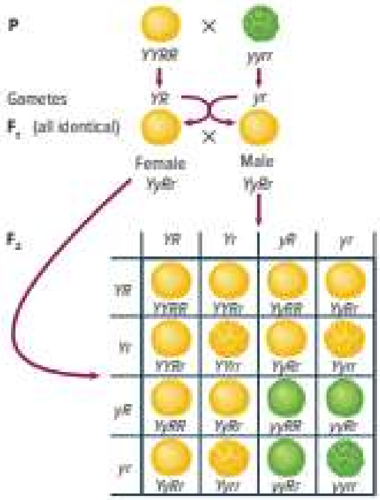


Figure 7 Freckles are a dominant trait. The Punnett square is a visual summary of the possible combinations of the alleles for the trait of freckles.

Dihybrid cross

Once Mendel established the inheritance patterns of a single trait, he began to examine simultaneous inheritance of two or more traits in the same plant. In garden peas, round seeds (*R*) are dominant to wrinkled seeds (*r*), and yellow seeds (*Y*) are dominant to green seeds (*y*). If Mendel crossed homozygous yellow, round-seed pea plants with homozygous green, wrinkle-seed pea plants, the P cross could be represented by *YYRR* × *yyrr*. The F_1 generation genotype would be *YyRr*—yellow, round-seed plants. These F_1-generation plants are called dihybrids because they are heterozygous for both traits.

Examine the Punnett square in **Figure 8**. The number of squares for a dihybrid cross in a Punnett square is determined by the number of different types of alleles—*YR*, *Yr*, *yR*, or *yr*—produced by each parent from the first filial generation (F_1). In this case, the square is 4 squares × 4 squares because each parent produces four different types of gametes. The male gametes are written across the horizontal side and the female gametes are written on the vertical side. The possible combinations of each male and female gamete are written on the inside of each corresponding square.



Type	Genotype	Phenotype	Number	Phenotypic ratio
Parental	Y_R_	yellow round	315/556	9:16
Recombinant	yyR_	green round	108/556	3:16
Recombinant	Y_rr	yellow wrinkled	101/556	3:16
Parental	yyrr	green wrinkled	32/556	1:16

Figure 8 The dihybrid Punnett square visually presents the possible combinations of the possible alleles from each parent.

Probability

The inheritance of genes can be compared to the probability of flipping a coin, as shown in **Figure 9**. The probability of the coin landing on heads is 1 out of 2, or 1/2. If the same coin is flipped twice, the probability of it landing on heads is 1/2 each time or $1/2 \times 1/2$, or 1/4 both times.

Actual data might not perfectly match the predicted ratios. You know that if you flip a coin twice you might not get heads 1 out of the 2 times. You might get heads twice, or you might get tails twice. However, the more times you flip the coin, the closer your results will be to the predicted ratio of heads to tails. Mendel's experimental results were not exactly a 9:3:3:1 ratio. However, the larger the number of offspring involved in a cross, the more likely it will match the results predicted by the Punnett square.

Figure 9 The probability of inheritance of genes can be modeled by flipping a coin.

Check Your Progress

Summary

- The study of genetics begins with Gregor Mendel, whose experiments with garden pea plants gave insight into the inheritance of traits.
- Mendel developed the law of segregation and the law of independent assortment.
- Punnett squares help predict the offspring of a cross.

Demonstrate Understanding

1. **Diagram** Use a Punnett square to explain how a dominant allele masks the presence of a recessive allele.
2. **Apply** the law of segregation and the law of independent assortment by giving an example of each.
3. **Use a Punnett square** In fruit flies, red eyes (*R*) are dominant to pink eyes (*r*). What is the phenotypic ratio of a cross between a heterozygous male and a pink-eyed female?

Explain Your Thinking

4. **Evaluate** the significance of Mendel's work to the field of genetics.
5. **MATH Connection** What is the probability of rolling a 2 on a six-sided die? What is the probability of rolling two 2s on two six-sided dice? How is probability used in the study of genetics?

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LESSON 2
GENETIC RECOMBINATION AND GENE LINKAGE

FOCUS QUESTION

How do genetic recombination and gene linkage compare?

Genetic Recombination

MATH Connection The combination of genes produced by crossing over and independent assortment is called **genetic recombination.** The possible combinations of genes due to independent assortment can be calculated using the formula 2^n, where n is the number of chromosome pairs. For example, pea plants have seven pairs of chromosomes. The possible combinations are 2^7, or 128 combinations. Because any possible male gamete can fertilize any possible female gamete, the number of possible combinations after fertilization is 16,384 (128 × 128). Genetic recombination increases genetic variation.

Gene Linkage

Chromosomes contain multiple genes that code for proteins. Genes that are located close to each other on the same chromosome are said to be linked and usually travel together during gamete formation. Follow closely related genes A and B in **Figure 10**.

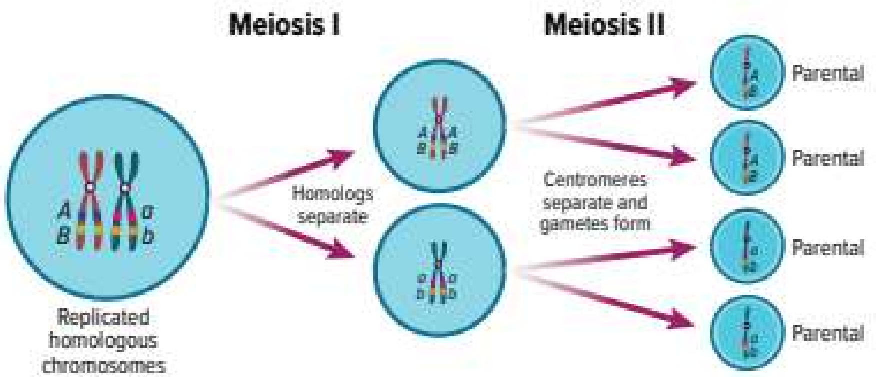

Figure 10 Genes that are linked together on the same chromosome usually travel together in the gamete.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Map Chromosomes
Analyze and interpret data to determine the location of specific genes on a chromosome.

CCC **Identify Crosscutting Concepts**
Create a table of the crosscutting concepts and fill in examples you find as your read.

Linked genes usually travel together during meiosis. However, some results using the fruit fly *Drosophila melanogaster* revealed that linked genes do not always travel together during meiosis. Scientists concluded that linked genes can separate during crossing over. Recall that in sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis, thereby creating new genetic combinations and thus more genetic variation. The linkage of genes on a chromosome results in an exception to Mendel's law of independent assortment because linked genes usually do not segregate independently.

Get It?

Analyze the effect of crossing over on linked genes.

Chromosome maps

Crossing over occurs more frequently between genes that are far apart than those that are close together. A drawing called a chromosome map shows the sequence of genes on a chromosome and can be created by using crossover data. The very first chromosome maps were published in 1913 using data from thousands of fruit fly crosses.

Figure 11 shows the first chromosome map created using fruit fly data. Recall that the higher the crossover frequency, the farther apart the two genes are. Genes that are closer together have a lower frequency of crossing over. In the example below, the genes for yellow body and white eyes are close together on the map because they show a low frequency of crossing over.

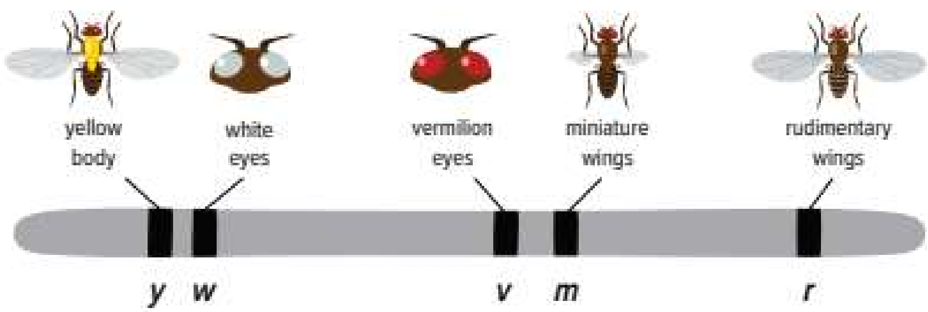

Figure 11 This chromosome map of the X chromosome of the fruit fly *Drosophila melanogaster* was created in 1913.

CCC CROSSCUTTING CONCEPTS

Scale, Proportion, and Quantity Geneticists measure the distance between genes on a chromosome using map units. A higher number of map units between two genes means they are farther apart on the chromosome. There are three genes on a chromosome: *c*, *t*, and *x*. The distance between the genes are: *c* and *t*: 20 map units; *c* and *x*: 10 map units; *t* and *x*: 2 map units. Explain which two genes are most likely to cross over. Cite evidence from the text in your response.

ACADEMIC VOCABULARY

confirmed

validated or made certain

Many crosses confirmed that linked genes usually travel together during meiosis.

Polyploidy

Figure 12 Various commercial plants, such as coffee, are polyploids.

Most species have diploid cells, but some have polyploid cells. **Polyploidy** is the occurrence of one or more extra sets of all chromosomes in an organism. A triploid organism, for instance, would be designated $3n$, which means that it has three complete sets of chromosomes. Polyploidy rarely occurs in animals. In humans, polyploidy is always lethal.

Roughly one in three species of known flowering plants are polyploid. Polyploid plants are often selected for by plant growers for their desirable characteristics, such as large flowers. Commercially grown bread wheat ($6n$), oats ($6n$), sugar cane ($8n$), and strawberries ($8n$) are polyploid crop plants. Polyploid plants, such as the one that produced the coffee shown in **Figure 12**, often have increased vigor and larger size.

Get It?

Explain why plant growers often select for polyploid plants.

Check Your Progress

Summary

- Genetic recombination involves both crossing over and independent assortment.
- Early chromosome maps were created based on the linkage of genes on the chromosome.
- Polyploid organisms have one or more extra sets of chromosomes.

Demonstrate Understanding

1. **Analyze** how crossing over is related to variation.
2. **Draw** Suppose genes C and D are linked on one chromosome and genes c and d are linked on another chromosome. Assuming that crossing over does not take place, sketch the daughter cells resulting from meiosis, showing the chromosomes and position of the genes.
3. **Describe** how polyploidy is used in the field of agriculture.

Explain Your Thinking

4. **Construct** a chromosome map for genes *A*, *B*, *C* and *D* using the following crossing over data: *A* to *D* = 25 percent; *A* to *B* = 30 percent; *C* to *D* = 15 percent; *B* to *D* = 5 percent; *B* to *C* = 20 percent.
5. **Evaluate** what advantage polyploidy would give to a plant breeder.
6. **WRITING Connection** Write a short story describing a society with no genetic variation in humans.

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LESSON 3
APPLIED GENETICS

FOCUS QUESTION

What are examples of selective breeding?

Selective Breeding

You might be familiar with different breeds of dogs, such as Saint Bernards, huskies, and German shepherds. Observe some of the phenotypic traits of these breeds in **Figure 13**. All three have strong, muscular bodies. Saint Bernards have traits such as a keen sense of smell that make them good rescue dogs. Huskies are endurance runners and pull sleds long distances. German shepherds are highly trainable for special services. Since ancient times, humans have bred animals with certain traits to obtain offspring that have desired traits. As a result, these traits become more common. Breeding for desired traits is not restricted to animals alone. Plants also are bred to produce desired traits, such as larger fruits and shorter growing times. The process by which desired traits of certain plants and animals are selected and passed on to their future generations is called **selective breeding.** Through the processes of hybridization and inbreeding, desired traits can be passed on to future generations.

Figure 13 Dogs have traits that make them suited for different tasks: Saint Bernard—keen sense of smell; husky—endurance to run long distances; and German shepherd—high trainability.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Model Hybridization

Use a model to determine the effect hybridization has on lily production.

Review the News

Obtain information from a current news story about the applied genetics and selective breeding. Evaluate your source and communicate your findings to your class.

Hybridization

Crossing parent organisms with different forms of a trait to produce offspring with specific traits results in hybrids. Farmers, animal breeders, scientists, and gardeners often use the production of hybrids, also known as hybridization. They select traits that will give hybrid organisms a competitive edge, such as disease-resistance or faster growth. For example, plant breeders might choose to cross two different varieties of tomato plants in order to produce a hybrid that has both the disease resistance of one parent and the fast growth rate of the other parent.

Care must be taken to cross organisms to yield the right combination of traits from both parents. A disadvantage of hybridization is that it is time consuming and expensive. For example, it took rice breeders three decades to produce hybrid rice varieties that can produce higher yields than nonhybrid varieties. Because hybrids can be bred to be more nutritious, to have the ability to adapt to a wide range of changes in the environment, and to produce greater numbers of offspring, the advantages of hybridization sometimes outweigh the disadvantages.

Inbreeding

Once a breeder observes a desired trait in an organism, a process is needed to ensure that the trait is passed on to future generations. This process, in which two closely related organisms are bred to have the desired traits and to eliminate the undesired ones in future generations, is called **inbreeding.**

Pure breeds are maintained by inbreeding. Clydesdale horses, Angus cattle, and German shepherd dogs are all examples of organisms produced by inbreeding. You might have seen Clydesdale horses at parades and petting zoos. Horse breeders first bred the Clydesdale horse in Scotland hundreds of years ago for use as a farm horse. Because of their strong build, agility, and obedient nature, Clydesdales originally were inbred and used extensively for pulling heavy loads.

A disadvantage of inbreeding is that harmful recessive traits also can be passed on to future generations. Inbreeding increases the chance of homozygous recessive offspring. If both parents carry the recessive allele for a harmful trait, that harmful trait likely will not be eliminated.

Get It?

Describe the disadvantages associated with hybridization and inbreeding.

Test Cross

When producing a hybrid, breeders must determine the genotype of the hybrid. The genotype is determined by performing a test cross. A **test cross** involves breeding an organism that has the unknown genotype with one that is homozygous recessive for the desired trait. If the parent's genotype is homozygous dominant, all the offspring will have the dominant phenotype; if it is heterozygous, the offspring will show a 1:1 phenotypic ratio.

Performing a test cross

Suppose a breeder wants to produce hybrid white grapefruits. In grapefruit trees, white fruit color is the dominant trait; red is recessive. Therefore, the red grapefruit trees in the orchard must be homozygous recessive *(ww)*. The genotype of the hybrid white grapefruit tree can be homozygous dominant *(WW)* or heterozygous *(Ww)*. The breeder can use a test cross to determine the genotype of the white grapefruit tree. When performing a cross, pollen from the flower of one plant is transferred to the female organ in a flower of another plant.

As shown in the top Punnett square in **Figure 14,** if the white grapefruit tree is homozygous dominant *(WW)* and is crossed with a red grapefruit tree *(ww)*, then all the offspring will be heterozygous *(Ww)* and white in color; the dominant phenotype. However, as shown in the second Punnett square in **Figure 14,** if the white grapefruit tree is heterozygous *(Ww)*, then half the number of offspring will be white and half will be red, and the phenotypic ratio will be 1:1.

Homozygous red grapefruit \ Homozygous white grapefruit	*W*	*W*
w	*Ww*	*Ww*
w	*Ww*	*Ww*

Homozygous red grapefruit \ Heterozygous white grapefruit	*W*	*w*
w	*Ww*	*ww*
w	*Ww*	*ww*

Figure 14 The genotype of a white grapefruit tree can be determined by a test cross.
Explain *How does a test cross show the relationship between genotype and phenotype?*

Check Your Progress

Summary

- Selective breeding is used to produce organisms with traits that are considered desirable.
- Hybridization produces organisms with desired traits from parent organisms with different traits.
- Inbreeding creates pure breeds.
- A test cross can be used to determine an organism's genotype.

Demonstrate Understanding

1. **Assess** the effect of selective breeding on food crops.
2. **Describe** three traits that might be desired in sheep. How can these traits be passed on to the next generation? Explain.
3. **Compare** and contrast inbreeding and hybridization.
4. **Predict** the phenotype of offspring from a test cross between a seedless orange (ss) and an orange with seeds (Ss).

Explain Your Thinking

5. **Evaluate** Should a cow and a bull that both carry recessive alleles for a mutation that causes decreased milk production be bred? Explain your answer using probability.
6. **MATH Connection** A breeder performs a test cross to determine the genotype of a black cat. He crosses the black cat (*BB* or *Bb*) with a white cat (*bb*). If 50 percent of the offspring are black, what is the genotype of the black cat?

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LESSON 4

BASIC PATTERNS OF HUMAN INHERITANCE

FOCUS QUESTION

Why is a pedigree helpful in analyzing the inheritance of traits through several generations?

Pedigrees

Review **Table 1**, and recall that a recessive trait is expressed when the individual is homozygous recessive for that trait. Therefore, those with at least one dominant allele will not express the recessive trait. An individual who is heterozygous for a recessive disorder is called a **carrier.** This information is applied to help study patterns of human inheritance, including the inheritance of dominant and recessive disorders.

Table 1 Review of Terms

Term	Example	Definition
Homozygous	True-breeding yellow-seed pea plants would be *YY*, and green-seed pea plants would be *yy*. 	An organism with two of the same alleles for a particular trait is said to be homozygous for that trait.
Heterozygous	A plant that is *Yy* would be a yellow-seed pea. 	An organism with two different alleles for a particular trait is said to be heterozygous for that trait. When alleles are present in the heterozygous state, the dominant trait will be observed.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Investigate Human Pedigrees
Obtain, evaluate, and communicate information about the patterns of genetic traits in a pedigree.

Revisit the Encounter the Phenomenon Question
What information from this lesson can help you answer the Unit and Module questions?

In organisms such as peas and fruit flies, scientists can perform crosses to study genetic relationships. In the case of humans, a scientist studies a family history using a **pedigree,** a diagram that traces the inheritance of a particular trait through several generations.

A pedigree, such as the one shown in **Figure 15,** uses symbols to illustrate inheritance of the trait. Males are represented by squares, and females are represented by circles. One who expresses the trait being studied is represented by a dark, or filled, square or circle, depending on their gender. One who does not express the trait is represented by an unfilled square or circle.

Get It?

Explain how symbols are used to represent individuals in a pedigree.

A horizontal line between two symbols shows that these individuals are the parents of the offspring listed below them. Offspring are listed in descending birth order from left to right and are connected to each other and their parents.

A pedigree uses a numbering system in which Roman numerals represent generations, and individuals are numbered by birth order using Arabic numbers. For example, in **Figure 15,** individual II1 is a female who is the firstborn in generation II.

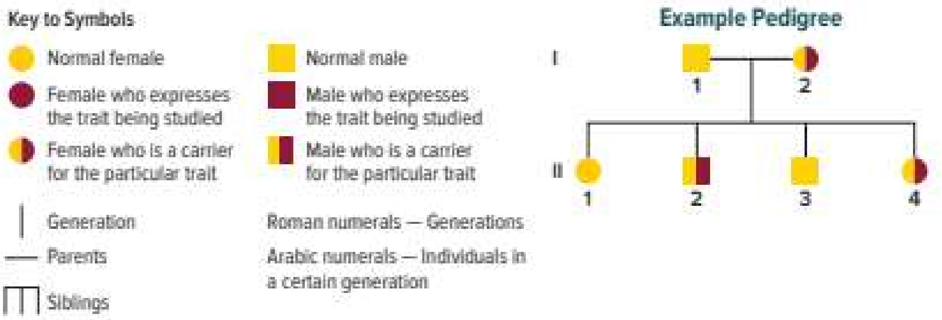

Figure 15 A pedigree uses standard symbols to indicate what is known about the trait being studied.
Summarize *the genotypes and phenotypes of the individuals in generation II for the trait being studied.*

Analyzing Pedigrees

Pedigrees can be applied to study the inheritance of both recessive traits and dominant traits within a family. A pedigree is constructed using all of the information available about the presence or absence of a particular trait in members of a family. It is then analyzed to reveal patterns of inheritence.

The study of pedigrees can be used to determine both X-linked and autosomal traits. The patterns revealed in a pedigree can be used to determine the mode of inheritance of a disease, disorder, or other trait. Patterns can also be used to infer genotypes of specific individuals and to predict the possibility of disorders occurring in future offspring of family members.

Recessive genetic disorders

A pedigree illustrating Tay-Sachs disease is shown in **Figure 16**. Tay-Sachs disease is a recessive genetic disorder caused by the lack of an enzyme involved in lipid metabolism. The missing enzyme causes lipids to build up in the central nervous system, which can lead to death.

Examine the pedigree in **Figure 16.** Note that two unaffected parents, I1 and I2, have an affected child–II3, indicating that each parent has one recessive allele–they both are heterozygous and carriers for the trait. The half-filled square and circle show that both parents are carriers.

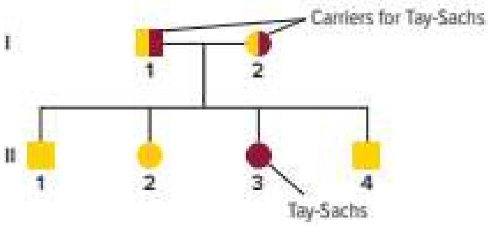

Figure 16 This pedigree illustrates the inheritance of the recessive disorder Tay-Sachs disease. Note that two unaffected parents (I1 and I2) can have an affected child (II3).

Dominant genetic disorders

The pedigree in **Figure 17** shows the inheritance of the dominant genetic disorder polydactyly (pah lee DAK tuh lee). People with this disorder have extra fingers and toes. Recall that with dominant inheritance the trait is expressed when at least one dominant allele is present. An individual with an unaffected parent and a parent with polydactyly could be either heterozygous or homozygous recessive for the trait. Each unaffected person would be homozygous recessive for the trait.

For example, in **Figure 17,** individual I2 has polydactyly, indicated by the dark circle. Because she shows the trait, she is either homozygous dominant or heterozygous. It can be inferred that she is heterozygous–having one dominant gene and one recessive gene–because offspring II3 and II4 do not have the disorder. Notice that II6 and II7, two unaffected parents, have an unaffected offspring–III2. What can be inferred about II2, based on the phenotype of her parents and her offspring?

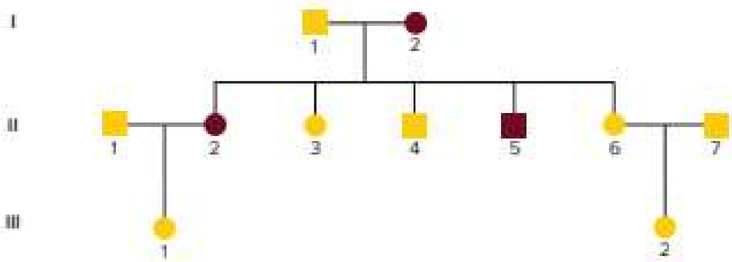

Figure 17 This pedigree illustrates the inheritance of a dominant disorder. Note that affected parents can pass on their genes (II2, II5), but unaffected parents cannot have an affected child (III2).

Inferring genotypes

Pedigrees are used to infer genotypes from the observation of phenotypes. By knowing physical traits, genealogists can determine what genes an individual is most likely to have. Phenotypes of entire families are analyzed in order to determine family genotypes.

Pedigrees help genetic counselors determine whether inheritance patterns are dominant or recessive. Once the inheritance pattern is determined by analyzing the available information, the genotypes of the individuals can largely be resolved, or identified, through pedigree analysis.

To analyze pedigrees, one particular trait is selected to be studied, and a determination is made as to whether that trait is dominant or recessive. Dominant traits are easier to recognize than recessive traits because dominant traits are exhibited in the phenotype of individuals.

A recessive trait will not be expressed unless the person is homozygous recessive for the trait. That means that a recessive allele is passed on by each parent. When recessive traits are expressed, the ancestry of the person expressing the trait is followed for several generations to determine which parents and grandparents were carriers of the recessive allele.

Get It?

Analyze What can be determined about the genotypes of the parents of an individual who expresses a recessive trait?

Predicting disorders

If good records have been kept within families, the possibility of disorders occurring in future offspring can be predicted. However, more accuracy can be expected if several individuals within the family can be evaluated. Having information about several generations of family members can provide valuable information. The study of human genetics can be difficult, because scientists are limited by time, ethics, and and availability of information.

For example, it takes decades for each generation to mature and then to have offspring when the study involves humans. Therefore, good record keeping, where it exists, helps scientists use pedigree analysis to study inheritance patterns, to determine phenotypes, and to ascertain genotypes within a family.

CCC CROSSCUTTING CONCEPTS

Cause and Effect Prepare a visual presentation that includes the pedigree of an inheritable condition or disorder in humans. Then present information that explains how the condition is inherited, using the information in the pedigree as evidence.

Types of Recessive Genetic Disorders

Review **Table 2** as you read about several recessive genetic disorders.

Table 2 Recessive Genetic Disorders in Humans

Disorder	Occurrence in the U.S.	Cause	Effect	Cure/Treatment
Albinism	1 in 17,000	Genes do not produce normal amounts of the pigment melanin.	• No color in the skin, eyes and hair • Skin susceptible to UV damage • Vision problems	• No cure • Protect skin from the Sun and other environ-mental factors • Visual rehabilitation
Cystic fibrosis	1 in 3500	The gene that codes for a membrane protein is defective.	• Excessive mucus production • Digestive and respiratory failure	• No cure • Daily cleaning of mucus from the lungs • Mucus-thinning drugs • Pancreatic enzyme supplements
Galactosemia	1 in 50,000 to 70,000	Absence of the gene that codes for the enzyme that breaks down galactose	• Mental disabilities • Enlarged liver • Kidney failure	• No cure • Restriction of lactose/galac-tose in the diet
Tay-Sachs disease	1 in 2500 (affects people of Jewish descent)	Absence of a necessary enzyme that breaks down fatty substances	• Buildup of fatty deposits in the brain • Mental disabilities	• No cure or treatment • Death by age 5

Albinism

In humans, albinism is caused by altered genes, resulting in the absence of the skin pigment melanin in hair and eyes. Albinism is found in other animals as well. A person with albinism has white hair, very pale skin, and pink pupils. The absence of pigment in eyes can cause problems with vision. Although we all must protect our skin from the Sun's ultraviolet radiation, those with albinism need to be especially careful.

Galactosemia

Galactosemia (guh lak tuh SEE mee uh) is characterized by the inability of the body to digest galactose. During digestion, lactose from milk breaks down into galactose and glucose. Glucose is the sugar used by the body for energy. Galactose is broken down into glucose by an enzyme named GALT. Persons who lack or have defective GALT cannot digest galactose and should avoid milk products.

Cystic fibrosis

One of the most common recessive genetic disorders that occurs among Caucasians is cystic fibrosis, which affects the mucus-producing glands, digestive enzymes, and sweat glands. Chloride ions are not properly transported out of the cells of a person with cystic fibrosis. This causes a high concentration of chloride ions in the cells, and water does not diffuse from the cells. This causes a secretion of thick mucus. The mucus clogs the ducts in the pancreas, interrupts digestion, and blocks the tiny respiratory pathways in the lungs. Patients with cystic fibrosis are at a higher risk of infection because of excess mucus that builds up in their lungs.

Treatment for cystic fibrosis currently includes physical therapy, medication, special diets, and the use of replacement digestive enzymes. Genetic tests are available to determine whether a person is a carrier.

Tay-Sachs disease

Tay-Sachs (TAY saks) disease is a recessive genetic disorder in humans. The gene for Tay-Sachs is found on chromosome 15. Often identified by a cherry-red spot on the back of the eye, Tay-Sachs disease (TSD) seems to be predominant among Jews of eastern European descent.

TSD is caused by the absence of the enzymes that are responsible for breaking down fatty acids called gangliosides. Normally, gangliosides are made and then are dissolved as the brain develops. In a person with Tay-Sachs disease, the gangliosides accumulate in the brain rather than being broken down. The gangliosides inflate and damage brain nerve cells and cause mental deterioration.

Types of Dominant Genetic Disorders

Some human disorders, such as the rare disorder Huntington's disease, are caused by dominant alleles. That means those who do not have the disorder are homozygous recessive for the trait. Review **Table 3** as you read about several dominant genetic disorders that occur in humans.

Table 3 Dominant Genetic Disorders in Humans

Disorder	Occurrence in the U.S.	Cause	Effect	Cure/Treatment
Huntington's disease	1 in 10,000	A gene affecting neurological function is defective.	• Decline of mental and neurological functions • Ability to move deteriorates	• No cure or treatment
Achondroplasia	1 in 25,000	A gene that affects bone growth is abnormal.	• Short arms and legs • Large head	• No cure or treatment

Huntington's disease

The dominant genetic disorder Huntington's disease affects the nervous system and occurs in one out of 10,000 people in the U.S. The symptoms of this disorder first appear in affected individuals between the ages of 30 and 50 years old. The symptoms include a gradual loss of brain function, uncontrollable movements, and emotional disturbances. Genetic tests are available to detect this dominant allele. However, no preventive treatment or cure for this disease exists.

Achondroplasia

An individual with achondroplasia (a kahn droh PLAY zhee uh) has a small body size and limbs that are comparatively short. Achondroplasia is the most common form of dwarfism. A person with achondroplasia will have an adult height of about four feet and will have a normal life expectancy.

Interestingly, 75 percent of individuals with achondroplasia are born to parents of average size. When children with achondroplasia are born to parents of average size, the conclusion is that the condition occurred because of a new mutation or a genetic change.

Get It?

Compare the chances of inheriting a dominant disorder to the chances of inheriting a recessive disorder if you have one parent with the disease.

Check Your Progress

Summary

- Genetic disorders can be caused by dominant or recessive alleles.
- Pedigrees are used to study human inheritance patterns.
- Cystic fibrosis is a genetic disorder that affects mucus and sweat secretions.
- Individuals with albinism do not have melanin in their skin, hair, and eyes.
- Huntington's disease affects the nervous system.
- Achondroplasia sometimes is called dwarfism.

Demonstrate Understanding

1. **Construct** a family pedigree of two unaffected parents with a child who suffers from cystic fibrosis.
2. **Explain** the type of inheritance associated with Huntington's disease and achondroplasia.
3. **Interpret** Can two parents with albinism have an unaffected child? Explain.
4. **Diagram** Suppose one parent is heterozygous for a dominant disorder and the other parent is homozygous normal. Draw a pedigree showing these parents and three possible offspring.

Explain Your Thinking

5. **MATH Connection** Phenylketonuria (PKU) is a recessive disorder. If both parents are carriers, what is the probability of this couple having a child with PKU? What is the chance of this couple having two children with PKU?
6. **Determine** What questions might a doctor ask a couple who request tests for the cystic fibrosis gene?

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LESSON 5

COMPLEX PATTERNS OF INHERITANCE

FOCUS QUESTION

What are examples of complex inheritance?

Incomplete Dominance

Recall that when an organism is heterozygous for a trait, its phenotype will be that of the dominant trait. For example, imagine a pea plant with the genotype *Tt*. If *T* is the allele for the dominant trait of tall plants, then a pea plant with the genotype *Tt* will be tall.

However, when red-flowered snapdragons with the genotype C^RC^R are crossed with white-flowered snapdragons with the genotype C^WC^W, the heterozygous offspring have pink flowers ($C^R C^W$), as shown in **Figure 18**. This is an example of **incomplete dominance,** in which the heterozygous phenotype is an intermediate phenotype between the two homozygous phenotypes. When the heterozygous F_1 generation snapdragon plants are allowed to self-fertilize, as in **Figure 18,** the flowers are red, pink, and white in a 1:2:1 ratio, respectively.

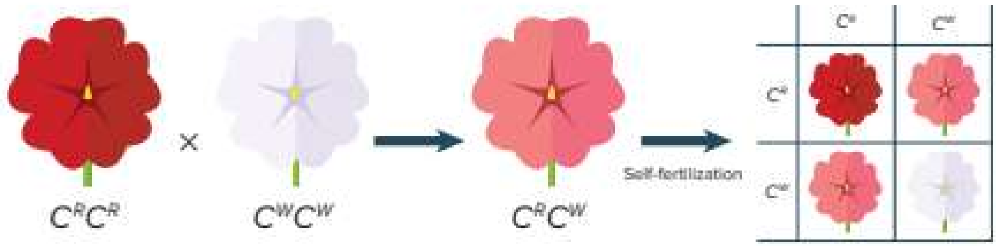

Figure 18 The color of snapdragon flowers is a result of incomplete dominance. When a plant with white flowers is crossed with a plant with red flowers, the offspring have pink flowers. Red, pink, and white offspring will result from self-fertilization of a plant with pink flowers.

Predict *what would happen if you crossed a pink-flowered snapdragon with a white-flowered snapdragon. Identify the genotypes and phenotypes possible in the offspring.*

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

BioLab: What's in a face? Investigate Inherited Human Facial Characteristics

Plan and carry out an investigation to determine if the structures in the face are genetically inherited.

Codominance

Recall that when an organism is heterozygous for a particular trait, the dominant phenotype is expressed. In a complex inheritance pattern called **codominance,** both alleles are expressed in the heterozygous condition. Sickle-cell disease in humans provides a case study of codominant inheritance.

Sickle-cell disease

The allele responsible for sickle-cell disease is particularly common in people of African descent, with about nine percent of African Americans having one form of the trait. Sickle-cell disease affects red blood cells and their ability to transport oxygen. The middle photograph in **Figure 19** shows the blood cells of an individual who is heterozygous for the sickle-cell trait. Compare the shape of the blood cell to the top photograph in **Figure 19** that shows a normal blood cell. Changes in hemoglobin—the protein in red blood cells—cause those blood cells to change to a sickle, or C-shape.

Sickle-shaped cells do not effectively transport oxygen because they block circulation in small blood vessels. Those who are heterozygous for the trait have both normal and sickle-shaped cells. These individuals can lead relatively normal lives, as the normal blood cells compensate for the sickle-shaped cells.

Sickle-cell disease and malaria

Note in the bottom image of **Figure 19** the distribution of both sickle-cell disease and malaria in Africa. Some areas with sickle-cell disease overlap with areas where malaria is widespread. Why might such high levels of the sickle-cell allele exist in central Africa? Scientists have discovered that those who are heterozygous for the sickle-cell trait also have a higher resistance to malaria. The death rate due to malaria is lower where the sickle-cell trait is higher. Because less malaria exists in those areas, more people live to pass on the sickle-cell trait to offspring. Consequently, sickle-cell disease continues to increase in Africa.

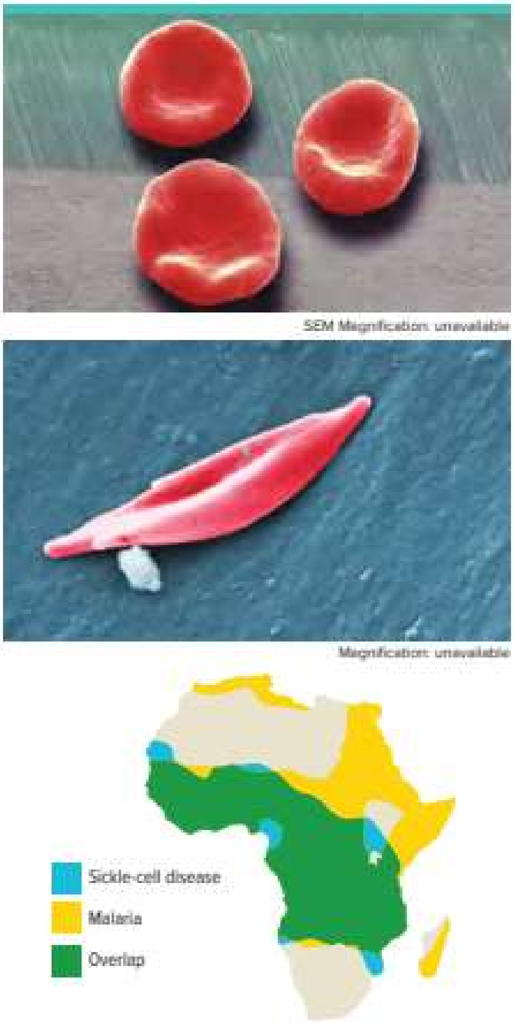

Figure 19

Top: Normal red blood cells are flat and disk-shaped.

Middle: Sickle-shaped cells are elongated and/or C-shaped. They can clump, blocking circulation in small vessels.

Bottom: The sickle-cell allele increases resistance to malaria.

Multiple Alleles

Not all traits are determined by two alleles. Some forms of inheritance are determined by more than two alleles. This is referred to as **multiple alleles.** An example of such a trait is human blood group.

Blood groups in humans

The ABO blood group, shown in **Figure 20,** has three forms of alleles, sometimes called AB markers: I^A is blood type A; I^B is blood type B; and i is blood type O. Type O is the absence of AB markers. Individuals with blood type O have the genotype ii.

Note that allele i is recessive to I^A and I^B. However, I^A and I^B are codominant. Blood type AB results when an individual inherits both an I^A allele and an I^B allele. Therefore, the ABO blood group is an example of both multiple alleles and codominance.

Get It?

Explain how genetic traits carried on multiple alleles can lead to a wide range of characteristics in humans.

The Rh blood group includes Rh factors, inherited from each parent. Rh factors are either positive or negative (Rh+ or Rh−); Rh+ is dominant and Rh− is recessive. The Rh factor is a blood protein named after the rhesus monkey because studies of the rhesus monkey led to discovery of that blood protein.

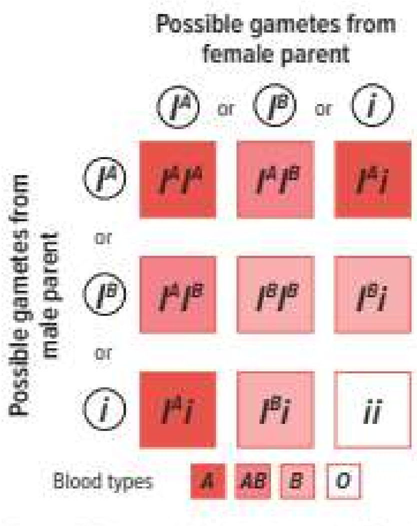

Figure 20 There are three forms of alleles in the ABO blood group—I^A, I^B, and i. I^A *and* I^B *are codominant.* i is recessive to both I^A *and* I^B.

Coat color in rabbits

Multiple alleles can demonstrate a hierarchy of dominance. In rabbits, four alleles code for coat color: C, c^{ch}, c^h, and c. Allele C is dominant to the other alleles and results in a full color coat. Allele c is recessive and results in an albino phenotype when the genotype is homozygous recessive. Allele c^{ch} is dominant to c^h, and allele c^h is dominant to c. The hierarchy of dominance can be written as $C > c^{ch} > c^h > c$.

Figure 21 shows the genotypes and phenotypes possible for rabbit-coat color. Full color is dominant over not full color, which is dominant over Himalayan, which is dominant over albino.

The presence of multiple alleles increases the possible number of genotypes and phenotypes. Without multiple-allele dominance, two alleles, such as *T* and *t*, produce only three possible genotypes—in this example *TT*, *Tt*, and *tt*—and two possible phenotypes. However, the four alleles for rabbit-coat color produce ten possible genotypes and four phenotypes, as shown in **Figure 21.** More variation in rabbit coat color comes from the interaction of the color gene with other genes.

Figure 21 Rabbits have multiple alleles for coat color. The four alleles provide four basic variations in coat color.

Epistasis

Coat color in Labrador retrievers can vary from yellow to black. This is the result of one gene hiding the effects of another gene, an interaction called **epistasis** (ih PIHS tuh sus). A Labrador's coat color is controlled by two sets of alleles. The dominant allele E determines whether the fur will have dark pigment. The fur of a dog with genotype *ee* will not have any pigment. The dominant *B* allele determines how dark the pigment will be. Study **Figure 22.** Genotypes *eebb, eeBb,* and *eeBB* will produce a yellow coat. If the dog's genotype is *EEbb* or *Eebb,* the dog's fur will be chocolate brown. If the dog's genotype includes at least one *E* allele and at least one *B* allele, the fur will be black.

Figure 22 The results of epistasis in coat color in Labrador retrievers show an interaction of two genes, each with two alleles.

Dosage Compensation

Human females have 22 pairs of autosomes and one pair of X chromosomes. Males have 22 pairs of autosomes, along with one X and one Y chromosome. The X chromosome is larger than the Y chromosome. The X chromosome carries a variety of genes that are necessary for the development of both females and males. The Y chromosome mainly has genes that relate to the development of male characteristics.

Because females have two X chromosomes, it seems as though females get two doses of the X chromosome and males get only one dose. To balance the difference in the dose of X-related genes, one of the X chromosomes stops working in each of the female's body cells. This often is called dosage compensation or X-inactivation. Which X chromosome stops working in each body cell is a completely random event. Dosage compensation occurs in all mammals.

As a result of the Human Genome Project, the National Institutes of Health (NIH) has released new information on the sequence of the human X chromosome. Researchers now think that some genes on the inactivated X chromosome are more active than was previously thought.

Get It?

Summarize dosage compensation and its effects.

Chromosome inactivation

The coat colors of the calico cat shown in **Figure 23** are caused by the random inactivation of a particular X chromosome. The resulting colors depend on the X chromosome that is activated. The orange patches are formed by the inactivation of the X chromosome carrying the allele for black coat color. Similarly, the black patches are a result of the inactivation of the X chromosome carrying the allele for orange coat color.

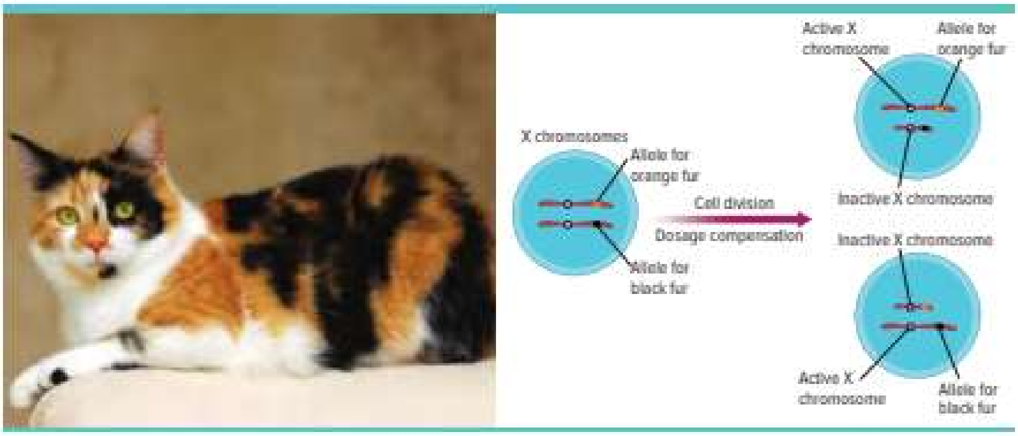

Figure 23 The calico coat of this cat results from the random inactivation of the X chromosomes in body cells. One X chromosome codes for orange fur, and one X chromosome codes for black fur, as illustrated on the right.

Barr bodies

The inactivated X chromosomes can be observed in cells. In 1949, Canadian scientist Murray Barr observed inactivated X chromosomes in female calico cats. He noticed a condensed, darkly stained structure in the nucleus. The darkly stained, inactivated X chromosomes, such as the one shown in **Figure 24,** are called Barr bodies. It was discovered later that only females, including human females, have Barr bodies in their cell nuclei.

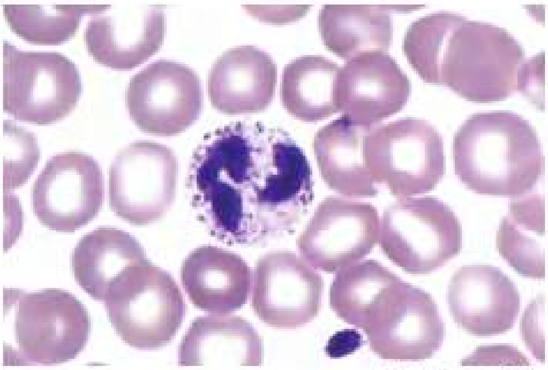

Figure 24 An inactivated X chromosome in a female body cell is called a Barr body, a dark body usually found near the nucleus.

Sex-Linked Traits

Traits controlled by genes located on the X chromosome are called **sex-linked traits,** or X-linked traits. Because genetically classified males have only one X chromosome, they are affected by recessive X-linked traits more often than are genetically classified females. Females are less likely to express a recessive X-linked trait because the other X chromosome may mask the effect of the trait.

Some traits that are located on autosomes may appear to be sex-linked, even though they are not. This occurs when an allele appears to be dominant in one sex, but recessive in the other. For example, the allele for baldness is recessive in females but dominant in males, causing hair loss that follows a typical pattern called male-pattern baldness. A male would be bald if he were heterozygous for the trait, while a female would be bald only if she were homozygous recessive.

Red-green colorblindness

The trait for red-green colorblindness, most commonly, is a recessive X-linked trait. About 8 percent of males in the United States have the trait of red-green color blindness. The right photo in **Figure 25** show how a person with red-green color blindness might view colors compared to the left photo that shows how colors appear to a person who does not have red-green color blindness.

Study the Punnett square shown in **Figure 25.** The mother is a carrier for color blindness because she has the recessive allele for color blindness on one of her X chromosomes. The father is not color blind because he does not have the recessive allele on his one X chromosome. The sex-linked trait is represented by writing the allele on the X chromosome. Notice that the only offspring that can possibly have red-green color blindness is a male child, and that it is also possible for male offspring of this cross to have normal vision. As a result of it being an X-linked trait, red-green color blindness is very rare in females.

X^B = Normal
X^b = Red-green color blindness
Y = Y chromosome

	X^B	Y
X^B	X^BX^B	X^BY
X^b	X^BX^b	X^bY

Figure 25 People with red-green color blindness view red and green as shades of gray.

Explain *why there are fewer females who have red-green color blindness than males.*

Hemophilia

Hemophilia, another recessive sex-linked disorder, is characterized by delayed clotting of the blood. Like red-green color blindness, this disorder is more common in males than in females.

A famous pedigree of hemophilia is one that arose in the family of Queen Victoria of England (1819-1901). Her son Leopold died of hemophilia, and her daughters Alice and Beatrice, as illustrated in the pedigree in **Figure 26**, were carriers for the disease. Alice and Beatrice passed on the hemophilia trait to the Russian, German, and Spanish royal families. Follow the generations in this pedigree to see how this trait was passed through Queen Victoria's family. Queen Victoria's granddaughter Alexandra, who was a carrier for this trait, married Tsar Nicholas II of Russia. Irene, another granddaughter, passed the trait on to the German royal family. Hemophilia was passed to the Spanish royal family through a third granddaughter, whose name also was Victoria.

Men with hemophilia usually died at an early age until the twentieth century when clotting factors were discovered and given to hemophiliacs. However, blood-borne viruses such as Hepatitis C and HIV were often contracted by hemophiliacs until the 1990s, when safer methods of blood transfusion were discovered.

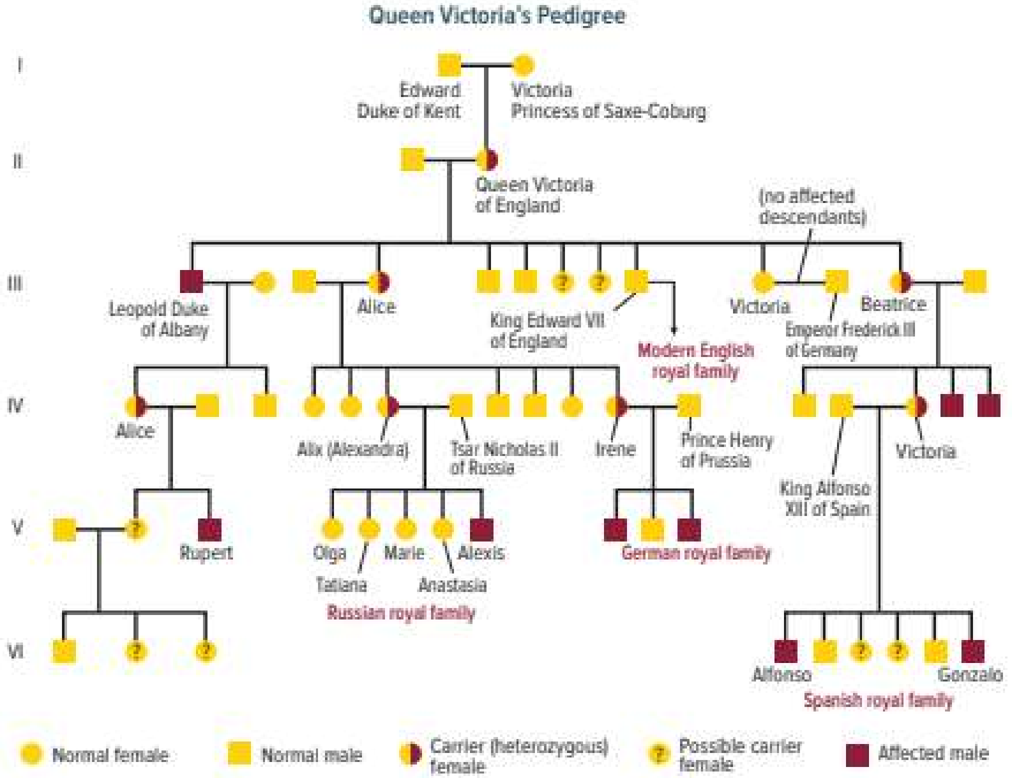

Figure 26 The pedigree above shows the inheritance of hemophilia in the royal families of England, Germany, Spain, and Russia, starting with the children of Queen Victoria.

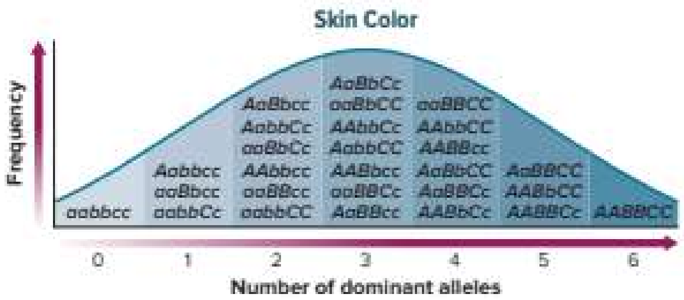

Figure 27 This graph shows possible shades of skin color from three sets of alleles, although the trait is thought to involve more than three sets of alleles.

Predict *Would more gene pairs increase or decrease the number of possible phenotypes?*

Polygenic Traits

You have examined traits determined by a pair of genes. Many phenotypic traits, however, arise from the interaction of multiple pairs of genes. Such traits are called **polygenic traits.** Traits such as skin color, height, eye color, and fingerprint pattern are polygenic traits. One characteristic of polygenic traits is that, when the frequency of the number of dominant alleles is graphed, as shown in **Figure 27**, the result is a bell-shaped curve. This shows that more of the intermediate phenotypes exist than do the extreme phenotypes.

Environmental Influences

The variation and distribution of traits in a population depends on not only genetic factors but also environmental factors. Because environmental factors affect the expression of some traits, they affect the probability of those traits appearing in a population. For example, the tendency to develop heart disease can be inherited. However, environmental factors such as diet and exercise also can contribute to the occurrence and seriousness of the disease. Sunlight, water, and temperature are environmental influences that commonly affect an organism's phenotype.

Sunlight and water

Without enough sunlight, most flowering plants do not bear flowers. Many plants lose their leaves in response to water deficiency.

Temperature

Most organisms experience phenotypic changes from extreme temperature changes. In extreme heat, for example, many plants' leaves droop, flower buds shrivel, chlorophyll disappears, and roots stop growing. These examples probably do not surprise you, although you may have never thought of them as phenotypic changes. Temperature also influences the expression of genes. Notice the fur of the Siamese cat shown in **Figure 28**. The gene that codes for production of the color pigment in the Siamese cat's body functions only under cooler conditions. Therefore, the cooler regions are darker; and the warmer regions, where pigment production is inhibited by temperature, are lighter.

Figure 28 Temperature affects the expression of color pigment in the fur of Siamese cats.

Twin Studies

Identical twins are genetically the same. If a trait is inherited, both twins will have it. Scientists conclude that traits that appear frequently in both identical twins are at least partially due to heredity. Traits expressed differently in identical twins are strongly influenced by environment. The percentage of twins who both express a given trait is called a concordance rate. **Figure 29** shows some traits and their concordance rates.

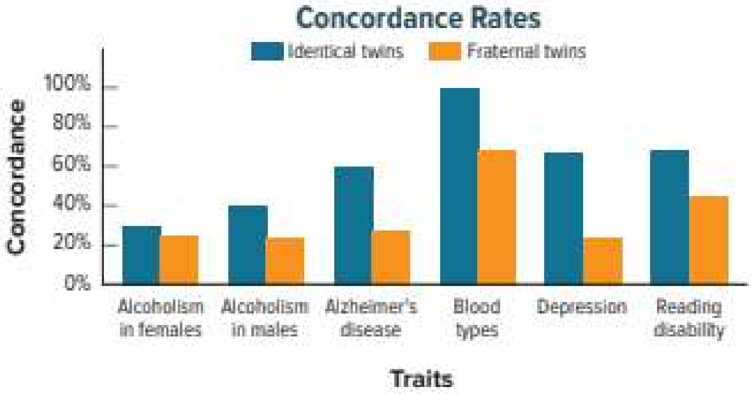

Figure 29 When a trait is found more often in both members of identical twins than in fraternal twins, the trait is presumed to have a significant inherited component.

Check Your Progress

Summary

- Some traits are inherited through complex inheritance patterns, such as incomplete dominance, codominance, and multiple alleles.
- Polygenic traits involve more than one pair of alleles.
- Both genes and environment influence an organism's phenotype.
- Studies of inheritance patterns of large families and twins give insight into complex human inheritance.

Demonstrate Understanding

1. **Describe** two patterns of complex inheritance and explain how they are different from Mendelian patterns.
2. **Explain** How is epistasis different from dominance?
3. **Determine** the genotypes of the parents if the father is blood type A, the mother is blood type B, the daughter is blood type O, one son is blood type AB, and the other son is blood type B.
4. **Analyze** how twin studies help to differentiate the effects of genetic and environmental influences.

Explain Your Thinking

5. **Evaluate** the influence of environmental factors on why the trait for sickle cell disease might be an advantage in central Africa.
6. **MATH Connection** What is the chance of producing a son with normal vision if the father is colorblind and the mother is homozygous normal? Explain.

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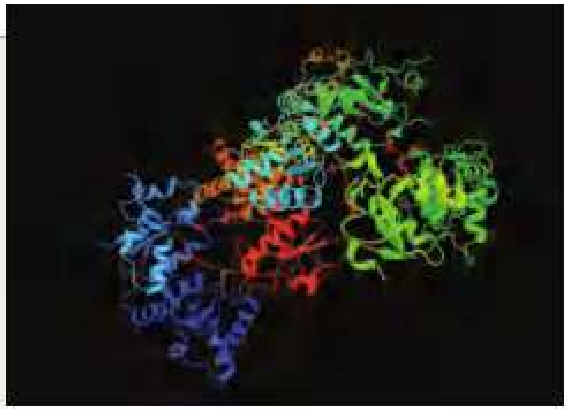
STEM AT WORK

Calculated Risks

Genetic counselors, who advise people about potential genetic disorders, may hold several types of positions. Some genetic counselors work one-on-one with families, and others work in genetic testing labs, interpreting test results and writing reports for doctors and patients. The goal of genetic counselors is to provide people with information so that they can make informed decisions about their healthcare.



Mutations in the BRCA1 gene significantly increase a person's risk of developing breast cancer.

Genetic Counseling

People who are concerned about their risk of having a genetic disorder or who are considering getting tested for a genetic disorder often consult with genetic counselors. The counselors ask clients about their family history of a disease, disorder, or condition. They provide information about genetic disorders and the types of tests that can detect them, including the tests' accuracy.

Genetic counselors discuss with clients the pros and cons of being tested for a disorder. The advantages include being able to take action to protect one's health. The disadvantages include the possibility of a false positive or an inconclusive test.

Identifying the Risk of Disease

Genetic counselors often help people identify genetic risks. For example, research has shown that mutations in the *BRCA1* or *BRCA2* gene often lead to breast cancer and ovarian cancer (in women) and breast cancer and prostate cancer (in men). Mutations shut down these genes' ability to produce proteins that help repair damaged DNA in cells. Without these proteins, malignant tumors can develop.

When people test positive for certain mutated genes, genetic counselors provide information about steps they can take to lessen their chances of developing diseases or conditions.

ANALYZE CONCEPTS OF STATISTICS AND PROBABILITY

Research a genetic disorder. Find out which mutated gene increases a person's risk. Write a short paper on the information that a genetic counselor might provide someone who tested positive for the mutated gene. Include the person's probability of developing the disorder.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 MENDELIAN GENETICS

- The study of genetics began with Gregor Mendel, whose experiments with garden pea plants gave insight into the inheritance of traits.
- Mendel developed the law of segregation and the law of independent assortment.
- Punnett squares help predict the offspring of a cross.

- genetics
- allele
- dominant
- recessive
- homozygous
- heterozygous
- phenotype
- genotype
- law of segregation
- hybrid
- law of independent assortment

Lesson 2 GENETIC RECOMBINATION AND GENE LINKAGE

- Genetic recombination involves both crossing over and independent assortment.
- Early chromosome maps were created based on the linkage of genes.
- Polyploid organisms have one or more extra sets of all chromosomes.

- genetic recombination
- polyploidy

Lesson 3 APPLIED GENETICS

- Selective breeding and hybridization are used to produce organisms with desired traits.
- A test cross can be used to determine an organism's genotype.
- Inbreeding creates pure breeds.

- selective breeding
- inbreeding
- test cross

Lesson 4 BASIC PATTERNS OF HUMAN INHERITANCE

- Genetic disorders can be caused by dominant or recessive alleles.
- Pedigrees are used to study human inheritance patterns.

- carrier
- pedigree

Lesson 5 COMPLEX PATTERNS OF INHERITANCE

- Some traits are inherited through complex inheritance patterns, such as incomplete dominance, codominance, and multiple alleles.
- Polygenic traits involve more than one pair of alleles.
- Both genes and environment influence an organism's phenotype.
- Studies of inheritance patterns of large families and twins give insight into complex human inheritance.

- incomplete dominance
- codominance
- multiple alleles
- epistasis
- sex-linked trait
- polygenic trait

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

Why are these siblings not identical?

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will summarize your evidence and apply it to the project.

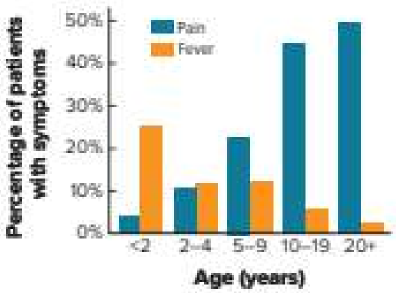
GO FURTHER

SEP Data Analysis Lab

What is the relationship between sickle-cell disease and other complications?

Patients who have been diagnosed with sickle-cell disease face many symptoms, including respiratory failure and neurological problems. The graph shows the relationship between age and two different symptoms—pain and fever—during the two weeks preceding an episode of acute chest syndrome and hospitalization.

Symptoms v. Age



*Data obtained from: Walters, et al. 2002. Novel therapeutic approaches in sickle cell disease. *Hematology* 17: 10-34.

CER Analyze and Interpret Data

1. **Claim, Evidence** Which age group has the highest level of pain before being hospitalized?
2. **Reasoning** Describe the relationship between age and fever before hospitalization.

MOLECULAR GENETICS

ENCOUNTER THE PHENOMENON

Why do the rungs of the DNA ladder appear "broken?"

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

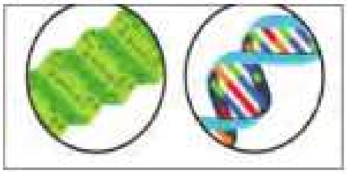
CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about why the rungs of the DNA ladder appear "broken." Explain your reasoning.

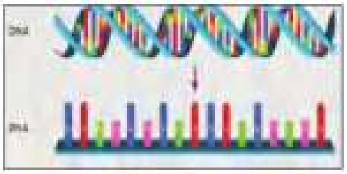
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.



LESSON 1: Explore & Explain: Discovery of DNA



LESSON 3: Explore & Explain: Central Dogma: DNA, RNA, and Protein

LESSON 1

DNA: THE GENETIC MATERIAL

FOCUS QUESTION

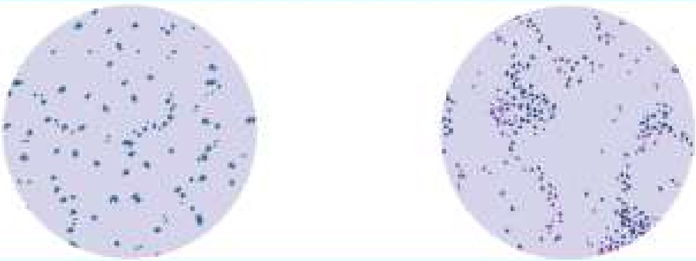
Which experiments led to the discovery of DNA, and which led to the structure of DNA?

Discovery of DNA

Once Mendel's work was rediscovered in the 1900s, scientists began to search for the molecule involved in inheritance. Scientists knew that genetic information was carried on the chromosomes in eukaryotic cells, and that the two main components of chromosomes are DNA and protein. For many years, scientists tried to determine which of these macromolecules—nucleic acid (DNA) or proteins—was the source of genetic information.

Griffith

The first major experiment that led to the discovery of DNA as the genetic material was performed by Frederick Griffith in 1928. Griffith studied two strains of the bacteria *Streptococcus pneumoniae*. He found that one strain could be transformed, or changed, into the other form. Of the two strains he studied, one had a sugar coat and one did not. Both strains are shown in **Figure 1.**



Smooth strain—*S. pneumoniae* | Rough strain—*S. pneumoniae*

Figure 1 The smooth (S) strain of *S. pneumoniae* can cause pneumonia, though the rough (R) strain is not disease-causing. The strains can be identified by the appearance of the colonies.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

BioLab: What is DNA?

Plan and carry out an investigation to determine if there are patterns when comparing DNA from various sources.

Revisit the Encounter the Phenomenon Question

What information from this lesson can help you answer the Module questions?

Follow Griffith's study in **Figure 2.** The coated strain causes pneumonia and is called the smooth (S) strain. The noncoated, or rough (R) strain, does not cause pneumonia. The live S cells killed the mouse in the study. The live R cells did not kill the mouse, and the killed S cells did not kill the mouse. When Griffith made a mixture of live R cells and killed S cells and injected the mixture into a mouse, the mouse died. Griffith isolated live bacteria from the dead mouse. When these isolated bacteria were cultured, the smooth trait was visible, suggesting that a disease-causing factor was passed from the killed S bacteria to the live R bacteria. Griffith concluded that there had been a transformation from live R bacteria to live S bacteria. This experiment set the stage for the search to identify the transforming substance.

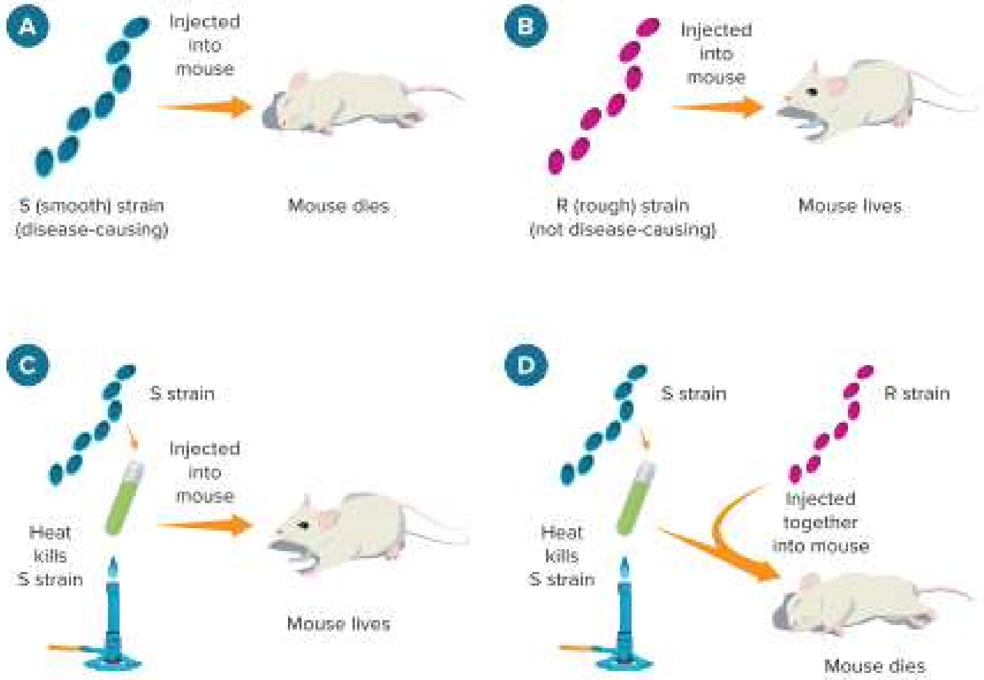


Figure 2 Griffith's transformation experiment demonstrates the change of rough bacteria into smooth bacteria.

Avery

In 1944, Oswald Avery and his colleagues identified the molecule that transformed the R strain of bacteria into the S strain. Avery isolated different macromolecules, such as DNA, proteins, and lipids, from killed S cells. Then he exposed live R cells to the macromolecules separately. When the live R cells were exposed to the S strain DNA, they were transformed into S cells. Avery concluded that when the S cells in Griffith's experiments were killed, DNA was released. Some of the R bacteria incorporated this DNA into their cells, and this changed the bacteria into S cells. Avery's conclusions were not widely accepted by the scientific community, and many biologists continued to question and experiment to determine whether proteins or DNA were responsible for the transfer of genetic material.

Get It?

Explain how Avery discovered the transforming factor.

Hershey and Chase

In 1952, Alfred Hershey and Martha Chase published results of experiments that provided definitive evidence that DNA was the transforming factor. These experiments involved a bacteriophage (bak TIHR ee uh fayj), a type of virus that attacks bacteria. Two components made the experiment ideal for confirming that DNA is the genetic material. First, the bacteriophage used in the experiment was made of DNA and protein. Second, viruses cannot replicate themselves. They must inject their genetic material into a living cell in order for replication to take place. Hershey and Chase labeled both parts of the virus to determine which part was injected into the bacteria and, thus, which part was the genetic material.

Radioactive labeling Hershey and Chase used a technique called radioactive labeling to trace the fate of the DNA and protein as the bacteriophages infected bacteria and reproduced. Follow along in **Figure 3,** which illustrates the Hershey-Chase experiment. They labeled one set of bacteriophages with radioactive phosphorus (^{32}P). Proteins do not contain phosphorous, so DNA and not protein in these viruses would be radioactive. Hershey and Chase labeled another set of bacteriophages with radioactive sulfur (^{35}S). Because proteins contain sulfur and DNA does not, proteins and not DNA would be radioactive.

Hershey and Chase infected bacteria with viruses from the two groups. When viruses infect bacteria, they attach to the outside of the bacteria and inject their genetic material. The infected bacteria then were separated from the viruses.

Tracking DNA Hershey and Chase examined Group 1 labeled with ^{32}P and found that the labeled viral DNA had been injected into the bacteria. Viruses later released from the infected bacteria contained ^{32}P, further indicating that DNA was the carrier of genetic information.

When examining Group 2 labeled with ^{35}S, Hershey and Chase observed that the labeled proteins were found outside of the bacterial cells. Viral replication had occurred in the bacterial cells, indicating that the viruses' genetic material had entered the bacteria, but no label (^{35}S) was found.

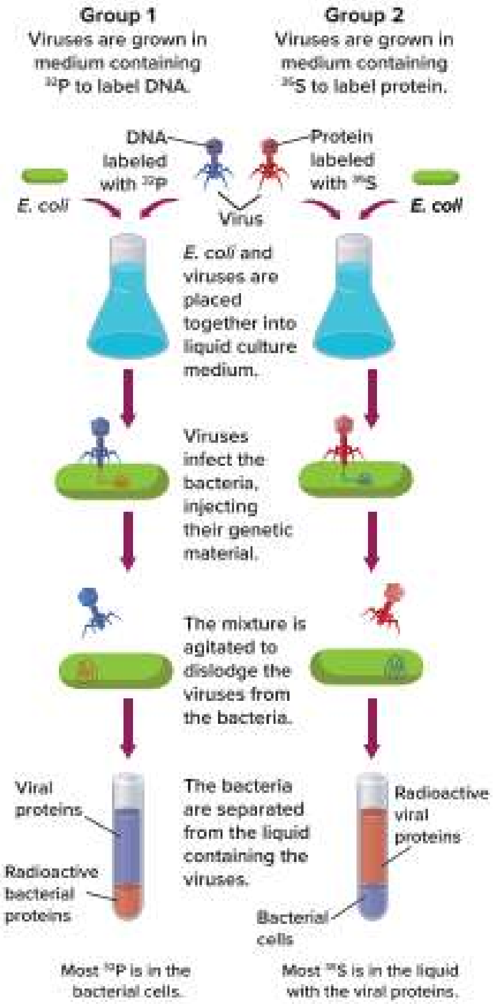


Figure 3 Hershey and Chase used radioactive labeling techniques to demonstrate that DNA is the genetic material in viruses.

Table 1 Summary of Hershey-Chase Results

Group 1 (Viruses labeled with ^{32}P)		Group 2 (Viruses labeled with ^{35}S)	
Infected Bacteria	**Liquid with Viruses**	**Infected Bacteria**	**Liquid with Viruses**
• Labeled viral DNA (^{32}P) found in the bacteria • Viral replication occurred • New viruses contained ^{32}P	• No labeled DNA • No viral replication	• No labeled viral proteins (^{35}S) • Viral replication occurred • New viruses did not have a label	• Labeled proteins found • No viral replication

Table 1 summarizes the results of the Hershey-Chase experiment. Based on their results, Hershey and Chase concluded that the viral DNA was injected into the cell and provided the genetic information needed to produce new viruses. This experiment provided powerful evidence that DNA, not protein, was the genetic material that could be passed from generation to generation in viruses.

Get It?

Explain why it is important that new viruses were produced in the bacteria.

Discovery of DNA Structure

After the Hershey-Chase experiment, scientists were more confident than ever that DNA was the genetic material of living things. The experimental results had led to the identification of the genetic material, but the questions of how nucleotides came together to form DNA molecules and how DNA could communicate information remained.

The structure question

Just as the work of many scientists led to the discovery that DNA was the genetic material, it took the work of many scientists to develop an understanding of the structure of DNA. For example, Erwin Chargaff's work led him to conclude that nucleotides paired together specifically. Rosalind Franklin, Maurice Wilkins, James Watson, and Francis Crick provided data, analysis, and insights that were pivotal in answering the DNA structure question.

CCC CROSSCUTTING CONCEPT

Structure And Function Use the evidence obtained by the experiments of Hershey and Chase to explain the conclusion that DNA was the structure that allowed characteristics to be passed from generation to generation.

ACADEMIC VOCABULARY

transform

to cause a change in type or kind

Alfred Hershey and Martha Chase published results of experiments that provided definitive evidence that DNA was the transforming factor.

Chargaff

Erwin Chargaff analyzed the amount of adenine, guanine, thymine, and cytosine in the DNA of various species. A portion of Chargaff's data, published in 1950, is shown in **Figure 4.** Chargaff found that the amount of guanine nearly equals the amount of cytosine, and the amount of adenine nearly equals the amount of thymine within a species. This finding is known as Chargaff's rule: C = G and T = A.

Chargaff's Data

	Base Composition (Mole Percent)			
Organism	A	T	G	C
Escherichia coli	26.0	23.9	24.9	25.2
Yeast	31.3	32.9	18.7	17.1
Herring	27.8	27.5	22.2	22.6
Rat	28.6	28.4	21.4	21.5
Human	30.9	29.4	19.9	19.8

Figure 4 Chargaff's data showed that though base composition varies from species to species, within a species C = G and A = T.

Franklin and Wilkins

Wilkins was working at King's College in London, England, with a technique called X-ray diffraction, a technique that involved aiming X rays at the DNA molecule. In 1951, Rosalind Franklin joined the staff at King's College. There she took the now famous Photo 51 and collected data eventually used by Watson and Crick. Photo 51, shown in **Figure 5,** indicated that DNA was a **double helix,** or twisted ladder shape, formed by two strands of nucleotides twisted around each other. The specific structure of the DNA double helix was determined later by Watson and Crick when they used Franklin's data and other mathematical data. DNA is the genetic material of all organisms, composed of two complementary, precisely paired strands of nucleotides wound in a double helix.

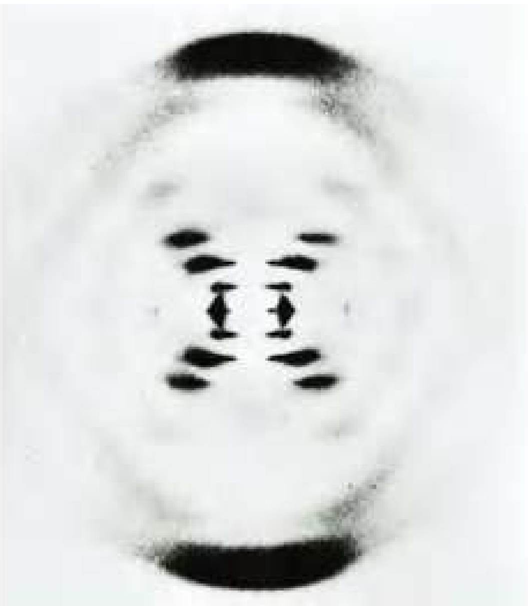


Figure 5 Rosalind Franklin's Photo 51 and X-ray diffraction data helped Watson and Crick solve the structure of DNA. When analyzed and measured carefully, the pattern shows the characteristics of a helical structure.

Watson and Crick

Watson and Crick were working at Cambridge University in Cambridge, England, when they saw Franklin's X-ray diffraction picture. Using Chargaff's data and Franklin's data, Watson and Crick measured the width of the helix and the spacing of the bases. Together, they built a model of the double helix that conformed to the others' research. The model that they built is shown in **Figure 6.** Some important features of their proposed molecule include the following:

1. Two outside strands consist of alternating deoxyribose and phosphate.
2. Cytosine and guanine bases pair to each other by three hydrogen bonds.
3. Thymine and adenine bases pair to each other by two hydrogen bonds.

Figure 6 Using Chargaff's and Franklin's data, Watson and Crick, shown here, solved the puzzle of the structure of DNA.

The announcement

In 1953, Watson and Crick surprised the scientific community by publishing a one-page letter in the scientific journal *Nature* that suggested a structure for DNA. The letter also hypothesized a method of replication for the molecule deduced from the proposed structure. In articles individually published in the same issue of *Nature*, Wilkins and Franklin presented evidence that supported the structure proposed by Watson and Crick. Still, the mysteries of how to prove DNA's replication and how DNA worked as a genetic code remained. Further investigations would be needed to build on the work of Wilkins, Franklin, Watson, and Crick and to solve these mysteries.

Get It?

Explain the structure shown in the image at the beginning of the Module.

Nucleotides

In the 1920s, the biochemist P. A. Levene determined the basic structure of nucleotides that make up DNA. Nucleotides are the subunits of nucleic acids and consist of a five-carbon sugar, a phosphate group, and a nitrogenous base. The two nucleic acids found in living cells are DNA and RNA. DNA nucleotides contain the sugar deoxyribose (dee ahk sih RI bos), a phosphate, and one of four nitrogenous bases: adenine (A duh neen), guanine (GWAH neen), cytosine (SI tuh seen), or thymine (THI meen). RNA nucleotides contain the sugar ribose, a phosphate, and one of four nitrogenous bases: adenine, guanine, cytosine, or uracil (YOO ruh sihl). Notice in **Figure 7** that guanine (G) and adenine (A) are double-ringed bases. This type of base is called a purine base. Thymine (T), cytosine (C), and uracil (U) are single-ringed bases called pyrimidine bases.

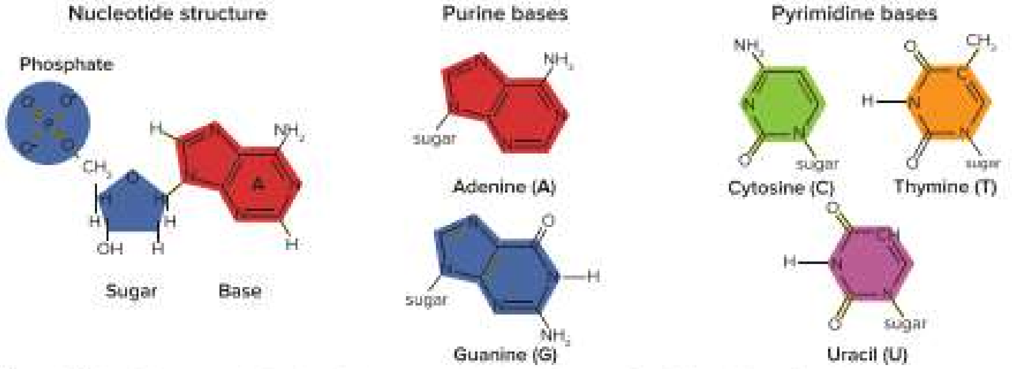


Figure 7 Nucleotides are made of a phosphate, sugar, and a base. There are five different bases found in nucleotide subunits that make up DNA and RNA.

Explain *the structural difference between purine and pyrimidine bases.*

DNA structure

DNA is often compared to a twisted ladder, with the rails of the ladder represented by the alternating deoxyribose and phosphate. The pairs of bases (cytosine–guanine or thymine–adenine) form the steps, or rungs, of the ladder. A purine base always binds to a pyrimidine base, ensuring a consistent distance between the two rails of the ladder. This proposed bonding of the bases also explains Chargaff's data, which suggested that the number of purine bases equaled the number of pyrimidine bases in a sample of DNA. Remember, cytosine and thymine are pyrimidine bases, adenine and guanine are purines, and C = G and A = T. Therefore, C + T = G + A, or purine bases equal pyrimidine bases. Complementary base pairing is used to describe the precise pairing of purine and pyrimidine bases between strands of nucleic acids. It is the characteristic of DNA replication through which the parent strand can determine the sequence of a new strand.

Get It?

Explain why Chargaff's data was an important clue for understanding the structure of DNA.

Orientation

Another unique feature of the DNA molecule is the direction, or orientation, of the two strands. Carbon molecules can be numbered in organic molecules. **Figure 8** shows the orientation of the numbered carbons in the sugar molecules on each strand of DNA. On the top rail, the orientation of the sugar has the 5′ (read "five-prime") carbon on the left, and on the end of that rail, the 3′ (read "three-prime") carbon is on the right of the sugar-phosphate chain. The strand is said to be oriented 5′ to 3′. The strand on the bottom runs in the opposite direction and is oriented 3′ to 5′. This orientation of the two strands is called antiparallel. Another way to visualize antiparallel orientation is to take two pencils and position them so that the point of one pencil is next to the eraser of the other.

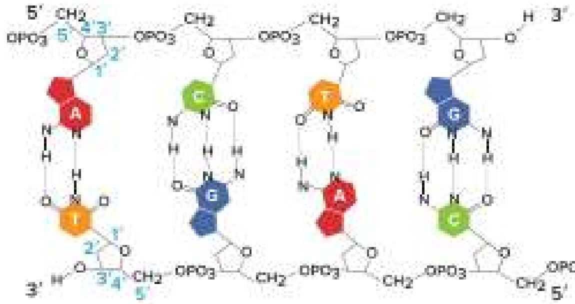


Figure 8 Two strands of DNA running antiparallel make up the DNA helix.

Explain *why the ends of the DNA strands are labeled 3′ and 5′.*

Check Your Progress

Summary

- Griffith's bacterial experiment and Avery's explanation first indicated that DNA is the genetic material.
- The Hershey-Chase experiment provided evidence that DNA is the genetic material of viruses.
- Chargaff's rule states that in DNA the amount of cytosine equals the amount of guanine and the amount of thymine equals the amount of adenine.
- The work of Watson, Crick, Franklin, and Wilkins provided evidence of the double-helix structure of DNA.

Demonstrate Understanding

1. **Summarize** the experiments of Griffith and Avery that indicated that DNA is the genetic material.
2. **Describe** the conclusions drawn by Hershey and Chase about the substance responsible for the transfer of genetic information.
3. **Describe** the data used by Watson and Crick to determine the structure of DNA.

Explain Your Thinking

4. **Describe** two characteristics that DNA needs to fulfill its role as a genetic material.
5. **Explain** what the story of determining the structure of DNA tells us about the nature of science.
6. **Evaluate** Hershey and Chase's decision to use radioactive phosphorus and sulfur for their experiments. Could they have used carbon or oxygen instead? Why or why not?

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LESSON 2
REPLICATION OF DNA

FOCUS QUESTION

How does DNA replicate?

Semiconservative Replication

When Watson and Crick presented their model of DNA to the science community, they also suggested a possible method of replication called semiconservative replication. During **semiconservative replication,** parental strands of DNA separate, serve as templates, and produce DNA molecules that have one strand of parental DNA and one strand of new DNA. Recall that DNA replication occurs during interphase of mitosis and meiosis, allowing genetic information to be transmitted during these processes. An overview of semiconservative replication is shown in **Figure 9.** The process of semiconservative replication occurs in three main stages: unwinding, base pairing, and joining.

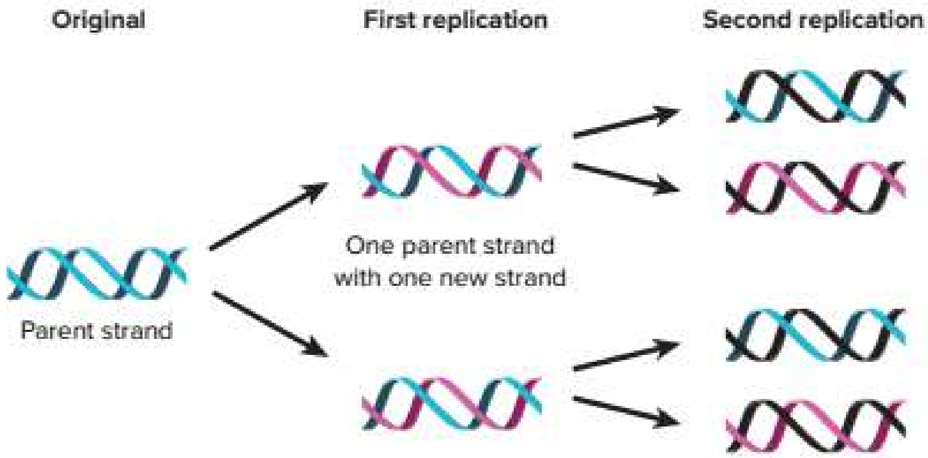

Figure 9 In semiconservative replication, the parental DNA strands separate and serves as templates to produce two daughter DNA molecules, which then can separate to produce four DNA molecules.

Explain *how replication ensures that DNA of successive generations of cells during mitosis is the same.*

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

BioLab: Forensics: How is DNA extracted?
Plan and carry out an investigation to determine the proportion and quantity of DNA found in corn.

Quick Investigation: Model DNA Replication
Use a model to determine the cause and effect of DNA replication.

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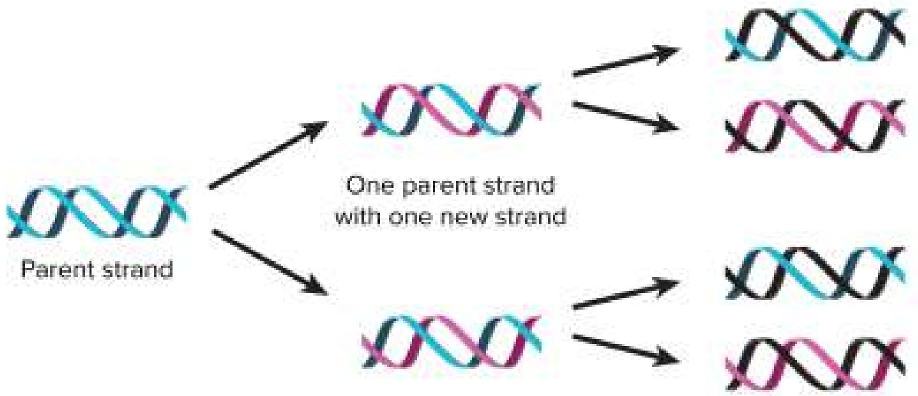

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Quick Investigation: Model DNA Replication
Use a model to determine the cause and effect of DNA replication.

Unwinding

DNA helicase, an enzyme, unwinds and unzips the double helix. The enzyme breaks the hydrogen bonds between the base pairs and the double helix unzips leaving single strands of DNA. Then, proteins called single-stranded binding proteins associate with the DNA to keep the strands separate. As the helix unwinds, another enzyme, RNA primase, adds a short segment of RNA, called an RNA primer, on each DNA strand.

Base pairing

The enzyme **DNA polymerase** catalyzes the addition of nucleotides to the new DNA strand. The nucleotides are added to the 3′ end of the new strand, as illustrated in **Figure 10**. DNA polymerase continues adding nucleotides to the chain by adding to the 3′ end of the new DNA strand. Recall that each base binds only to its complement—A binds to T and C binds to G. In this way, the templates allow identical copies of the original double-stranded DNA to be produced.

Notice in **Figure 10** that the two strands are made in a slightly different manner. The leading strand is elongated as the DNA unwinds. This strand is built continuously by the addition of nucleotides to the 3′ end in the 5′ to 3′ direction. The lagging strand elongates away from the replication fork. It is synthesized discontinuously into small segments, called **Okazaki fragments,** by DNA polymerase in the 3′ to 5′ direction. These fragments are later connected by the enzyme DNA ligase. Each Okazaki fragment is about 100–200 nucleotides long in eukaryotes. Because one strand is synthesized continuously and the other is synthesized discontinuously, DNA replication is semidiscontinuous as well as semiconservative.

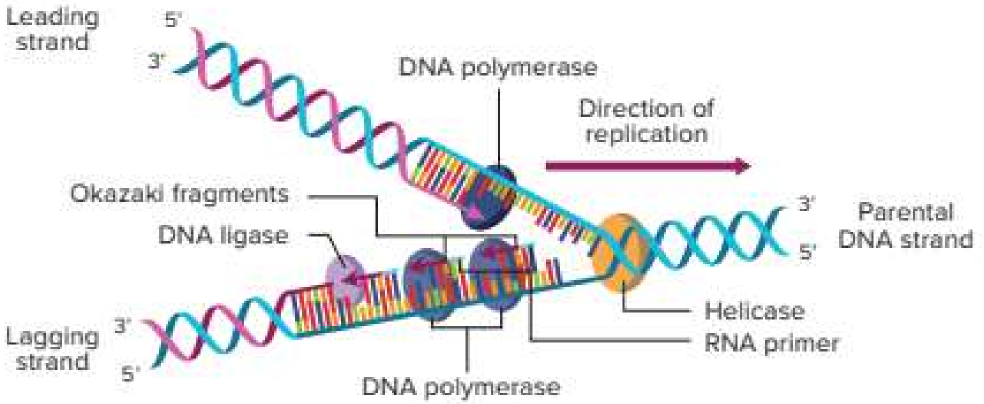

Figure 10 The DNA strands are separated during replication as each parent strand serves as a template for new strands.

Joining

In eukaryotes, DNA replication often begins at many areas along the chromosome. When the DNA polymerase comes to an RNA primer on the DNA, it removes the primer and fills in the place with nucleotides. When the RNA primer has been replaced, DNA ligase links the two sections.

Comparing DNA Replication in Eukaryotes and Prokaryotes

Eukaryotic DNA unwinds in multiple areas as DNA is replicated. Each individual area of a chromosome replicates as a section, which can vary in length from 10,000 to one million base pairs. Multiple replication origins look like bubbles in the DNA strand, as shown in **Figure 11**.

In prokaryotes, the circular DNA strand is opened at one origin of replication, as shown in **Figure 11**. Notice that DNA replication occurs in two directions, just as it does in eukaryotes. Prokaryotic DNA is typically shorter than eukaryotic DNA and remains in the cytoplasm, not packaged in a nucleus.

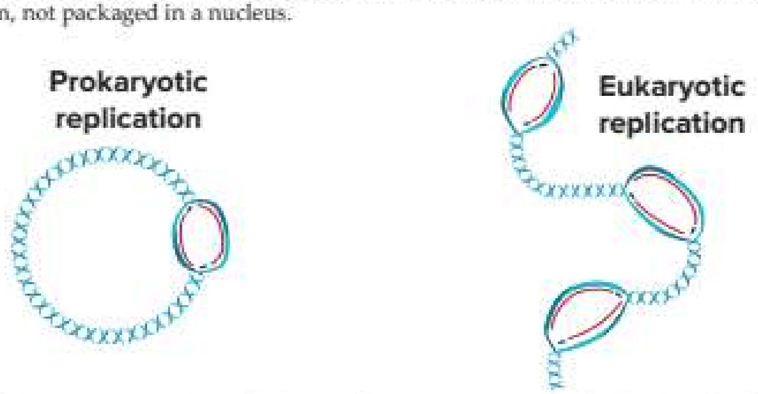

Figure 11 Eukaryotes have many origins of replication. Bacteria have one origin of replication, with the DNA replicating in both directions when it unzips.

Check Your Progress

Summary

- The enzymes DNA helicase, RNA primase, DNA polymerase, and DNA ligase are involved in DNA replication.
- The leading strand is synthesized continuously, but the lagging strand is synthesized discontinuously, forming Okazaki fragments.
- Prokaryotic DNA opens at a single origin of replication, whereas eukaryotic DNA has multiple areas of replication.

Demonstrate Understanding

1. **Indicate** the sequence of the template strand if a nontemplate strand has the sequence 5′ ATGGGGCGC 3′.
2. **Describe** the role of DNA helicase, DNA polymerase, and DNA ligase.
3. **Diagram** the way leading and lagging strands are synthesized.
4. **Explain** why DNA replication is more complex in eukaryotes than in bacteria.

Explain Your Thinking

5. **MATH Connection** If *E. coli* bacteria synthesize DNA at a rate of 100,000 nucleotides per min and it takes 30 min to replicate the DNA, how many base pairs are in an *E. coli* chromosome?

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LESSON 3
DNA, RNA, AND PROTEIN

FOCUS QUESTION

How is DNA and RNA involved in transcription and translation?

Central Dogma

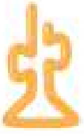
One of the important features of DNA that remained unresolved beyond the work of Watson and Crick was how DNA served as a genetic code for the synthesis of proteins. Recall that proteins function as structural building blocks for the cells and as enzymes.

Geneticists now accept that the basic mechanism of reading and expressing genes is from DNA to RNA to protein. This chain of events occurs in all living things—from bacteria to humans. Scientists refer to this mechanism as the central dogma of biology: DNA codes for RNA, which guides the synthesis of proteins.

Types of RNA

RNA is a nucleic acid that is similar to DNA. However, **RNA** contains the sugar ribose, the base uracil replaces thymine, and usually is single stranded. **Table 2** compares the structures and functions of the three major types of RNA found in living cells.

Table 2 Comparison of Three Types of RNA

Name	mRNA	rRNA	tRNA
Function	Carries genetic information from DNA in the nucleus to direct protein synthesis in the cytoplasm	Associates with protein to form the ribosome	Transports amino acids to the ribosome
Example			

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Applying Practices: Transcription and Translation

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.

Messenger RNA (mRNA) molecules are long strands of RNA nucleotides that are formed complementary to one strand of DNA. They travel from the nucleus to the ribosome to direct the synthesis of a specific protein. **Ribosomal RNA** (rRNA) is the type of RNA that associates with proteins to form ribosomes in the cytoplasm. The third type of RNA, **transfer RNA** (tRNA) are smaller segments of RNA nucleotides that transport amino acids to the ribosome.

Transcription

The first step of the central dogma involves the synthesis of mRNA from DNA in a process called **transcription** (trans KRIHP shun). Through transcription, the DNA code is transferred from a strand of DNA to mRNA in the nucleus. The mRNA then can take the code into the cytoplasm for protein synthesis. Follow along with the process of transcription in **Figure 12**. The DNA is unzipped in the nucleus and **RNA polymerase,** an enzyme that regulates RNA synthesis, binds to a specific section where an mRNA will be synthesized. As the DNA strand unwinds, the RNA polymerase initiates mRNA synthesis and moves along one of the DNA strands in the 3′ to 5′ direction. The strand of DNA that is read by RNA polymerase is called the template strand, and mRNA is synthesized as a complement to the DNA nucleotides. The DNA strand not used as the template strand is called the nontemplate strand. The mRNA transcript is manufactured in a 5′ to 3′ direction, adding each new RNA nucleotide to the 3′ end. Uracil is incorporated instead of thymine as the mRNA molecule is made. Eventually, the mRNA is released, and the RNA polymerase detaches from the DNA. The new mRNA then moves out of the nucleus through nuclear pores into the cytoplasm.

Get It?

Explain the direction in which the mRNA transcript is manufactured.

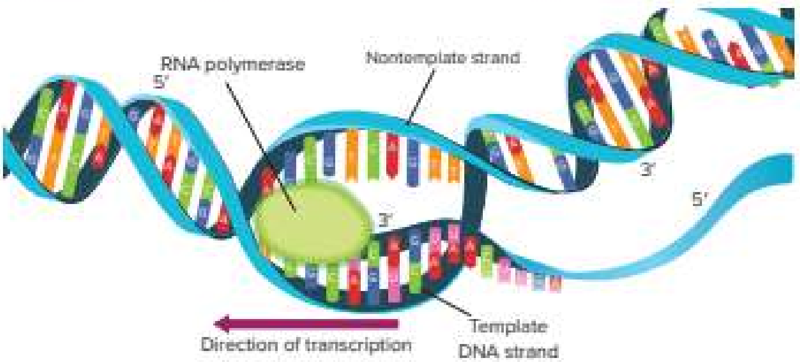


Figure 12 RNA is grown in the 5′ to 3′ direction.
Identify *which enzyme adds nucleotides to the growing RNA.*

CCC CROSSCUTTING CONCEPT

Structure and Function Our knowledge of protein synthesis has been gathered through extensive ongoing biochemical research. The evidence obtained from this research is the source of the information presented in this lesson. Use this evidence to create a chart or table summarizing the functions of the main cellular structures involved in protein synthesis.

ACADEMIC VOCABULARY

transfer
to pass from one thing or place to another
The process of transcription transfers the DNA code to mRNA in the nucleus.

RNA processing

When scientists compared the coding region of the DNA with the mRNA that ultimately coded for a protein, they found that the mRNA code is significantly shorter than the DNA code. Upon closer examination, they discovered that the code on the DNA is interrupted periodically by sequences of code that are not found in the final mRNA. These sequences are called intervening sequences, or **introns.** The coding sequences that remain in the final mRNA are called **exons.**

In eukaryotes, the original mRNA made in the nucleus is sometimes called pre-mRNA. The pre-mRNA contains all of the DNA code. Before the pre-mRNA leaves the nucleus, the introns are removed from it, leaving the sequences contained in the exons. Other processing of the pre-mRNA that occurs includes adding a protective cap on the 5′ end and adding a tail of many adenine nucleotides, called the poly-A tail, to the 3′ end of the mRNA.

Research shows that the 5′ end cap aids in ribosome recognition, while the 3′ end poly-A tail stabilizes the mRNA. The 3′ end poly-A tail also prevents mRNA degradation in the cytoplasm, and allows the mRNA to be exported from the nucleus. The mRNA that reaches the ribosome has been processed.

Get It?
Summarize how pre-mRNA is changed during RNA processing.

The Code

Biologists began to hypothesize that the instructions for protein synthesis are encoded in the DNA. They recognized that the only way the DNA varied among organisms was in the sequence of the bases and therefore the instructions for forming species' characteristics are carried in DNA. Scientists knew that 20 amino acids were used to make proteins in living things, so they knew that the DNA must somehow provide at least 20 different codes.

MATH Connection The hypothesis for how the DNA bases formed the code is based on both math and logic. Consider that if each base coded for a single amino acid, then the four bases could code for only four amino acids. If each pair of bases coded for one amino acid, then the four bases could only code for 16 (4×4 or 4^2) amino acids. However, if a group of three bases coded for one amino acid, there would be 64 ($4 \times 4 \times 4$ or 4^3) possible codes. This provides many more than the 20 codes needed for the 20 amino acids, but is the smallest possible combination of bases to provide enough codes for the amino acids.

This reasoning meant that the code was not contained in the base pairs themselves, but must run along a single strand of the DNA. Experiments performed during the 1960s demonstrated that the DNA code was indeed a three-base code. The three-base code in DNA or mRNA is called a **codon.** Each of the three bases of a codon in the DNA is transcribed into the mRNA code.

Figure 13 shows a "dictionary" of the genetic code. This code is often called universal and it is common to almost all living things. Notice that all but three codons are specific for an amino acid; these three are stop codons. Codon AUG codes for the amino acid methionine and also functions as the start codon.

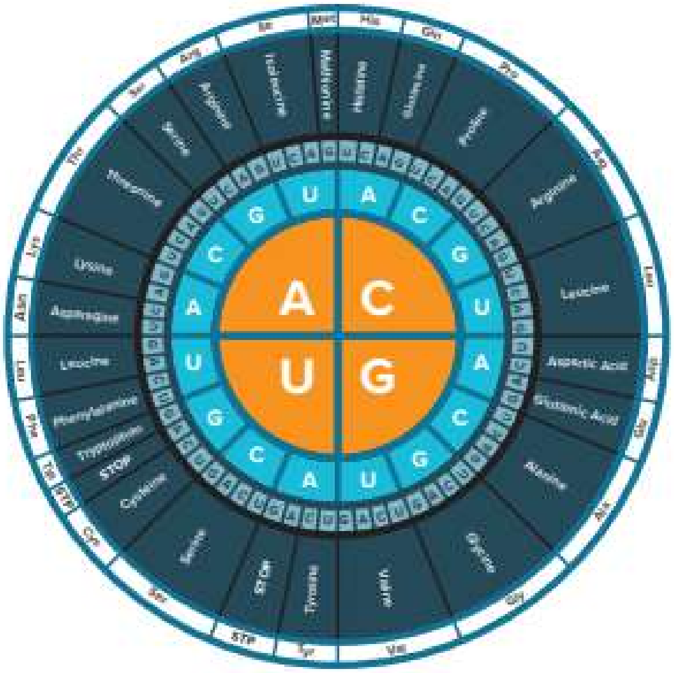


Figure 13 This "dictionary" of the genetic code is helpful for knowing which codons code for which amino acids.

Translation

Once the mRNA is synthesized and processed, it moves to the ribosome. In eukaryotes, this means the mRNA must leave the nucleus and enter the cytoplasm. Once in the cytoplasm, the 5′ end of the mRNA connects to the ribosome. This is where the code is read and translated to make a protein through a process called **translation.** Follow along in **Figure 14** on the next page as you learn about translation.

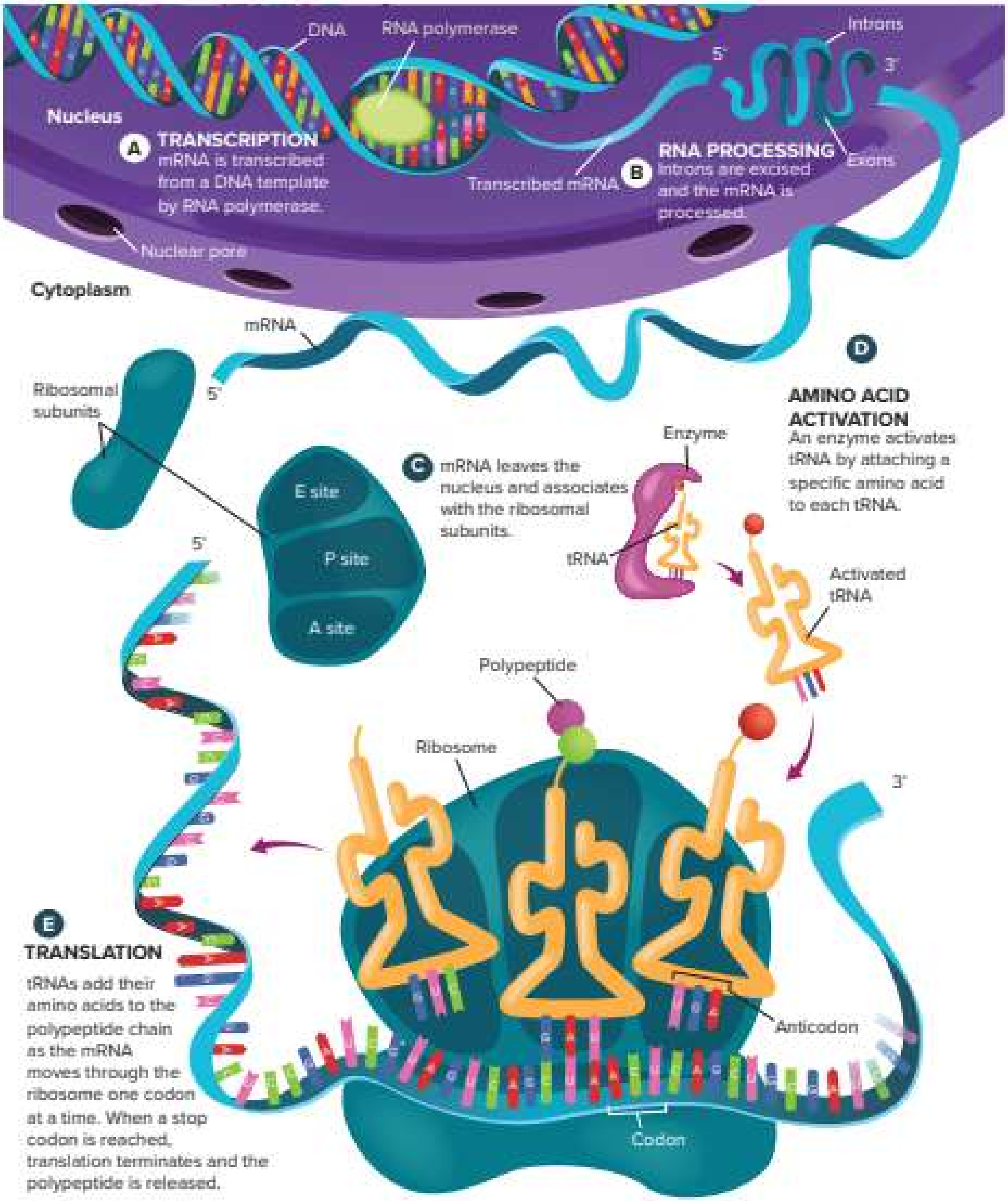
In translation, tRNA molecules act as the interpreters of the mRNA codon sequence. The tRNA is folded into a cloverleaf shape and is activated by an enzyme that attaches a specific amino acid to the 3′ end. At the middle of the folded strand, there is a three-base coding sequence called the **anticodon.** Each anticodon is complementary to a codon on the mRNA. Though the code in DNA and RNA is read 5′ to 3′, the anticodon is read 3′ to 5′.

Get It?

Explain how the processes of transcription and translation are essential for life.

Figure 14 Visualizing Transcription and Translation

Transcription takes place in the nucleus. Translation occurs in the cytoplasm and results in the formation of polypeptides.



The role of the ribosome

The ribosome consists of two subunits, as shown in **Figure 14**. These subunits are not associated when they are not involved in protein translation. When the mRNA leaves the nucleus, the two parts of the ribosome come together and attach to the mRNA to complete the ribosome. Once the mRNA is associated with the ribosome, a tRNA with the anticodon CAU carrying a methionine will move in and bind to the mRNA start codon—AUG—on the 5′ end of the mRNA. The ribosome structure has a groove, called the P site, where the tRNA that is complementary to the mRNA moves in.

A second tRNA moves into a second groove in the ribosome, called the A site, and corresponds to the next codon of the mRNA. The next codon is UUU, so a tRNA with the anticodon AAA moves in, carrying the amino acid phenylalanine.

Part of the rRNA in the ribosome now acts as an enzyme catalyzing the formation of a bond between the new amino acid in the A site and the amino acid in the P site. As the two amino acids join, the tRNA in the P site is released to the third site, called the E site, where it exits the ribosome. The ribosome then moves so the tRNA found in the A site is shifted to the P site, as shown in **Figure 14.** Now a new tRNA will enter the A site, complementing the next codon on the mRNA.

This process will continue adding and linking amino acids in the sequence determined by the mRNA. The ribosome continues to move along until the A site contains a stop codon. The stop codon signals the end of protein synthesis and does not complement any tRNA. Proteins called release factors cause the mRNA to be released from the last tRNA and the ribosome subunits to disassemble, ending protein synthesis.

One Gene—One Enzyme

Once scientists learned how DNA works as a code, they needed to learn the relationships between the genes and the proteins for which they coded. Experiments on the mold *Neurospora* were the first to demonstrate the relationship between genes and enzymes. In the 1940s, George Beadle and Edward Tatum provided evidence that a gene can code for an enzyme. They studied mold spores that were mutated by exposure to X-rays.

Normally, *Neurospora*, a kind of mold, can grow on an artificial medium that provides no amino acids, called minimal medium. Complete medium provides all the amino acids that *Neurospora* needs to function. Beadle and Tatum used this information as they designed their investigation.

CCC CROSSCUTTING CONCEPTS

Cause and Effect Study the illustrations in Figures 13 and 14. As an example, imagine that a polypeptide being synthesized in the ribosome requires the amino acid alanine. Use the evidence presented in this lesson to predict the possible anticodons on the tRNA for which such a segment of tRNA could move into site A of the ribosome. Write an explanation for your prediction.

STUDY TIP

Flowchart Draw a flowchart that connects the processes of DNA replication, transcription, and translation.

Examine **Figure 15** to follow along with Beadle and Tatum's experiment. In the experiment, the spores were exposed to X-rays and grown on a complete medium. To test for a mutated spore, the scientists grew spores on a minimal medium. When a spore was unable to grow on the minimal medium, the mutant was tested to see what amino acid it lacked. When the mutant spore type grew on a minimal medium with a supplement such as arginine, Beadle and Tatum hypothesized that the mutant was missing the enzyme needed to synthesize arginine. Beadle and Tatum came up with what is known as the "one gene–one enzyme" hypothesis. Further research built upon the work of Beadle and Tatum and today, because we know that polypeptides make up enzymes, their hypothesis has been modified slightly to refer to the fact that one gene codes for one polypeptide.

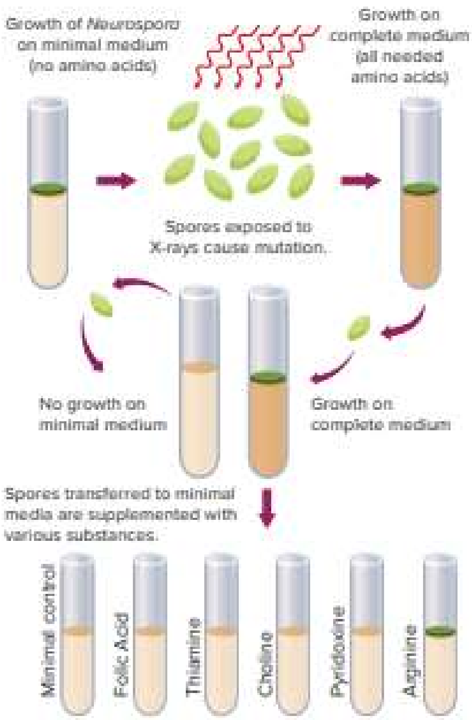


Figure 15 The Beadle and Tatum experiment showed that a gene codes for an enzyme. We now know that a gene codes for a polypeptide.

Check Your Progress

Summary

- Three major types of RNA are involved in protein synthesis: mRNA, tRNA, and rRNA.
- The synthesis of the mRNA from the template DNA is called transcription.
- Translation is the process through which the mRNA attaches to the ribosome and a protein is assembled.
- In eukaryotes, mRNA contains introns that are excised before leaving the nucleus. A cap and poly-A tail are added to the mRNA.

Demonstrate Understanding

1. **Summarize** the process by which the DNA code results in the production of a protein.
2. **Describe** the function of each of the following in protein synthesis: rRNA, mRNA, and tRNA.
3. **Explain** why scientists concluded that the instructions for species characteristics were carried in DNA.
4. **Explain** the role of RNA polymerase in mRNA synthesis.
5. **Conclude** why Beadle and Tatum's "one gene, one enzyme" hypothesis has been modified since they presented it in the 1940s.

Explain Your Thinking

6. **MATH Connection** If the genetic code used four bases as a code instead of three, how many code units could be encoded?

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LESSON 4

GENE REGULATION AND MUTATION

FOCUS QUESTION

How do prokaryotes and eukaryotes regulate their genes?

Prokaryote Gene Regulation

Gene regulation is the ability of an organism to control which genes are transcribed in response to the environment. In prokaryotes, an operon often controls the transcription of genes in response to changes in the environment. An **operon** is a section of DNA that contains the genes for the proteins needed for a specific metabolic pathway. The parts of an operon include an operator, promoter, regulatory gene, and the genes coding for proteins. The operator is a segment of DNA that acts as an on/off switch for transcription. A second segment of DNA, called the promoter, is where the RNA polymerase first binds to the DNA. The bacteria *Escherichia coli* (*E. coli*) respond to tryptophan (an amino acid) and lactose (a sugar) through two operons.

The *trp* operon

In bacteria, tryptophan synthesis occurs in a series of five steps. Each step is catalyzed by a specific enzyme. The five genes that code for these enzymes are clustered together on the bacterial chromosome with a group of DNA, called the tryptophan (trp) operon, which controls whether or not these genes undergo transcription.

The *trp* operon is referred to as a repressible operon because transcription of the five enzyme genes normally is repressed, or turned off. When tryptophan is present in the cell's environment, the cell has no need to synthesize it and the *trp* repressor gene turns off, or represses, the transcription process by making a repressor protein, as shown in **Figure 16** on the next page. When this repressor protein binds to the operator, it prohibits the synthesis of tryptophan.

When tryptophan levels are low, the repressor is not bound to tryptophan and is inactive. The RNA polymerase is able to bind to the operator, turning on transcription of the five enzyme genes. This enables the synthesis of tryptophan by the cell. Notice the location of the repressor protein in **Figure 16** when the operon is turned off and on.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Applying Practices: Transcription and Translation

HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occuring during replication, and/or (3) mutations caused by environmental factors.

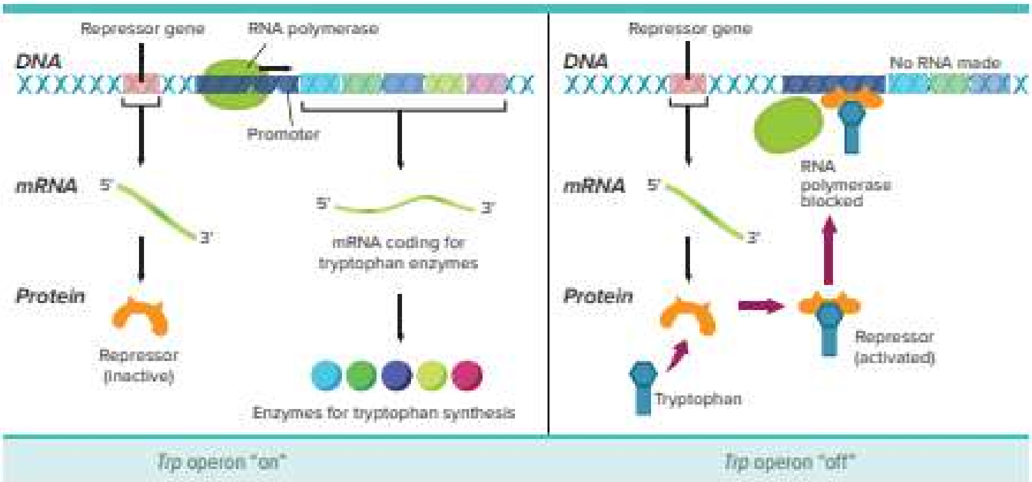


Figure 16 The *trp* operon is an example of the gene expression of repressible enzymes.

The *lac* operon

When lactose is present in the cell, *E. coli* makes enzymes that enable it to use lactose as an energy source. The lactose (*lac*) operon, illustrated in **Figure 17**, contains a promoter, an operator, a regulatory gene, and three enzyme genes that control lactose digestion. In the *lac* operon, the regulatory gene makes a repressor protein that binds to the operator in the promoter sequence and prevents the transcription of the enzyme genes. When a molecule called an inducer is present, the inducer binds to the repressor and inactivates it. In the *lac* operon, the inducer is allolactose, a molecule that is present in food that contains lactose. Thus, when lactose is present, the allolactose binds to the repressor and inactivates it. With the repressor inactivated, RNA polymerase then can bind to the promoter and begin transcription. The *lac* operon is called an inducible operon because transcription is turned on by an inducer.

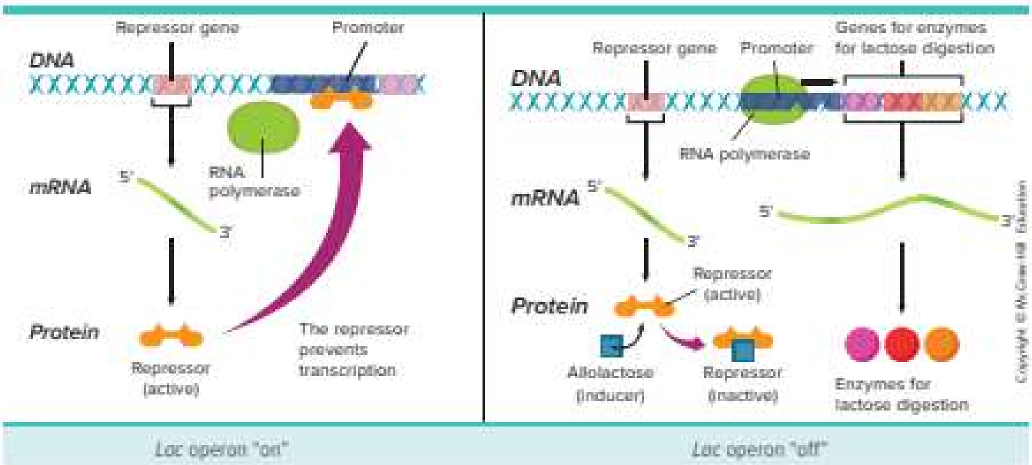


Figure 17 The *lac* operon is an example of the gene expression of inducible enzymes.

Eukaryotic Gene Regulation

All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Eukaryotic cells must control what genes are expressed at different times in the organism's lifetime. In eukaryotic cells, many genes interact with one another, requiring more elements than a single promoter and operator for a set of genes. The organization and structure of eukaryotic cells is more complex than in prokaryotic cells, increasing the complexity of the control system.

Controlling transcription

One way that eukaryotes control gene expression is through proteins called transcription factors. Transcription factors ensure that a gene is used at the right time and that proteins are made in the right amounts. There are two main sets of transcription factors. One set forms complexes that guide and stabilize the binding of the RNA polymerase to a promoter. The other set includes regulatory proteins that help control the rate of transcription. For instance, proteins called activators fold DNA so that enhancer sites are close to the complex and increase the rate of gene transcription. Repressor proteins also bind to specific sites on the DNA and prevent the binding of activators. The complex structure of eukaryotic DNA also regulates transcription. Recall that eukaryotic DNA is wrapped around histones to form nucleosomes. This structure provides some inhibition of transcription, although regulatory proteins and RNA polymerase still can activate specific genes even when they are packaged in the nucleosome.

Hox genes

Gene regulation is crucial as multicellular eukaryotes develop from a single cell called a zygote. The zygote undergoes mitosis, producing all the different kinds of specialized cells in the organism through the process of differentiation. One group of genes that controls differentiation has been discovered. These genes, called homeobox genes, are important for determining the body plan of an organism. They code for transcription factors and are active in zones of the embryo in the same order as the genes on the chromosome. For example, the colored regions of the fly and fly embryo in **Figure 18** correspond to the colored genes on the piece of DNA in the figure. One group of homeobox genes, called the Hox genes, helps determine the development of embryonic regions along the anterior-posterior axis. A mutation or the loss of a segment in one of these genes can affect the order of structures along this axis. For example, one specific mutation in the Hox genes of fruit flies results in flies with legs growing where their antennae should be. Scientists study these flies to understand more about how genes control an organism's body plan. Similar clusters of Hox genes that control body plans have been found in all animals.

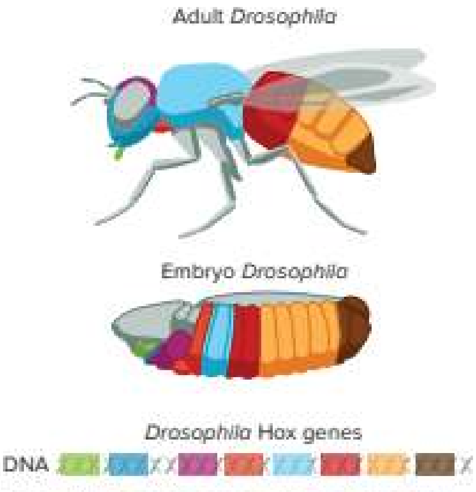


Figure 18 Hox genes are responsible for the general body pattern of most animals. Notice that the order of the genes is the same as the order of the body sections the genes control.

RNA interference

Another method of eukaryotic gene regulation is RNA interference (RNAi). Small pieces of double-stranded RNA in the cytoplasm of the cell are cut by an enzyme called dicer. The resulting double-stranded segments are called small interfering RNA. They bind to a protein complex that degrades one strand of the RNA. The resulting single-stranded small interfering RNA and protein complex bind to sequence-specific sections of mRNA in the cytoplasm, causing the mRNA in this region to be cut and thus preventing its translation. **Figure 19** shows the single-stranded small interfering RNA and protein complex binding to the mRNA. Research and clinical trials are being conducted to investigate the possibility of using RNAi to treat cancer, diabetes, and other diseases.

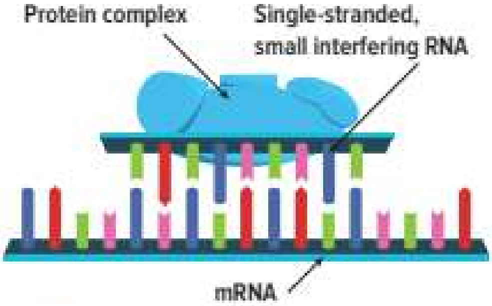


Figure 19 RNA interference can stop the mRNA from translating its message.
Describe *how the RNA-protein complex prevents the translation of the mRNA.*

Get It?
Explain how RNA interference can regulate eukaryotic gene expression.

Mutations

Just as you might make a mistake when typing, cells sometimes make mistakes during replication. These mistakes are rare, and the cell has mechanisms that can repair some damage. Usually DNA replication conserves the genetic information in the DNA molecules, and allows it to be transmitted without any changes. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in a permanent change, called a **mutation,** in a cell's DNA. Some mutations are sources of genetic variation. However, mistakes during replication can impact personal health.

Recall that one inheritance pattern that Mendel studied was round and wrinkled pea seeds. It is now known that the wrinkled phenotype is associated with the absence of an enzyme that influences the shape of starch molecules in the seeds. Because the mutation in the gene causes a change in the protein that is made, the enzyme is nonfunctional.

CCC CROSSCUTTING CONCEPT
Cause and Effect Use evidence from this lesson or from the Internet and other sources to prepare a brief presentation supporting or refuting the following statement: Mutations have harmful effects on the health of an individual organism.

ACADEMIC VOCABULARY
substitution
the act of replacing one thing with another
The substitution of adenine for guanine in the DNA caused a dysfunctional protein.

Types of mutations

Mutations in an organism's DNA sequence may or may not result in phenotypic change. Mutations can range from changes in a single base pair in the coding sequence of DNA to the deletions of large pieces of chromosomes. Point mutations involve a chemical change in just one base pair and can be enough to cause a genetic disorder. A point mutation in which one base is exchanged for another is called a substitution. Sometimes, a point mutation does not change the amino acid coded for but most substitutions are missense mutations, in which the DNA code is altered so that it codes for the wrong amino acid. Other substitutions, called nonsense mutations, change the codon for an amino acid to a stop codon. Nonsense mutations cause translation to terminate early. Nearly all nonsense mutations lead to proteins that cannot function normally.

Another type of mutation involves the gain or loss of a single nucleotide in the DNA sequence. Insertions are additions of a nucleotide to the DNA sequence; deletions are the loss of a nucleotide. Both of these types of mutations change the multiples of three bases from the point of the insertion or deletion. These are called frameshift mutations because they change the "frame" of the amino acid sequence. **Table 3** illustrates the effect of these mutations on the DNA sequence, and describes how these mutations can affect individuals.

Sometimes mutations are associated with diseases and disorders. One example is alkaptonuria. Individuals with this disorder have a mutation in their DNA coding for an enzyme involved in digesting the amino acid phenylalanine. This mutation results in the black colored homogentisic acid that discolors the urine. Studies have shown that patients with alkaptonuria have a high occurrence of frameshift mutations and missense mutations in a specific region of their DNA. **Table 3,** on the next page, lists more examples of diseases associated with mutations.

Large portions of DNA can also be involved in a mutation. A piece of an individual chromosome containing one or more genes can be deleted or moved to a different location on the chromosome, or even to a different chromosome. Such rearrangements often have drastic effects on the expression of these genes.

HEALTH Connection In 1991, a new kind of mutation was discovered that involves an increase in the number of copies of repeated codons, called tandem repeats. The increase in repeated sequences seems to be involved in a number of inherited diseases and disorders. The first known example was fragile X syndrome, which results in a number of mental and behavioral impairments. Near the end of a normal X chromosome, there is a section of CGG codons that repeat about 30 times. Individuals with fragile X have CGG codons that repeat hundreds of times. The syndrome received its name because the repeated area on the tip of the X chromosomes appears as a fragile piece hanging off the X chromosome, as illustrated in **Figure 20**. Currently, the mechanism by which the repeats expand from one generation to the next is not known.

Figure 20 Fragile X syndrome is due to many extra repeated CGG units near the end of the X chromosome, making the lower tip of the X chromosome appear fragile.

Table 3 Mutations

Mutation Type	Analogy Sentence	Example of Associated Disease
Normal	THE BIG FAT CAT ATE THE WET RAT	
Missense (substitution) (wrong amino acid)	THE BIZ FAT CAT ATE THE WET RAT	Achondroplasia: improper development of cartilage on the ends of the long bones of arms and legs resulting in a form of dwarfism
Nonsense (substitution) (premature stop codon)	THE BIG RAT	Muscular dystrophy: progressive muscle disorder characterized by the progressive weakening of many muscles in the body
Deletion (causing frameshift)	THB IGF ATC ATA TET HEW ETR AT	Cystic fibrosis: characterized by abnormally thick mucus in the lungs, intestines, and pancreas
Insertion (causing frameshift)	THE BIG ZFA TCA TAT ETH EWE TRA	Crohn's disease: chronic inflammation of the intestinal tract, producing frequent diarrhea, abdominal pain, nausea, fever, and weight loss
Duplication	THE BIG FAT FAT CAT ATE THE WET RAT	Charcot-Marie-Tooth disease (type 1A): damage to peripheral nerves leading to weakness and atrophy of muscles in hands and lower legs
Expanding mutation (tandem repeats) **Generation 1** **Generation 2** **Generation 3**	THE BIG FAT CAT ATE THE WET RAT THE BIG FAT CAT CAT CAT ATE THE WET RAT THE BIG FAT CAT CAT CAT CAT CAT CAT ATE THE WET RAT	Huntington's disease: a progressive disease in which brain cells waste away, producing uncontrolled movements, emotional disturbances, and mental deterioration

Protein folding and stability

You might expect that large changes in the DNA code, such as frameshift mutations or changes in position, lead to genetic disorders. However, small changes like substitutions also can lead to genetic disorders. The change of one amino acid for another can change the sequence of amino acids in a protein enough to change both the folding and stability of the protein.

One example of a genetic disorder caused by a single point mutation is sickle-cell disease, as illustrated in **Figure 21**. In the case of sickle-cell disease, the codon for a glutamic acid (GAG) has been changed to the codon for a valine (GTG) in the protein. This change in amino acid sequence changes the structure of hemoglobin and is the cause of this disorder.

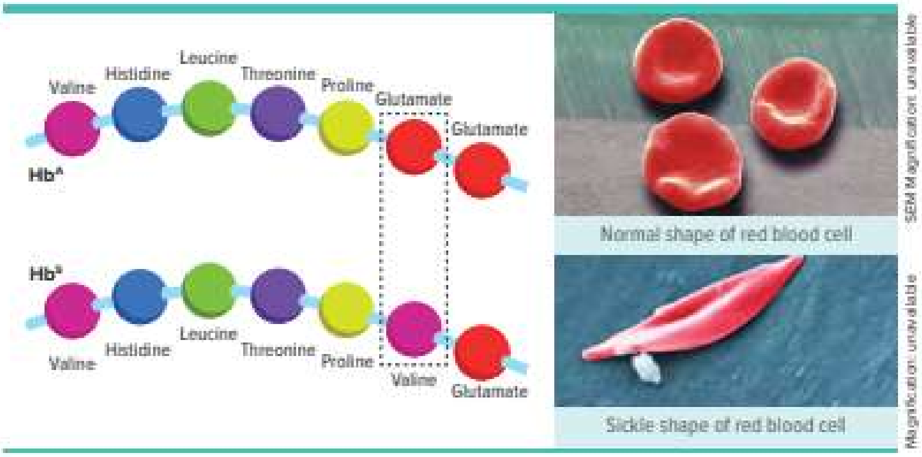


Figure 21 A single amino acid substitution can cause the genetic disorder sickle-cell disease.
Recall *what happens to the protein with the substituted amino acid.*

Hemoglobin is made of four polypeptide chains, which are two sets of two identical chains. The molecule also contains a large carbon-ring structure that binds iron, called the heme group. The substituted glutamic acid is located near the start of one set of chains, as shown in **Figure 21.**

Glutamic acid is a polar amino acid, but the valine that substitutes for it in sickle-cell disease is a nonpolar amino acid. Because of the charge difference in these two amino acids, the sickle-cell hemoglobin folds differently than normal hemoglobin. The abnormal folding of the protein caused by the mutation results in a change in the shape of the red blood cell. Compare the normal red blood cell and the red blood cell of an individual with sickle-cell disease, shown in **Figure 21.** Numerous other diseases involve problems with protein folding caused by mutations, including Alzheimer's disease, cystic fibrosis, diabetes, and cancer.

Get It?

Explain how a change in a single base pair can result in a change in the shape of a protein.

Causes of mutation

Some mutations, especially point mutations, can occur spontaneously. During replication, DNA polymerase sometimes adds the wrong nucleotides. Because the DNA polymerase has a proofreading function, the wrong nucleotide gets added only for one in one hundred thousand bases; it goes unfixed in less than one in one billion.

Certain environmental factors, such as chemicals and radiation also can damage DNA and cause mutations in genes. Substances which cause mutations are called **mutagens** (MYEW tuh junz). Many different chemicals have been classified as mutagens. Some of these chemicals affect DNA by changing the chemical structure of the bases. Often these changes cause bases to mispair, or bond with the wrong base. Other chemical mutagens have chemical structures that resemble nucleotides so closely that they can substitute for them. Once these imposter bases are incorporated into the DNA, it cannot replicate properly. This type of chemical has become useful medically, especially in the treatment of HIV—the virus that causes AIDS. Many drugs used to treat HIV and other viral infections mimic various nucleotides. Once the drug is incorporated in the viral DNA, the DNA cannot copy itself properly.

High-energy forms of radiation, such as X-rays and gamma rays, are highly mutagenic. When the radiation reaches the DNA, electrons absorb the energy. The electrons can escape their atom, leaving behind a free radical. Free radicals are charged atoms with unpaired electrons that react violently with other molecules, including DNA. Ultraviolet (UV) radiation from the Sun contains less energy than X-ray radiation and does not cause electrons to be ejected from the atoms. However, UV radiation can cause adjacent thymine bases to bind to each other, disrupting the structure of DNA, as shown in **Figure 22**. DNA with this structure disruption, or kink, is unable to replicate properly unless repaired.

Figure 22 Ultraviolet radiation can cause adjacent thymines to bind to each other instead of to their complementary bases, making the DNA "kink" and preventing replication.

WORD ORIGINS

mutagen

comes from the Latin word *mutare*, meaning *to change* and from the Greek word *genes*, meaning *born*

STEM CAREER Connection

Clinical Laboratory Geneticist

Are you interested in how mutations cause human diseases and disorders? Does the diagnosis of genetic disorders interest you? Clinical laboratory geneticists develop and use tests to diagnose genetic mutations and abnormalities.

Body-cell v. sex-cell mutation

When a mutation in a body cell, also called a somatic cell, escapes the repair mechanism, it becomes part of the genetic sequence in that cell and in future daughter cells. Somatic cell mutations are not passed on to the next generation. In some cases, the mutations do not cause problems for the cell. They could be sequences not used by the adult cell when the mutation occurred, the mutation might have occurred in an intron, or the mutation might not have changed the amino acid for which it coded. These mutations are called neutral mutations. When the mutation results in the production of an abnormal protein, the cell might not be able to perform its normal function, and cell death might occur. Recall that mutations in body cells that cause the cell cycle to be unregulated can lead to cancer. All of these effects are contained within the cells of the organism as long as only body cells are affected.

When mutations occur in sex cells, also called germ cells, the mutations are passed on to the organism's offspring and will be present in every cell of the offspring. In many cases, these mutations do not affect the function of cells in the organism, though they may result in phenotypic changes in offspring. When the mutations result in an abnormal protein in the sex cell, the offspring inherits the mutation. However, the offspring is not impacted when an abnormal protein is produced in an isolated body cell.

Check Your Progress

Summary

- Prokaryotic cells regulate their protein synthesis through a set of genes called operons.
- Eukaryotic cells regulate their protein synthesis using various transcription factors, eukaryotic nucleosome structures, and RNA interference.
- Mutations range from point mutations to the deletion or movement of large sections of a chromosome.
- Mutagens, such as chemicals and radiation, cause mutations.

Demonstrate Understanding

1. **Relate** gene regulation and mutations.
2. **Identify** the two main types of mutagens.
3. **Diagram** how adding lactose to a culture affects the *lac* operon of *E. coli*.
4. **Analyze** how a point mutation can affect the overall protein shape and function, using hemoglobin as an example.
5. **Compare and contrast** prokaryotic and eukaryotic gene regulation.

Explain Your Thinking

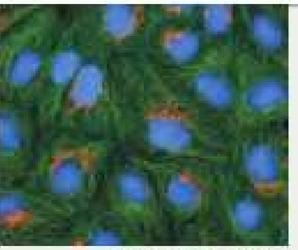
6. **Explain** why most mutations in eukaryotes are recessive.
7. **Hypothesize** why DNA replication has such accuracy.
8. **WRITING Connection** Write an article describing how Hox genes regulate development in animals.

LEARNSMART Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

SCIENCE & SOCIETY

A Question of Ethics

In 1951, an American woman named Henrietta Lacks died at the young age of 31 from cervical cancer. Without Lacks' permission, a surgeon who was treating her took cell samples from her cervix and gave them to cancer researchers. In the decades since then, Lacks' cells—called HeLa cells—have been the basis of many major medical discoveries and treatments. Even so, her cells were taken without consent, which has sparked a continuing conversation on the ethics of using humans in biomedical research.



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Henrietta Lacks' cells are used extensively in the fields of cellular and molecular biology.

HeLa cells

For decades, scientists were frustrated by their inability to keep human cells alive in cultures. But Lack's cells changed everything. From the time they were taken from her body, the cells reproduced every day, like clockwork—generation after generation. Scientists began to use the HeLa cell line in all manner of research. Today, trillions of HeLa cells are used in laboratories all over the world.

HeLa cells have made invaluable contributions to the field of medicine. Scientists have studied them to learn how cells age, which genes cause cancer, and which ones help prevent it. Research with these cells led to the development of polio and HPV (human papillomavirus) vaccines, as well as drugs to treat leukemia, hemophilia, Parkinson's disease, influenza, and other diseases and conditions.

Studying HeLa cells helped scientists learn how to fight viruses such as HIV (human immunodeficiency virus) and measles as well as the effects of chemotherapy, X-rays, and radiation on cells. HeLa cells also contributed to the Human Genome Project, cloning, and *in vitro* fertilization.

Ethical considerations

Taking Lacks' cells without her permission has led to an ongoing examination focused on the ethics of using a person's cells or DNA. Today, scientists debate whether researchers should have to obtain informed consent from people before their cells can be used in biomedical research.

ENGAGE IN ARGUMENT FROM EVIDENCE

Work with a group to construct an argument in favor of or against requiring researchers to get informed consent before using a person's cells in medical research. Debate the issue with a group that takes the opposite position.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 DNA: THE GENETIC MATERIAL

- Griffith's bacterial experiment and Avery's explanation first indicated that DNA is the genetic material.
- The Hershey-Chase experiment provided evidence that DNA is the genetic material of viruses.
- Chargaff's rule states that in DNA the amount of cytosine equals the amount of guanine and the amount of thymine equals the amount of adenine.
- The work of Watson, Crick, Franklin, and Wilkins provided evidence of the double-helix structure of DNA.

- double helix

Lesson 2 REPLICATION OF DNA

- The enzymes DNA helicase, RNA primase, DNA polymerase, and DNA ligase are involved in DNA replication.
- The leading strand is synthesized continuously, but the lagging strand is synthesized discontinuously, forming Okazaki fragments.
- Prokaryotic DNA opens at a single origin of replication, whereas eukaryotic DNA has multiple areas of replication.

- semiconservative replication
- DNA polymerase
- Okazaki fragment

Lesson 3 DNA, RNA, AND PROTEIN

- Three major types of RNA are involved in protein synthesis: mRNA, tRNA, and rRNA.
- The synthesis of the mRNA from the template DNA is called transcription.
- Translation is the process through which the mRNA attaches to the ribosome and a protein is assembled.
- In eukaryotes, mRNA contains introns that are excised before leaving the nucleus. A cap and poly-A tail are added to the mRNA.
- One gene codes for one polypeptide.

- RNA
- messenger RNA
- ribosomal RNA
- transfer RNA
- transcription
- RNA polymerase
- intron
- exon
- codon
- translation
- anticodon

Lesson 4 GENE REGULATION AND MUTATION

- Prokaryotic cells regulate their protein synthesis through a set of genes called operons.
- Eukaryotic cells regulate their protein synthesis using various transcription factors, eukaryotic nucleosome structures, and RNA interference.
- Mutations range from point mutations to the deletion or movement of large sections of a chromosome.
- Mutagens, such as chemicals and radiation, cause mutations.

- gene regulation
- operon
- mutation
- mutagen

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

Why do the rungs of the DNA ladder appear "broken?"

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will summarize your evidence and apply it to the project.

GO FURTHER

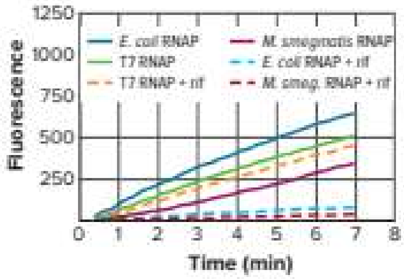
SEP Data Analysis Lab

How can a virus affect transcription?

To study RNA synthesis, a group of scientists used a fluorescent molecular beacon to trace molecules. This beacon becomes fluorescent when it binds to newly synthesized RNA. The fluorescence increases as the RNA chain lengthens. Thus, the beacon can be used to follow RNA synthesis.

Data and Observations In this experiment, scientists added the antibiotic rifampin (rif) to RNA polymerase from a virus (T7 RNAP), *Escherichia coli* (*E. coli* RNAP), and *Mycobacterium smegmatis* (*M. smegmatis* RNAP) and followed RNA synthesis.

Comparison of Fluorescence with the Addition of Rifampin



*Data obtained from: Marras, Salvatore A.E., et al. 2004. Real-time measurement of in vitro transcription. *Nucleic Acids Research* 32.9.e: 72.

CER Analyze and Interpret Data

1. **Describe** the relationship between fluorescence level and time in each experiment not exposed to rifampin.
2. **Claim, Evidence** Infer what the relationship is between fluorescence level and time in each case where rifampin was added.
3. **Reasoning** Interpret which organism's RNA synthesis is affected most by rifampin.

BIOTECHNOLOGY

ENCOUNTER THE PHENOMENON

What is this scientist putting into the tube?

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

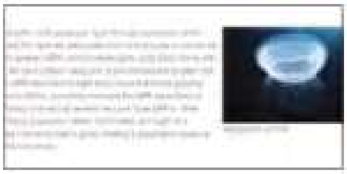
CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about what this scientist is putting into the tube. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.



LESSON 1: Explore & Explain: Genetic Engineering

LESSON 2: Explore & Explain: The Human Genome Project

LESSON 1
DNA TECHNOLOGY

FOCUS QUESTION

What is genetic engineering and why is it useful?

Genetic Engineering

By about 1970, researchers had discovered the structure of DNA and had determined the central dogma that information flowed from DNA to RNA and from RNA to proteins. However, scientists did not know much about the function of individual genes.

The situation changed when scientists began using **genetic engineering,** technology that involves manipulating the DNA of one organism in order to insert exogenous DNA (the DNA of another organism). For example, researchers have inserted a gene for a bioluminescent protein called green fluorescent protein (GFP) into various organisms. GFP, which is a substance naturally found in jellyfishes that live in the north Pacific Ocean, emits a green light when it is exposed to ultraviolet light. Organisms that have been genetically engineered to synthesize the DNA for GFP, such as the mosquito larvae shown in **Figure 1**, can be easily identified in the presence of ultraviolet light. The GFP DNA is attached to exogenous DNA to verify that the DNA has been inserted into the organism. These genetically engineered organisms are used in various processes, such as studying the expression of a particular gene, investigating a variety of cellular processes, studying the development of a certain disease, and selecting traits that might be beneficial to humans.

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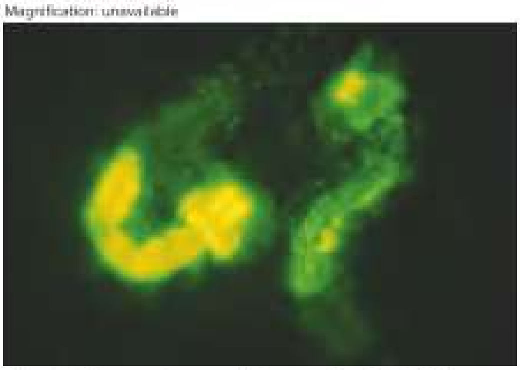


Figure 1 The gene for green fluorescent protein (GFP) was introduced into mosquito larvae so that researchers could verify that exogenous DNA was inserted.

Predict *how genetic engineering might be used in the future by the medical field.*

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

BioLab: Forensics: How can genetic engineering be used to solve a crime?
Plan and carry out an investigation to determine the proportion and quantity of DNA found at a "crime scene."

Quick Investigation: Model Restriction Enzymes
Use a model to determine the proportion and quantity of DNA fragments.

DNA Tools

Genetic engineering can be used to increase or decrease the expression of specific genes in selected organisms. It has many applications from human health to agriculture.

An organism's **genome** is the total DNA present in the nucleus of each cell. As you will learn in the next lesson, genomes, such as the human genome, can contain millions and millions of nucleotides. In order to study a specific gene, DNA tools can be used to manipulate DNA and to isolate genes from the rest of the genome.

Restriction enzymes

Some types of bacteria contain powerful defenses against viruses. These cells contain proteins called **restriction enzymes** that recognize and bind to specific DNA sequences and cleave the DNA within that sequence. A restriction enzyme, also called an endonuclease (en doh NEW klee ayz), cuts the viral DNA into fragments after it enters the bacteria. Since their discovery in the late 1960s, scientists have identified and isolated hundreds of restriction enzymes. Restriction enzymes are used as powerful tools for isolating specific genes or regions of the genome. When the restriction enzyme cleaves genomic DNA, it creates fragments of different sizes that are unique to every individual.

*Eco*RI

One restriction enzyme that is used widely by scientists is known as *Eco*RI. As illustrated in **Figure 2**, *Eco*RI (read as 'Eco R one') specifically cuts DNA containing the sequence GAATTC. The ends of the DNA fragments created by *Eco*RI are called sticky ends because they contain single-stranded DNA. The ability of some restriction enzymes to create fragments with sticky ends is important because these sticky ends can be joined together with other DNA fragments that have complementary sticky ends.

Get It?

Generalize how restriction enzymes are used.

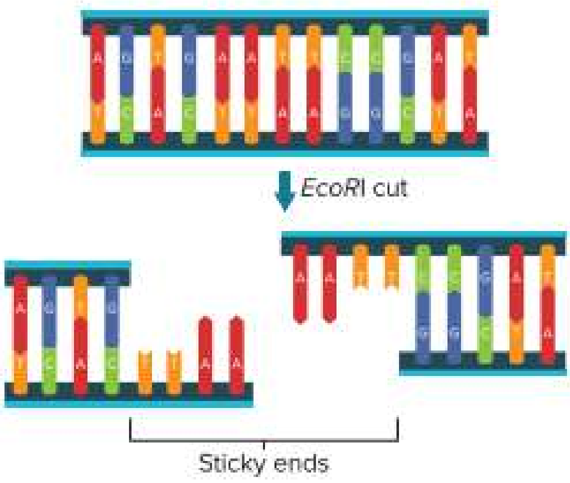


Figure 2 DNA containing the sequence GAATTC can be cut by the restriction enzyme *Eco*RI to produce sticky ends.

However, not all restriction enzymes create sticky ends. Some enzymes produce fragments containing blunt ends—created when the restriction enzyme cuts straight across both strands. Blunt ends do not have regions of single-stranded DNA and can join to any other DNA fragment with blunt ends.

Get It?
Differentiate between blunt ends and sticky ends and explain how each can be used.

Gel electrophoresis

PHYSICS Connection An electric current is used to separate DNA fragments according to the size of the fragments in a process called **gel electrophoresis. Figure 3** shows how the DNA fragments are loaded on the negatively charged end of a gel. When an electric current is applied, the DNA fragments move toward the positive end of the gel. The smaller fragments move faster than the larger ones. The unique pattern created based on the size of the DNA fragment can be compared to known DNA fragments for identification. Also, portions of the gel containing each band can be removed for further study.

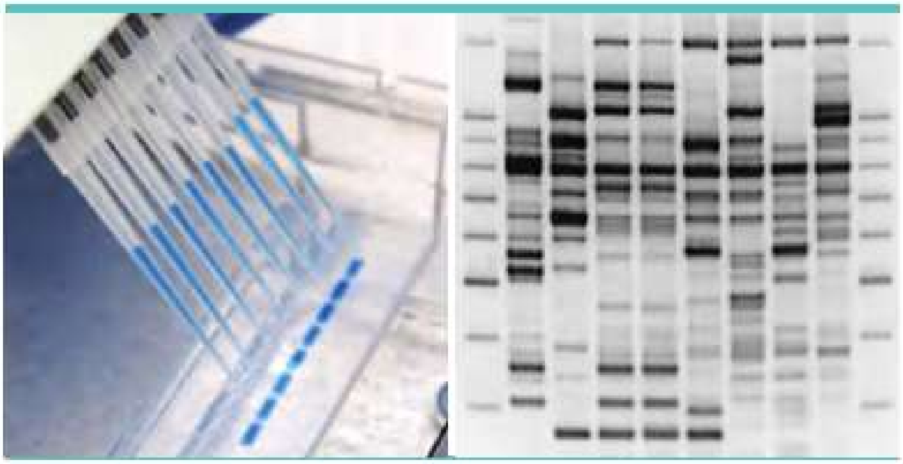


Figure 3 When the loaded gel is placed in an electrophoresis tank and the electric current is turned on, the DNA fragments separate.

Observe *carefully the DNA fragments shown in the image on the right.* **Predict** *which way the fragments were moving when the electric current was applied. Explain your prediction.*

CCC CROSSCUTTING CONCEPT

Science is a Human Endeavour Basic scientific research has increased our understanding of how DNA works. The knowledge gained from this research has been applied to problems that affect individuals and society. Using evidence from your textbook and other sources, prepare a news release about a relatively new DNA technology that has already influenced society or holds the potential for future breakthroughs.

ACADEMIC VOCABULARY

manipulate

to manage or utilize skillfully

Scientists use technology to manipulate genetic information in order to test scientific hypotheses.

Recombinant DNA Technology

When DNA fragments have been separated by gel electrophoresis, fragments of a specific size can be removed from the gel and combined with DNA fragments from another source. This newly generated DNA molecule, with DNA from different sources, is called **recombinant DNA.** Recombinant DNA technology has revolutionized the way scientists study DNA because it enables individual genes to be studied.

Large quantities of recombinant DNA molecules are needed in order to study them. A carrier, called a vector, transfers the recombinant DNA into a bacterial cell called the host cell. Plasmids and viruses are commonly used vectors. **Plasmids**—small, circular, double-stranded DNA molecules that occur naturally in bacteria and yeast cells—can be used as vectors because they can be cut with restriction enzymes. If a plasmid and a DNA fragment obtained from another genome have been cleaved by the same restriction enzyme, the ends of each DNA fragment will be complementary and can be combined, as shown in **Figure 4**. An enzyme normally used by cells in DNA repair and replication, called **DNA ligase,** joins the two DNA fragments chemically. Ligase joins DNA fragments that have sticky ends as well as those that have blunt ends.

Examine **Figure 4** again. Notice that the resulting circular DNA molecule contains the plasmid DNA and the DNA fragment isolated from another genome. This recombinant plasmid DNA molecule now can be inserted into a host cell so that large quantities of this type of recombinant DNA can be made.

Get It?
Relate restriction enzymes to recombinant DNA.

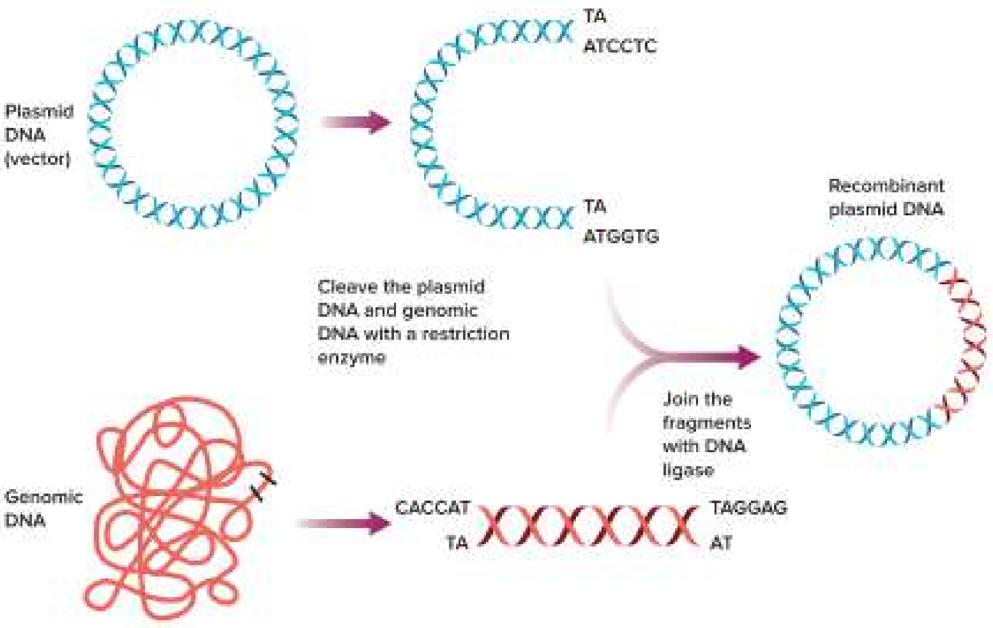


Figure 4 Recombinant DNA is created by joining together DNA from two different sources.

Gene cloning

To make a large quantity of recombinant plasmid DNA, bacterial cells are mixed with recombinant plasmid DNA. Some of the bacterial cells take up the recombinant plasmid DNA through a process called **transformation,** as shown in **Figure 5**. Bacterial cells can be transformed using electric pulsation or heat. Recall that all cells, including bacterial cells, have plasma membranes. A short electric pulse or a brief rise in temperature temporarily creates openings in the plasma membrane of the bacteria. These temporary openings allow small molecules, such as the recombinant plasmid DNA, to enter the bacterial cell. The bacterial cells make copies of the recombinant plasmid DNA during cell replication. Large numbers of genetically identical bacteria, each containing the inserted DNA molecules, can be produced through this process called **cloning.**

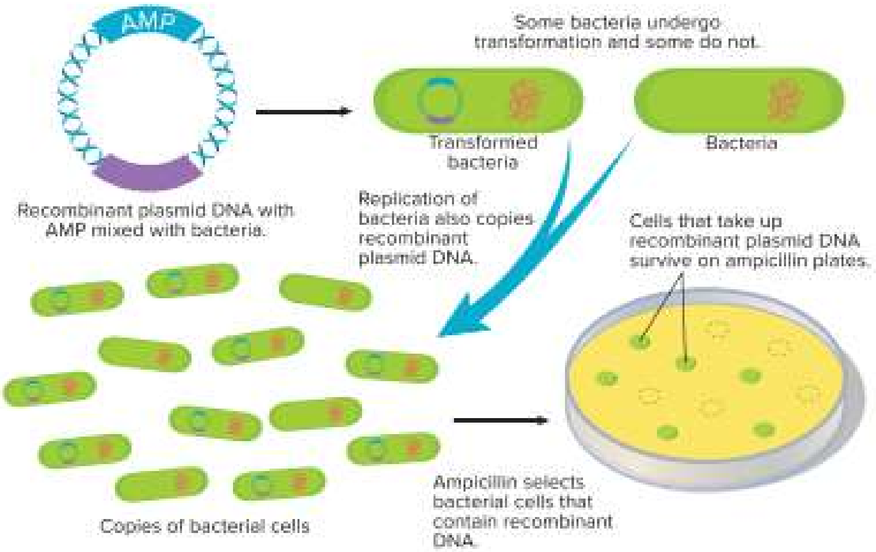


Figure 5 Clones containing copies of the recombinant DNA can be identified and used for further study when the bacterial cells that do not contain recombinant DNA die.

Recombinant plasmid DNA contains a gene that codes for resistance to an antibiotic such as ampicillin (AMP). Researchers use this gene to distinguish between bacterial cells that have taken up the recombinant plasmid DNA and those that have not. Notice in **Figure 5** that when the transformed bacterial cells are exposed to the specific antibiotic, only the bacterial cells that have the plasmid survive.

DNA sequencing

The sequence of the DNA nucleotides of most organisms is unknown. Knowing the sequence of an organism's DNA or of a cloned DNA fragment provides scientists with valuable information for further study. The sequence of a gene can be used to predict the function of the gene, to compare genes with similar sequences from other organisms, and to identify mutations or errors in the DNA sequence. Because the genomes of most organisms are made up of millions of nucleotides, the DNA molecules used for sequencing reactions first must be cut into smaller fragments using restriction enzymes.

Follow **Figure 6** to understand how DNA is sequenced. Scientists mix an unknown DNA fragment, DNA polymerase, and the four nucleotides–A, C, G, T–in a tube. A small amount of each nucleotide is tagged with a different color of fluorescent dye, which also modifies the structure of the nucleotide. Every time a modified fluorescent-tagged nucleotide is incorporated into the newly synthesized strand, the reaction stops. This produces DNA strands of different lengths. Then the tagged DNA fragments are separated by gel electrophoresis. The gel is then analyzed in a DNA sequencing machine that detects the color of each tagged nucleotide. The sequence of the original DNA template is determined from the order of the tagged fragments.

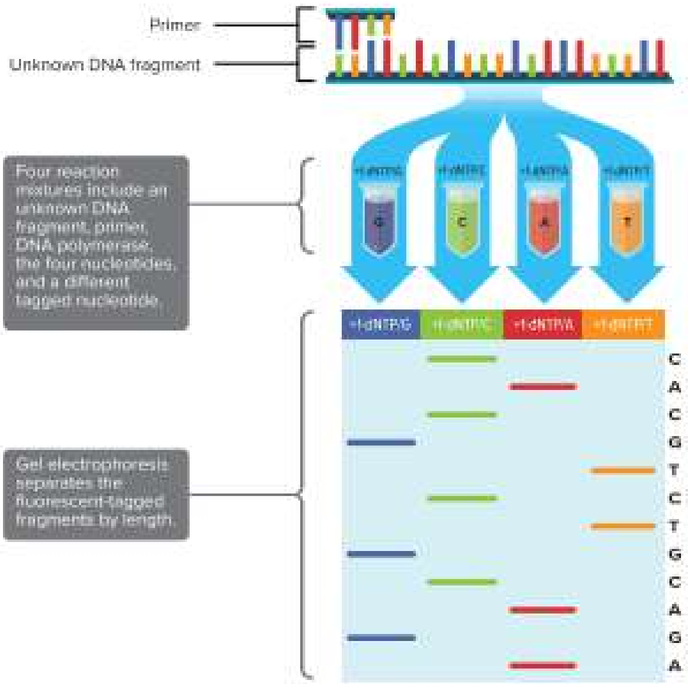


Figure 6 DNA can be sequenced using fluorescent-tagged nucleotides.

Describe *how the sequence of the original DNA template is determined.*

Polymerase chain reaction

Once the sequence of a DNA fragment is known, a technique called the **polymerase chain reaction** (PCR) can be used to make millions of copies of a specific region of the DNA fragment. PCR is extremely sensitive and can detect a single DNA molecule in a sample. PCR is useful because this single DNA molecule then can be copied, or amplified, numerous times to be used for DNA analysis.

PCR components PCR is performed by placing the DNA fragment to be copied, DNA polymerase, the four DNA nucleotides, and two short single-stranded pieces of DNA called primers in a tube. The primers are complementary to the ends of the DNA fragment that will be copied and are used as starting points for DNA synthesis. An automated instrument called a thermocycler is used to cycle the tube containing all of the components involved in PCR through various hot and cool temperatures.

Denaturation The first step in PCR is denaturation, as shown in **Figure 7**. Denaturation involves breaking bonds within the DNA molecules; it occurs when the thermocycler heats the tube to an extreme temperature. The heat separates the two strands of the template DNA fragment by breaking the hydrogen bonds between the base pairs. The double-stranded DNA molecule becomes two single-stranded DNA molecules.

Annealing When the thermocycler cools the tube, the annealing process begins. The primers in the mixture bind to each strand of the template DNA. Each primer is made to bind to one strand of the DNA fragment, as shown in **Figure 7**.

Extension Once the primers are bound, DNA polymerase incorporates the correct nucleotides between the two primers as occurs in DNA replication. Like DNA replication, for every one original double-stranded DNA fragment, two double-stranded DNA molecules are generated. This ends the first cycle of amplification. The two DNA strands will start a new cycle and serve as the new templates. This process of heating, cooling, and nucleotide incorporation is repeated 20 to 40 times, resulting in millions of copies of the original fragment. Because the separation of DNA strands requires heat, the DNA polymerase used in PCR has to be able to withstand high temperatures. This special DNA polymerase, called *Taq* polymerase, was isolated from a thermophilic, or heat-loving, bacterium such as those found living in the hot springs of Yellowstone National Park.

Because PCR can detect a single DNA molecule in a sample, it has become one of the most powerful tools used by scientists. PCR is not used only by researchers in laboratories, but also by forensic scientists to identify suspects and victims in crime investigations, and by doctors to detect infectious diseases, such as HIV.

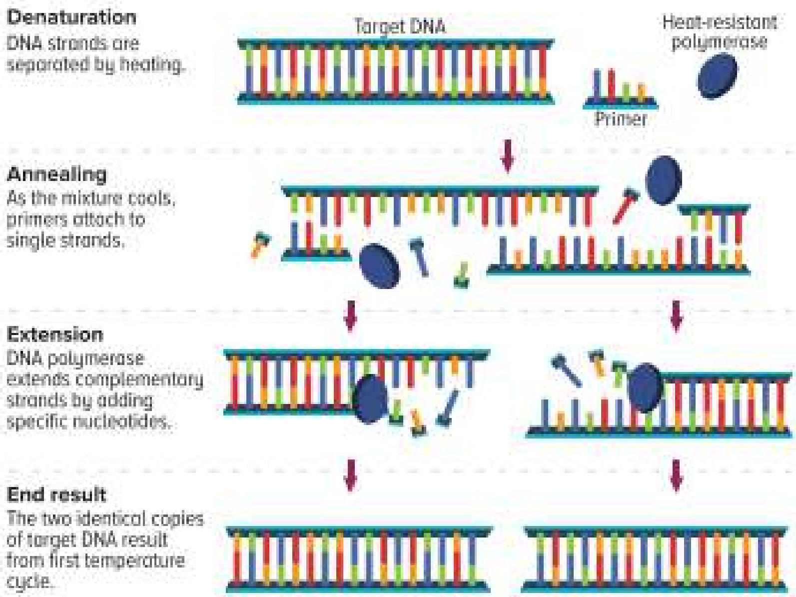


Figure 7 PCR is a biological version of a copy machine. During each PCR cycle, the reaction mixture is heated to separate the DNA strands and then cooled to allow primers to bind to complementary sequences. The DNA polymerase then adds nucleotides to form new DNA molecules.

Table 1 Genetic Engineering

Tool/Process	Function	Applications
Restriction enzymes Example: *EcoRI*	Cuts DNA strands into fragments	Used to create DNA fragments with sticky ends or blunt ends that can join with other DNA fragments
Gel electrophoresis	Separates DNA fragments by size	Used to study DNA fragments of various sizes
Recombinant DNA technology	Combines a DNA fragment with DNA from another source (exogenous DNA)	Used to create recombinant DNA to be used to study individual genes and genetically engineered organisms, and in the treatment of certain diseases
Gene cloning	Produces large numbers of identical recombinant DNA molecules	Used to create large amounts of recombinant DNA to be used in genetically engineered organisms
DNA sequencing	Identifies the DNA sequence of cloned recombinant DNA molecules for further study	Used to identify errors in the DNA sequence, to predict the function of a particular gene, and to compare to other genes with similar sequences from different organisms
Polymerase chain reaction (PCR)	Makes copies of specific regions of sequenced DNA	Used to copy DNA for any scientific investigation, including forensic analysis and medical testing

Genetic engineering uses powerful tools, summarized in **Table 1**, to study and manipulate DNA. Although researchers investigate many different problems, their experimental procedures often include cleavage by a restriction enzyme, isolation of fragments, combination with exogenous DNA, cloning or PCR, and identification of sequences.

Biotechnology

Biotechnology—the use of genetic engineering to find solutions to problems—makes it possible to produce organisms that contain individual genes from another organism. Recall that organisms such as the mosquito larvae shown in **Figure 1** have one or more genes from another organism. Such organisms are called **transgenic organisms.** Transgenic animals, plants, and bacteria are used for research, medical, and agricultural purposes.

Transgenic animals

Currently, most transgenic animals are produced for research. Mice, fruit flies, and the roundworm *Caenorhabditis elegans*, also called *C. elegans*, are used to study diseases and treatments. Some transgenic organisms have been produced to improve the food supply and human health. Transgenic goats have been engineered to secrete antithrombin III, a protein used to prevent human blood from clotting during surgery. Researchers are working to produce transgenic chickens and turkeys that are resistant to diseases. In the future, transgenic organisms might be used as a source of organs for transplants.

Transgenic plants

Figure 8 This researcher is examining cotton plant leaves. The leaf on the left has been genetically engineered to resist insect infestation.

Many species of plants have been genetically engineered to be more resistant to insect or viral pests. In 2014, about 181 million hectares grown by 18 million farmers in 28 countries were planted with transgenic crops. These crops included herbicide- and insecticide-resistant soybeans, corn, cotton, and canola. Scientists now are producing genetically engineered cotton, as shown in **Figure 8,** that resists insect infestation of the bolls. Researchers also are developing peanuts and soybeans that do not cause allergic reactions. Other crops are being grown commercially and being field tested. These crops include sweet-potato plants that are resistant to a virus that could kill most of the African harvest, rice plants with increased iron and vitamins that could decrease malnutrition in Asian countries, and a variety of plants that has been genetically engineered to survive extreme weather.

Transgenic bacteria

Insulin, growth hormones, and substances that dissolve blood clots are made by transgenic bacteria. Transgenic bacteria also clean up oil spills, decompose garbage, and slow the formation of ice crystals on crops to help prevent frost damage.

Check Your Progress

Summary

- Genetic engineering is used to produce organisms that are useful to humans.
- Recombinant DNA technology is used to study individual genes.
- DNA fragments can be separated using gel electrophoresis.
- Cloning can be used to produce genetically identical bacteria which contain recombinant DNA.
- The polymerase chain reaction (PCR) is used to make many copies of small DNA sequences.
- Transgenic organisms are being created to solve human problems.

Demonstrate Understanding

1. **Sequence** how recombinant DNA is made and manipulated.
2. **Explain** why some plasmids contain a gene for resistance to an antibiotic.
3. **Describe** and give examples of how genetic engineering and biotechnology can improve human health.
4. **Describe** three examples of transgenic organisms and explain how each is useful to humans.

Explain Your Thinking

5. **Evaluate** Several popular movies and books involve organisms produced by genetic engineering. Are these transgenic organisms a possibility? Why or why not?
6. **WRITING Connection** Why would a business synthesize and sell DNA? Who would their customers be? Write a list of possible uses for DNA that is synthesized in a laboratory.

LEARNSMART Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

LESSON 2
THE HUMAN GENOME

FOCUS QUESTION

Why does the Human Genome Project continue to be significant?

The Human Genome Project

Genomics, the study of an organism's genome, has become one of the most powerful strategies for identifying human genes and interpreting their functions. The "genomic era" began with the sequencing of the human genome. One of the biggest achievements in the last 20 years was the completion of the Human Genome Project, an international effort in which the goal was to determine the sequence of the approximately three billion nucleotides that make up human DNA, modeled in **Figure 9**, and to identify all of the human genes.

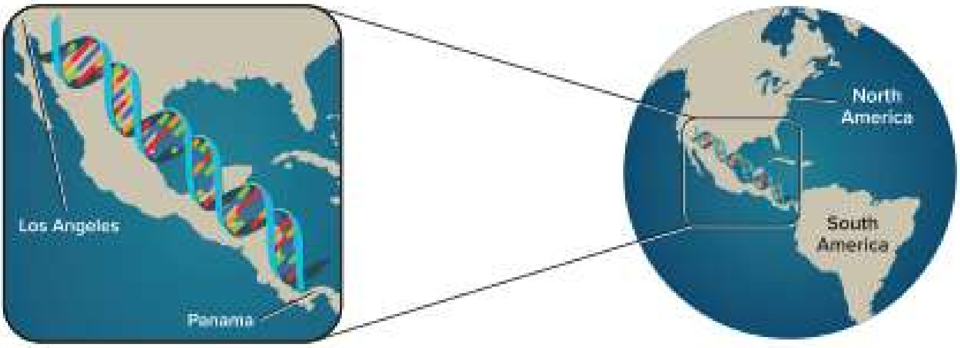


Figure 9 This image shows how far the nucleotides in the human genome would stretch if each of the approximately three billion nucleotides in human DNA were the size of the type on this page, and if all of the DNA in the human genome were fused together in one continuous line.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

BioLab: Forensics: Who did it?
Plan and carry out an investigation to determine how patterns of DNA are compared to a suspect's DNA.

Virtual Investigation: Gene Splicing
Use a model to determine the cause and effect of splicing an organism's genes.

The Human Genome Project started in 1990 and was 90 percent complete in February 2001. It was completed in April 2003. Upon completing the project, scientists planned out the next steps: determine what genes would code for specific proteins, understand the locations of genes related to inherited diseases, advance the field of medicine and treatment, and develop and train the next generation of molecular biologists.

Sequencing the genome

Human DNA is organized into 46 chromosomes (23 pairs). In order to determine one continuous human genome sequence, each of the 46 human chromosomes was cleaved, or cut into pieces. Several different restriction enzymes were used in order to produce fragments with overlapping sequences. These fragments were combined with vectors to create recombinant DNA, cloned to make many copies, and sequenced using automated sequencing machines. Computers then analyzed the overlapping regions to generate one continuous sequence.

Decoding the sequence of the human genome can be compared to reading a book that was printed in code. Imagine the genome as words in a book written without capitalization, punctuation, or breaks between words, sentences, or paragraphs. Suppose there are random strings of letters scattered between and within sentences. **Figure 10** illustrates how a page from such a book might look. In order to understand what is written, you have to decode the jumbled text. Similarly, scientists had to decode the genetic code in the human genome.

After sequencing the entire human genome, scientists observed that less than two percent of all of the nucleotides in the human genome code for all the proteins in the body. These nucleotides make up approximately 22,300 genes that code for proteins or are involved in regulatory or structural functions. The remaining more than 98% of the genome is filled with long stretches of repeated sequences that have no as-yet known function. These regions are called noncoding sequences.

Figure 10 The genetic information contained within the human genome has to be decoded in order to uncover important sequences.

Interpret *the text by decoding the jumbled sentences.*

Comparing genomes

Though the Human Genome Project is finished, analysis of the vast amount of data generated from this project will continue for many decades. To complete this huge task, researchers also have studied the genomes of many other organisms, including the fruit fly, the mouse, and *Escherichia coli*—a bacterium present in the human intestines. Studies in nonhuman organisms helped to develop the technology required to handle the large amounts of data produced by the Human Genome Project. These technologies help to analyze and interpret the functions of newly identified human genes.

Identifying genes

Now that the human genome is completely sequenced, the next step in the process is to identify the sections of the sequence that are genes and determine the functions of the genes. The functions of many of the genes in the human genome are still unknown. Researchers use techniques that integrate computer analysis and recombinant DNA technology to determine the function of these genes.

For organisms such as bacteria and yeast, whose genomes do not have large regions of noncoding DNA, researchers have identified genes by scanning the sequence for open reading frames (or ORFs, pronounced "orphs"). ORFs are stretches of DNA containing at least 100 codons that begin with a start codon and end with a stop codon. While these sequences might indicate a gene, they must be tested to determine if these sequences produce functioning proteins.

Recall that a codon is a group of three nucleotides that code for an amino acid. Researchers look for the start codon AUG and a stop codon such as UAA, UGA, or UAG. ORF analysis has been used to identify correctly over 90 percent of genes in yeast and bacteria. However, the identification of genes in more complex organisms such as humans requires more sophisticated computer programs called algorithms. These algorithms use information, such as the sequence of the genomes of other organisms, to identify human genes.

Get It?

Explain why identifying genes in bacterial genomes is less complex than identifying genes in the human genome.

Bioinformatics

The completion of the Human Genome Project and the sequencing of the genomes of other organisms have resulted in large amounts of data. Not only has this enormous amount of data required careful storage, organization, and indexing of sequence information, but it also has created a new field of study. This field of study, called **bioinformatics,** involves creating and maintaining databases of biological information. The field of bioinformatics draws on other disciplines—computer science, biology, mathematics, and engineering—to analyze and interpret the data.

The analysis of sequence information involves finding genes in DNA sequences of various organisms and developing methods to predict the structure and function of newly discovered proteins. Scientists also study the evolution of genes by grouping protein sequences into families of related sequences and comparing similar proteins from different organisms.

DNA Typing

You may have heard about DNA fingerprinting. The process is well-known because of the crime scene television shows where forensic scientists use it to identify suspects and victims, and to determine paternity. However, in forensics, the term DNA fingerprinting is inappropriate because forensic scientists also examine actual latent fingerprints. Forensic scientists prefer the term DNA typing or DNA analysis. **DNA typing** is the process of separating an individual's unique sequence of DNA fragments to observe distinct patterns.

Unlike the protein-coding regions of DNA that are almost identical among individuals, the long stretches of noncoding regions of DNA are unique to each individual. With the exception of identical twins, there is an extremely rare chance that two people in the world have the same stretches of noncoding regions of DNA. DNA typing analysis involves separating these DNA fragments using electrophoresis in order to observe the distinct patterns that are unique to every individual. Forensic scientists use DNA typing to identify suspects and victims in criminal cases, to determine paternity, and to identify soldiers killed in war.

Figure 11 People can be identified using the genetic information contained in blood, hair, semen, or skin.

DNA typing process

Samples obtained from humans, such as blood, hair, and saliva, shown in **Figure 11**, can be used by forensic scientists for DNA typing. DNA is extracted from any of these types of samples using chemicals. The polymerase chain reaction (PCR) is then used to amplify, or copy, the small amount of extracted DNA to create a larger sample for analysis.

Different markers used during electrophoresis allow the different segments of the amplified DNA to be analyzed. The results from the fragments are compared to DNA segments from known sources, such as victims and suspects in a criminal case, to identify similar fragment patterns. There is a high probability that the two DNA samples came from the same person if the two fragment patterns match. Since its development in England in 1984 by Alec Jeffreys, the technique of DNA typing has been used not only to identify and convict criminals but also to exonerate, or free, innocent people who had been wrongfully imprisoned. **Figure 12,** on the next page, provides a closer look at the history of genetic technology.

STEM CAREER Connection

Forensic Lab Technician

Do you prefer lab activities over classroom activities? Do you enjoy searching for clues to solve problems? Does a good murder mystery entertain you? You may be destined for a career as a forensic lab technician! Forensic lab technicians spend most of their time in a forensic laboratory and are responsible for the preparation and analysis of evidence in criminal and civil investigations.

STUDY TIP

BioJournal As you read about the human genome, list several beneficial uses of this information.

Figure 12

Discoveries in Genetics

Many studies in genetics have led to advances in biotechnology.

1 **1959** Down syndrome is the first chromosomal abnormality identified in humans.

2 **1972** Paul Berg creates the first recombinant DNA molecules.

3 **1977** Fred Sanger first sequences DNA and develops what is known as Sanger's method, in which colored dyes are used to identify the DNA bases.

4 **1983** Kary Mullis invents the polymerase chain reaction, for which he will be awarded the Nobel Prize in Chemistry in 1993.

5 **1990** The Human Genome Project, which begins an international effort to sequence the human genome, launches.

6 **2003** All 3 billion base pairs of the human genome is officially sequenced and completed.

7 **2005** Avian flu outbreaks in Asia step up efforts to create new vaccines.

8 **2010** The first synthetic cell is created at the J. Craig Venter Institute.

DNA Microarrays

Analyzing all the expressed genes from a given organism or a specific cell type can provide useful information for researchers. This analysis can be done using **DNA microarrays,** which are tiny microscope slides or silicon chips that are spotted with DNA fragments. DNA microarrays can contain a few genes, such as the genes that control the cell cycle, or they can include all of the genes of the human genome. Therefore, a large amount of information can be gathered and stored using one small slide or chip. DNA microarrays can help researchers determine whether the expression of certain genes is caused by genetic factors or environmental factors.

Get It?

Summarize the type of information that can be learned by analysis of a DNA microarray.

Follow the steps involved in carrying out the DNA microarray technique by analyzing the information in **Figure 13,** on the next page. mRNA from two different populations of cells is isolated, or purified, as illustrated in Step A of the figure. Then, an enzyme called reverse transcriptase allows the isolated mRNA from both sets of cells to build complementary DNA (called cDNA) strands.

The complementary DNA from each cell population is then labeled with a different, specific fluorescent dye. In **Figure 13** Step B, red dye is used for the cDNA from the cancer cells and green dye is used for the cDNA from normal cells. Then, the pools of complementary DNA are combined, placed on the microarray slide, and incubated (shown in Steps C and D in the figure).

Figure 13 shows the fluorescent signals that are produced during the analysis of the microarray slide. When the expression of a gene is the same in both the normal cells and the cancer cells, a yellow spot is produced on the chip. If the expression of a gene is higher in cancer cells than in normal cells, then the spot formed is red. However, if the expression is higher in normal cells than it is in cancer cells, then the spot formed is green.

Because a single DNA microarray slide can contain thousands of genes, researchers can examine changes in the expression patterns of a large number of genes at the same time. Scientists also are using DNA microarrays to identify previously unknown genes and to identify and analyze changes in the expression of proteins under different growth conditions.

CCC CROSSCUTTING CONCEPT

Patterns DNA typing can be used to determine the identity of individuals based on the analysis of samples of body tissues, such as blood or hair, or body fluids, such as saliva or semen. Using evidence from your textbook and other sources, explain how a forensic scientist relies on patterns to identify suspects and victims in criminal cases. Assume the role of an expert witness in a murder trial and present your evidence to the court in a written or oral presentation.

ACADEMIC VOCABULARY

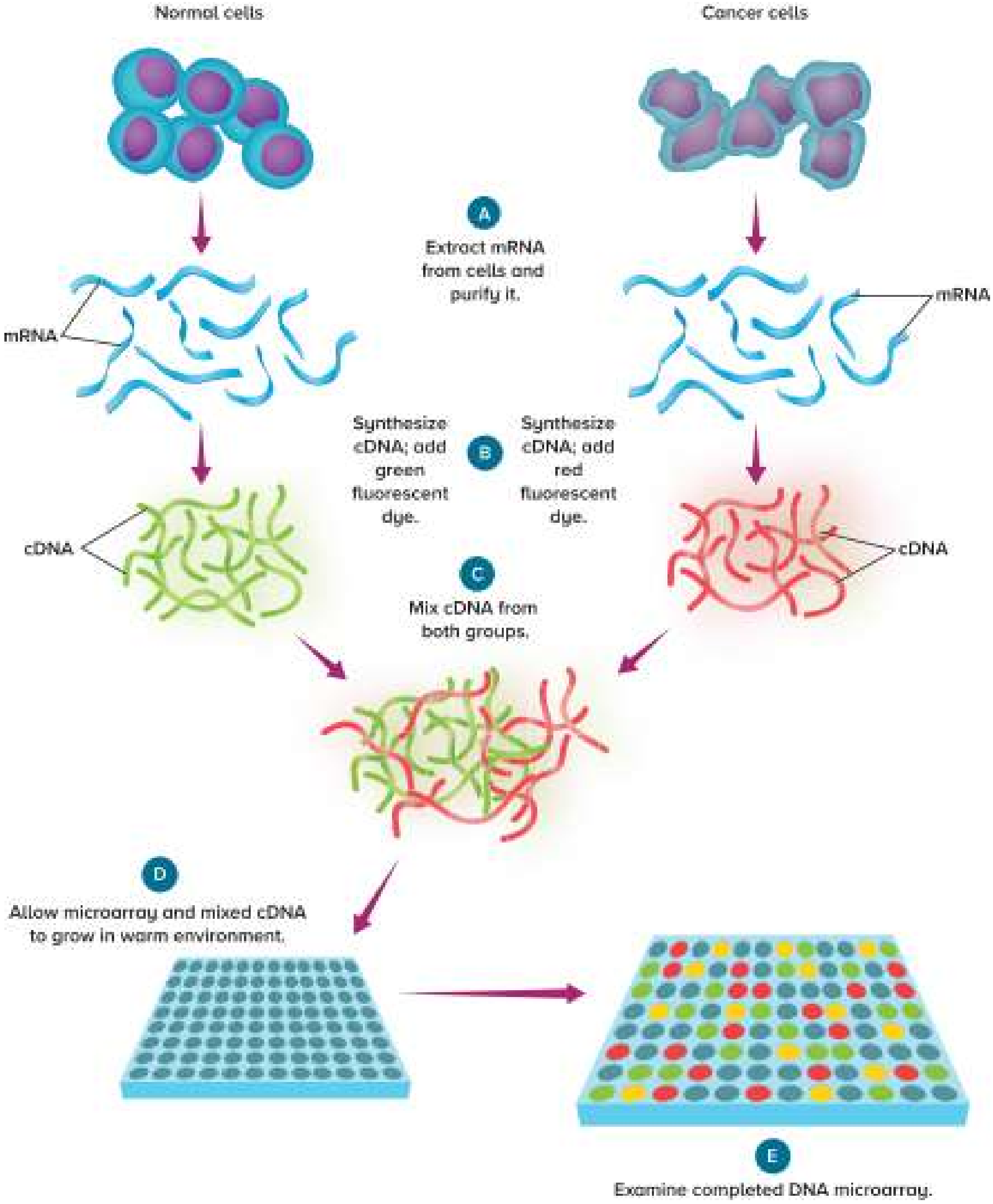
analysis

a detailed examination or study

The analysis of a DNA microarray experiment can help scientists determine whether expression of certain genes is caused by genetic factors or environmental factors.

Figure 13 Visualizing Microarray Analysis

The expression of thousands of human genes can be detected using DNA microarray analysis. Each spot on the microarray chip represents a gene. A red spot indicates the expression of a gene is higher in cancer cells compared to normal cells. A green spot indicates the expression in normal cells is higher. Yellow spots indicate no difference in the expression between cancer cells and normal cells.



Applications of the Human Genome Project

Although more than 99 percent of all nucleotide base sequences are exactly the same in all people, sometimes there are variations that are linked to human diseases. These point mutations in the DNA sequence that occur when a single nucleotide in the genome is altered are called **single nucleotide polymorphisms** or SNPs (pronounced 'snips'); they are found most commonly in the noncoding regions. For a variation to be considered a SNP, it must occur in at least one percent of the human population. Most SNPs have no effect on the function of the cell, but scientists hypothesize that SNP maps will help identify many genes associated with many different types of genetic disorders and other complex diseases.

The HapMap project

An international group of scientists is currently creating a catalog of common patterns of genetic variation that occur in humans. The project to create this catalog is called the haplotype map, or HapMap project. Linked genes are inherited together and similarly, genetic variations located close together also tend to be inherited together. These regions of linked variations in the human genome, known as **haplotypes,** can be located. Assembling the HapMap involves identifying groups of SNPs in a specific region of DNA.

Figure 14 shows how the genome is divided into haplotypes. After three phases, the HapMap describes what these haplotypes are, where they occur in our DNA, and how they are distributed among people within populations and among several populations in different parts of the world. This information will help researchers take the next step to find genes that cause disease, such as cancer, stroke, and diabetes, and affect an individual's response to drugs.

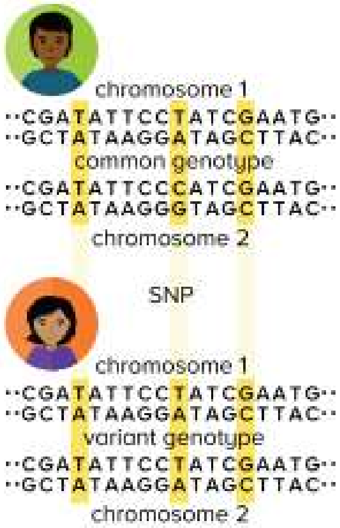


Figure 14 The HapMap project involves grouping all adjacent SNPs that are inherited together into haplotypes.

Get It?

Summarize how the HapMap project could impact human health.

Pharmacogenomics

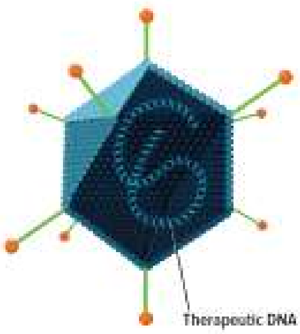
Sequencing the human genome combines the knowledge of genes, proteins, and SNPs with other areas of science. The patterns of genetic variation found while analyzing the human genome have been applied to medicine. The study of how genetic inheritance affects the body's response to drugs is called **pharmacogenomics** (far muh koh jeh NAW mihks).

The benefits of pharmacogenomics include more accurate dosing of drugs that are safer and more specific. Researchers hope that pharmacogenomics will allow for drugs to be custom-made for individuals based on their genetic makeups. Prescribing drugs based on an individual's genetic makeup will increase safety, speed recovery, and reduce side effects. Perhaps one day when you are sick, your doctor will read your genetic code and prescribe medicine tailor-made for you.

Gene therapy

A technique aimed at correcting mutated genes that cause human diseases is called **gene therapy.** Scientists insert a normal gene into a chromosome to replace a dysfunctional gene. In most gene therapy studies, inserting a normal gene into a viral vector, like the one in **Figure 15,** produces recombinant DNA. Target cells in the patient are infected with the virus and the recombinant DNA material is released into the affected cells. Once deposited into cells, the normal gene inserts itself into the genome and begins functioning.

Figure 15 DNA can be encapsulated in a virus and delivered into a patient to replace a defective gene. Once the virus enters the cells, the new genetic information is released into the nucleus and inserted into the genome.



HEALTH Connection In 1990, the first clinical gene therapy trial at the National Institutes of Health was conducted on a four year old child with severe combined immunodeficiency (SCID). The Food and Drug Administration (FDA) monitors new medical trials, including gene therapy. Gene therapy has seen its share of setbacks, but the possibilities are endless when it comes to new treatments. Recent gene therapy trials include work aimed at correcting mutated genes related to diabetes, cancer, retinal disease, Parkinson's disease, and others.

Get It?

Compare and contrast pharmacogenomics and gene therapy.

Proteomics

Genes are the primary information storage units, whereas proteins are the machines of a cell. Recall that when a gene is expressed, a protein is produced. Therefore, an understanding of how proteins function is also important. For instance, if the genome represents the words in a dictionary, the proteome, which represents all the proteins found in a cell, provides the definition of these words and how to use these words in a sentence. The large-scale study and cataloging of the structure and function of proteins in the human body is called **proteomics.**

The growth of proteomics is a logical development resulting from genomics and the sequencing of the human genome. The causes and effects of diseases, disorders, aging, and environmental impacts cannot be determined by studying the genes alone. It is essential that researchers examine the proteins that are the consequences of gene expression in order to confirm the role of individual genes. Proteomics allows researchers to look at hundreds or thousands of proteins at the same time. This type of broad analysis will better define both normal and disease states.

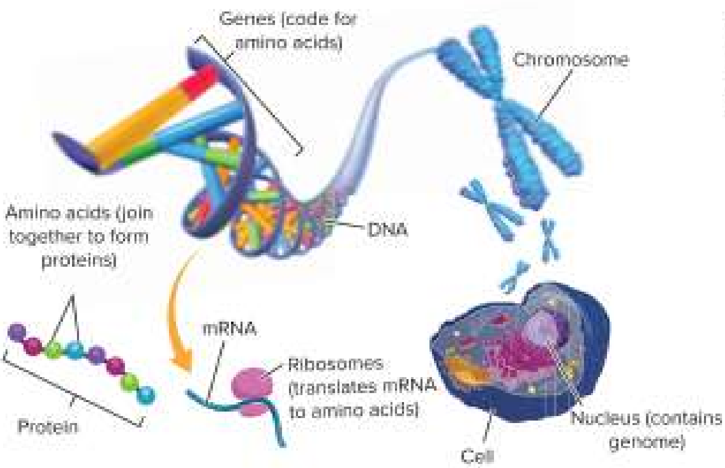


Figure 16 The central dogma is that the information in genes flows from DNA to RNA and RNA to proteins.

Proteomics is based on the central dogma illustrated in **Figure 16.** Proteomics is revolutionizing the development of new drugs to treat diseases such as Type II diabetes, obesity, and atherosclerosis.

Check Your Progress

Summary

- Genomics is the study of an organism's genome.
- Researchers who worked on the HGP sequenced all nucleotides in the human genome.
- DNA typing can be used to identify individuals.
- DNA microarrays allow researchers to study all the genes in the genome.
- Gene therapy is a technique aimed at correcting mutated genes that cause human diseases or genetic disorders.
- Proteomics is the study of the proteins in the human body.

Demonstrate Understanding

1. **Relate** the human genome to blueprints for a house.
2. **Analyze** the role of DNA typing in criminal and civil investigations.
3. **Indicate** why the HapMap project is useful in diagnosing human disease.
4. **Explain** the process of gene therapy. What is the ultimate goal of gene therapy?

Explain Your Thinking

5. **Hypothesize** Most of the human genome consists of noncoding DNA. Where did all of this noncoding DNA originate?
6. **MATH Connection** If 1.5 percent of the human genome consists of protein-coding sequences, and the entire genome has 3.2×10^9 nucleotides, how many codons are in the human genome? Remember that a codon is three nucleotides in length.

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ENGINEERING & TECHNOLOGY

Smartphone Diagnostics

Researchers have built a microscope that uses a smartphone camera to detect a gene mutation that occurs in many cases of colon cancer.

The microscope and image processing equipment are built into a smartphone case.

The microscope uses the phone's camera for DNA sequencing. Sequencing techniques amplify and label copies of DNA using fluorescence. The microscope then images the sequencing products. This technology has been made possible by advances in smartphone imaging, sensing, and cloud computing.

The case containing the microscope is attached to a smartphone and interacts with the smartphone's camera. The attachment also contains the equipment needed for the imaging process, including equipment for fluorescence imaging.

Presently, most of the microscopic information used to make a diagnosis is gathered in specialized laboratories that are located far away from patients and their primary care physicians. The developers found that the new technology is just as reliable as diagnostics in regular laboratories. The new technology has the potential to reduce the cost of disease diagnostics and bring these services right to a patient's health care professional and remote areas where expertise and resources often are scarce or not available.

The future of diagnostics

This technology might be helpful in the diagnosis of infectious diseases, particularly during outbreaks. The technology could be used in the field with results sent remotely to pathologists and other experts. Other recent developments in mobile diagnostics include cell phone apps for detecting skin cancer and eye disease.

Scientists and engineers are still working to improve the technology so it really can be used everywhere. They are also working to reduce the cost and the amount of training needed to use it.

ASK QUESTIONS TO CLARIFY

Ask questions to clarify how mobile technologies could be particularly useful during disease outbreaks. Find out more about how infectious diseases are currently diagnosed during outbreaks. Share your findings with the class.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

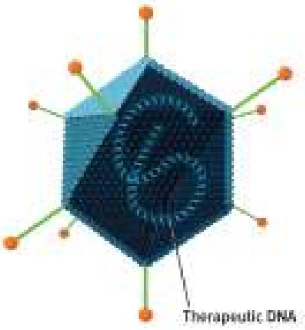
Lesson 1 DNA TECHNOLOGY

- Genetic engineering is used to produce organisms that are useful to humans.
- Recombinant DNA technology is used to study individual genes.
- DNA fragments can be separated using gel electrophoresis.
- Cloning can be used to produce genetically identical bacteria which contain recombinant DNA.
- The polymerase chain reaction is used to make copies of small DNA sequences.
- Transgenic organisms are being created to increase the quality of human life.

- genetic engineering
- genome
- restriction enzyme
- gel electrophoresis
- recombinant DNA
- plasmid
- DNA ligase
- transformation
- cloning
- polymerase chain reaction
- transgenic organism

Lesson 2 THE HUMAN GENOME

- Genomics is the study of an organism's genome.
- Researchers who worked on the HGP sequenced all nucleotides in the human genome.
- DNA typing can be used to identify individuals.
- DNA microarrays allow researchers to study all the genes in the genome.
- Gene therapy is a technique aimed at correcting mutated genes that cause human diseases or genetic disorders.
- Proteomics is the study of the proteins in the human body.



- genomics
- bioinformatics
- DNA typing
- DNA microarray
- single nucleotide polymorphism
- haplotype
- pharmacogenomics
- gene therapy
- proteomics

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

What is this scientist putting into the tube?

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will apply your evidence from this module and complete your project.

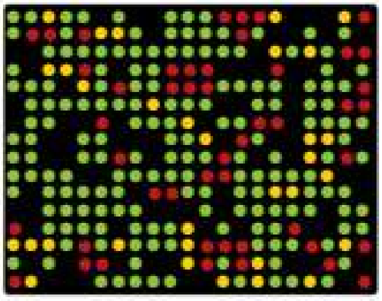
GO FURTHER

SEP Data Analysis Lab

How can DNA microarrays be used to classify types of prostate cancer?

The gene expression profiles between normal prostate cells and prostate cancer cells can be compared using DNA microarray technology.

Data and Observations The diagram shows a subset of the data obtained.



*Data obtained from: Lapointe, et al. 2004. Gene expression profiling identifies clinically relevant subtypes of prostate cancer. *PNAS* 101: 811–816.

CER Analyze and Interpret Data

1. **Calculate** the percentage of spots that are yellow. Then, calculate the percentage of green spots and red spots.
2. **Claim, Evidence** Explain why some of the spots are black.
3. **Reasoning** How would you choose a gene to study as a cause of prostate cancer?

EVOLUTION

ENCOUNTER THE PHENOMENON

Look for the insect in this photo. Why would an animal try to look like a plant?

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

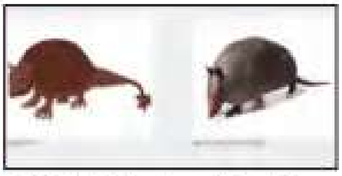
Make Your Claim Use your CER chart to make a claim about why an animal would try to look like a plant. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 1: Explore & Explain: Darwin's Theory of Evolution by Natural Selection



LESSON 2: Explore & Explain: Support for Evolution—The Fossil Record

LESSON 1

DARWIN'S THEORY OF EVOLUTION BY NATURAL SELECTION

FOCUS QUESTION

What is the theory of evolution by natural selection?

Developing the Theory of Evolution

People had been suggesting theories about the origins of Earth's species for thousands of years by the time Charles Darwin, shown in **Figure 1**, boarded the HMS Beagle in 1831. Darwin considered both the observations he made and the existing theories to arrive at his theory of evolution.

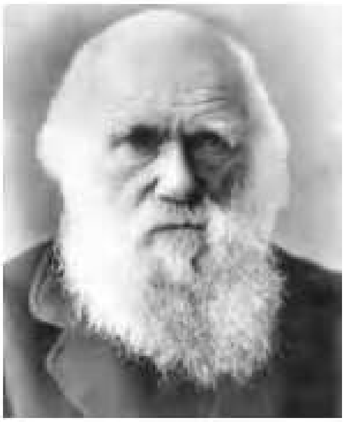


Figure 1 Charles Darwin (1809–1882)

Darwin on the HMS Beagle

The primary mission of the Beagle was to survey the coast of South America. In 1831, the Beagle set sail from England for Maderia and then proceeded to South America, as shown on the map in **Figure 2** on the next page.

Darwin's role on the ship was as a naturalist and companion to the captain. His job was to collect biological and geological specimens during the ship's travels. Darwin had a degree in theology from Christ's College, Cambridge, although he previously had studied medicine and the sciences.

Over the course of the ship's five-year voyage, Darwin made extensive collections of rocks, fossils, plants, and animals. He also read the first volume of Charles Lyell's *Principles of Geology*. The *Principles of Geology* was a set of three books that proposed Earth was millions of years old. Lyell's ideas influenced Darwin's thinking as he observed fossils of marine life at high elevations in the Andes, unearthed what looked like giant fossil versions of smaller living mammals, and saw how earthquakes could lift rocks great distances very quickly.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

CCC **Identify Crosscutting Concepts**

Create a table of the crosscutting concepts and fill in examples you find as you read.

Review the News

Obtain information from a current news story about evolution by natural selection. **Evaluate** your source and **communicate** your findings to your class.

The Galápagos Islands

In 1835, the *Beagle* arrived in the Galápagos (guh LAH puh gus) Islands off the coast of South America. Darwin was initially disappointed by the stark barrenness of these volcanic islands. However, as he began to collect mockingbirds, finches, and other animals on the four islands that he visited, he noticed that the different islands seemed to have their own, slightly different varieties of animals. These differences, however, only sparked a mere curiosity. He took little notice of the comment from the colony's vice governor that the island origins of the giant tortoises could be identified solely by the appearance of the tortoises' shells.

A few years after Darwin returned to England, he began reconsidering his observations. He took note of the work of John Gould, an ornithologist who was classifying the birds Darwin brought back from the Galápagos. Gould discovered that the Galápagos finches were separate species and determined that the finches of the Galápagos did not live anywhere else in South America. In fact, almost every specimen that Darwin had collected on the islands was new to European scientists. These new species most closely resembled species from mainland South America, although the Galápagos and the mainland had different environments. Island and mainland species should not have resembled one another so closely unless, as Darwin began to suspect, populations from the mainland changed after reaching the Galápagos.

Get It?

Summarize some of the experiences and observations that influenced Darwin during his voyage on the Beagle.

Figure 2 The map shows the route of the Beagle's voyage.

Infer *How did the first organisms reach the Galápagos Islands?*

Darwin continued his studies

Darwin hypothesized that new species could appear gradually through small changes in ancestral species, but he could not see how such a process would work. To understand it better, he turned to animal breeders--pigeon breeders in particular.

Different breeds of pigeons have certain distinctive traits that also are present in these breeds' offspring. A breeder can promote these traits by selecting and breeding pigeons that have the most exaggerated expressions of those traits. For example, to produce pigeons with fan-shaped tails, the breeder will breed pigeons that most show that characteristic. The process of directed breeding to produce offspring with desired traits, referred to as selective breeding, was called **artificial selection** by Darwin.

Artificial selection also occurs when humans develop new breeds of dogs or new strains of crop plants. Darwin inferred that if humans could change species by artificial selection, then perhaps the same process could work in nature. Further, Darwin thought that, given enough time, perhaps this process could produce new species.

Natural selection

While thinking about artificial selection, Darwin read an essay by economist Thomas Malthus. The essay suggested that the human population, if unchecked, eventually would outgrow its food supply, leading to a competitive struggle for existence. Darwin realized that Malthus's ideas could be applied to the natural world. He reasoned that some competitors in the struggle for existence would be better equipped for survival than others. Those less equipped would tend to die more often. Here, finally, was the framework for a new theory about the origin of species.

Darwin's theory of evolution by **natural selection** has four basic principles that explain how traits of a population can change over time. First, individuals in a population show differences, or variations. Second, at least some variations are inherited, meaning that they are passed down from parent to offspring. Third, some organisms have more offspring than can survive on available resources. Finally, variations that increase reproductive success will have a greater chance of being passed on than those that do not increase reproductive success.

Notice that two types of variation in a population must be present for natural selection to occur. A population must have genetic variation between organisms. There also must be variation in how genes are expressed in the form of traits. This variation in traits is what enables some individuals to survive and reproduce more successfully than others, and to pass the favorable traits to the next generation.

Given enough time, natural selection could modify a population enough to produce a new species. Natural selection is a mechanism by which evolution takes place. **Figure 3** on the next page shows an example of natural selection.

The Origin of Species

Darwin had likely formulated his theory of evolution by natural selection by about 1840. He began writing a multivolume book compiled of evidence for evolution and explaining how natural selection might provide a mechanism for the origin of species. **Table 1** p. 372 summarizes the principles of natural selection described in Darwin's work.

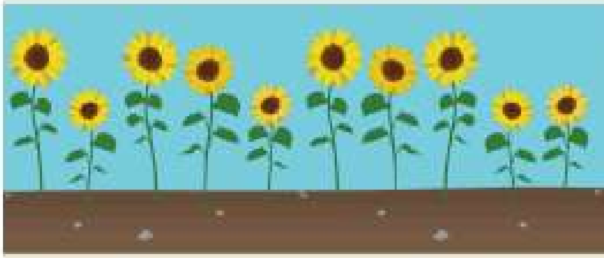
Figure 3:

Visualizing Natural Selection

The theory of natural selection includes four principles that explain how this can occur: variation, heritability, overproduction, and reproductive advantage.

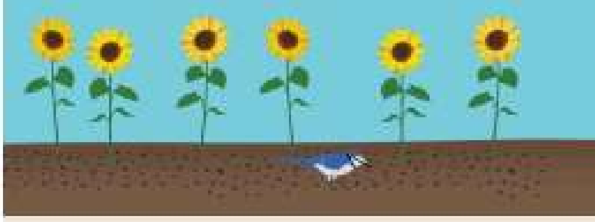
Variation

Individuals in a population differ from one another. For example, some sunflowers are taller than others.



Heritability

Some variations are inherited from parents. Tall sunflowers produce tall sunflowers, and short sunflowers produce short sunflowers.



Overproduction

Populations produce more offspring than can survive. Each sunflower has hundreds of seeds, most of which will not germinate.

Reproductive Advantage

Some variations allow the organism that possesses them to have more offspring than the organism that does not possess them. For example, in this habitat, shorter sunflowers reproduce more successfully.

Table 1 Basic Principles of Natural Selection

Principles	Example
Individuals in a population show variations among others of the same species.	The students in a classroom all look different.
Certain variations are inherited.	You look similar to your parents.
Some organisms have more young than can survive on the available resources.	The average cardinal lays nine eggs per summer. If each cardinal lived only one year and all offspring survived, in seven years there would be a million cardinals.
Heritable variations that increase reproductive success will be more common in the next generation.	If having a fan-shaped tail increases the reproductive success of pigeons, then more pigeons in the next generation will have fan-shaped tails.

In 1859, Darwin published *On the Origin of Species by Means of Natural Selection*—a condensed version of the book he had started many years before. In his book, Darwin used the term *evolution* only on the last page. Today, biologists use the term **evolution** to define cumulative changes in groups of organisms through time. Natural selection is not synonymous with evolution; it is a mechanism by which evolution occurs.

Get It?
Explain how Darwin's ideas about natural selection support the theory of evolution.

Check Your Progress

Summary

- Darwin drew from his observations on the HMS Beagle and other studies to develop his theory of evolution by natural selection.
- Natural selection is based on ideas of variation, inheritance, excess reproduction, and advantages of certain traits in certain environments.
- Darwin reasoned that the process of natural selection eventually could result in the appearance of new species.

Demonstrate Understanding

1. **Describe** the evidence Charles Darwin gathered that led to his theory of evolution.
2. **Explain** how the idea of artificial selection contributed to Darwin's ideas on natural selection.
3. **Describe** the four conditions required for natural selection to occur and explain how evolution is a consequence of the interactions of these factors.
4. **Discuss** why natural selection could not occur if organisms didn't have to compete for the resources they need to survive and reproduce.

Explain Your Thinking

5. **Infer** the consequences for evolution if species did not vary.
6. **WRITING Connection** Write a short story about what it might have been like to visit the Galápagos Islands with Darwin.

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LESSON 2
EVIDENCE OF EVOLUTION

FOCUS QUESTION

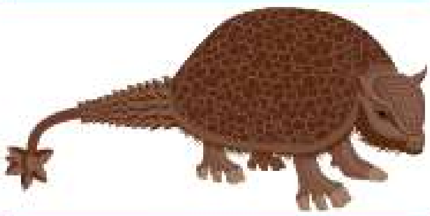
How does the fossil record, morphology, biochemistry, and adaptation provide evidence of evolution?

Support for Evolution

Darwin's book *On the Origin of Species* explained how evolution might happen. The book also provided evidence that evolution has occurred on our planet. The concepts of natural selection and evolution are different, though related. Darwin's theory of evolution by natural selection is part of the larger theory of evolution. Recall that a theory provides an explanation for a natural phenomenon based on observations. Theories explain available data and suggest further areas for experimentation. The theory of evolution states that all organisms on Earth descend with modifications from their ancestors.

The fossil record

Fossils provide a record of species that lived long ago, and they supply some of the most significant evidence of evolutionary change. This record can show how ancient species are similar to current species, as illustrated in **Figure 4**. Fossils also show that some species, such as the horseshoe crab, have remained unchanged for millions of years. The fossil record is an important source of information for determining the ancestry of organisms and patterns of evolution.



Glyptodont

Armadillo

Figure 4 The giant armadillo-like glyptodont, *Glyptodon*, is an extinct animal that Darwin thought must have been related to living armadillos.

Observe *What features of the 2000-kg glyptodont are similar to those of the 4-kg armadillo?*

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COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Applying Practices: Could You Beat Natural Selection Using Camouflage?

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

Although Darwin recognized the limitations of the fossil record, he predicted the existence of fossils intermediate in form between species. Today, scientists studying evolutionary relationships have found hundreds of thousands of transitional fossils that contain features shared by different species. For example, certain dinosaur fossils have feathers like modern birds and teeth and bony tails of reptiles. **Figure 5** shows an artist's rendering of *Archaeopteryx*, one of the first birds. *Archaeopteryx* fossils provide evidence of characteristics that classify it as a bird, and also show that the bird retained several distinct dinosaur features.

Figure 5 This artist's rendering of Archaeopteryx shows that it shares many features with modern birds while retaining ancestral dinosaur features.
Infer *why transitional fossils like Archaeopteryx are important to studying evolution.*

Researchers consider two major classes of traits when studying transitional fossils: derived traits and ancestral traits. **Derived traits** are newly evolved features, such as feathers, that do not appear in the fossils of common ancestors. **Ancestral traits,** on the other hand, are more primitive features, such as teeth and tails, that do appear in ancestral forms. Transitional fossils provide detailed patterns of evolutionary change for the ancestors of many modern animals, including mollusks, horses, whales, and humans.

Comparative anatomy

Why do the vertebrate forelimbs shown in **Figure 6** on the next page have different functions but appear to be constructed of similar bones in similar ways? Evolutionary theory suggests that the answer lies in shared ancestry.

Homologous structures Anatomical structures inherited from a common ancestor are called **homologous structures.** Evolution predicts that an organism's body parts are more likely to be modifications of ancestral body parts than they are to be entirely new features. The limbs illustrated in **Figure 6** move animals in different ways, yet they share similar construction.

Bird wings and reptile limbs are another example. Although birds use their wings to fly and reptiles use their limbs to walk, bird wings and reptile forelimbs are similar in shape and construction, which indicates that they were inherited from a common ancestor. While homologous structures alone are not evidence of evolution, they are an example for which evolution is the best available explanation for the biological data.

WORD ORIGINS

homologous
comes from the Greek words *homos*, meaning *same*, and *logos*, meaning *relation* or *reasoning*.

STEM CAREER Connection

Evolutionary Biologist
Are you interested in learning about the diversity of living things? Do you like genetics and ecology? Evolutionary biologists piece together clues from many sources, including DNA, anatomical structures, and the fossil record to determine how organisms are related, and to try and unravel the mystery of how new species evolve.

Figure 6 The forelimbs of vertebrates illustrate homologous structures. Each limb is adapted for different uses, but they all have similar bones.

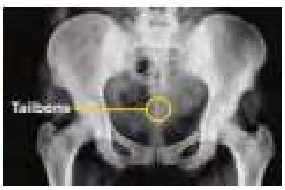
Infer *how the structures of a mouse forelimb would compare to the limbs shown.*

Vestigial structures A bird's strong, lightweight skeleton is one adaptation that allows flight. In some cases, a functioning structure in one species is smaller or less functional in a closely related species. For example, most birds have wings that enable flight. Kiwis, however, have very small wings that cannot be used for flying. The kiwi wing is a kind of homologous structure called a vestigial structure. **Vestigial structures** have either a reduced function or no function in an adult organism. These structures are functional in related organisms, or were functional in an ancestral organism. **Table 2** illustrates some vestigial structures in different species. Evolutionary theory predicts that features of ancestors that decrease fitness for that species will become smaller over time until they are lost.

Get It?

Explain why vestigial structures are examples of homologous structures.

Table 2 **Vestigial Structures**

Trait	Wisdom teeth	Emu wings	Tailbone
Example			
Description	Since modern humans do not share the same plant heavy diet as our ancestors, they can be removed when they emerge	The wings of emus are too small to be of any use in flight.	The tailbone, or coccyx, is the remnant of the tail that all mammals, including humans, develop at some point.

Not all anatomically similar features are evidence of common ancestry. **Analogous structures** can be used for the same purpose and can be superficially similar in construction but are not inherited from a common ancestor. As shown in **Figure 7**, the wings of an eagle are used to fly, as are the wings of dragonflies and other insects. However, the wings of insects are constructed in different ways and from different materials than the wings of birds. While analogous structures do not indicate close evolutionary relationships, they do show that functionally similar features can evolve independently in similar environments.

Figure 7 Eagles and insects use their wings to fly, but their wing structures are different.

Explain *how scientists know that the wings of eagles and insects are analogous structures.*

Comparative embryology

Vertebrate embryos provide more glimpses into evolutionary relationships. An **embryo** is an early, prebirth stage of an organism's development. Scientists have found that vertebrate embryos exhibit homologous structures during certain phases of development that become totally different structures in the adult forms. The embryos shown in **Figure 8**, like all vertebrate embryos, have a tail and paired structures called pharyngeal pouches. In fish, the pouches develop into gills. In reptiles, birds, and mammals, these structures become parts of the ears, jaws, and throats. Although the adult forms differ, the shared features in the embryos suggest that vertebrates evolved from a shared ancestor.

Figure 8 Embryos reveal evolutionary history. Bird and mammal embryos share several developmental features.

Comparative molecular biology

Scientific data also show that common ancestry can be seen in the complex metabolic molecules that many different organisms share. Cytochrome *c* is an enzyme that is essential for respiration and is highly conserved in animals. This means that despite slight variations in its amino acid sequence, the molecule has changed very little over time.

Evolutionary theory predicts that molecules in species with a recent common ancestor should share certain ancient amino acid sequences. The more closely related the species are, the greater the number of sequences that will be shared.

This predicted pattern is what scientists find to be true in cytochrome *c*. For example, as illustrated in **Figure 9**, the cytochrome *c* in the pig and in the monkey share more amino acid sequences with humans than the cytochrome *c* in the duck shares with humans.

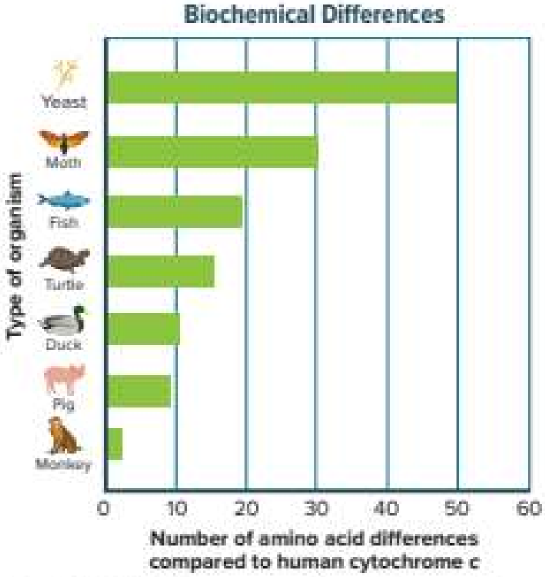


Figure 9 This illustration compares amino acid sequences of cytochrome c in humans and other organisms.

Infer *Would the cytochrome c of a reptile or a bird be expected to have more amino acid differences when compared with that of a human? Explain.*

Scientists have found similar biochemical patterns in other proteins, as well as in DNA and RNA. DNA and RNA form the molecular basis of heredity in all living organisms. The fact that many organisms have the same complex molecules suggests that these molecules evolved early in the history of life and were passed on through the life-forms that have lived on Earth. Comparisons of the similarities in these molecules across species reflect evolutionary patterns seen in comparative anatomy and in the fossil record. Organisms with closely related morphological features have more closely related molecular features.

Geographic distribution

The distribution of plants and animals that Darwin saw during his South American travels first suggested evolution to Darwin. He observed that animals on the South American mainland were more similar to other South American animals than they were to animals living in similar environments in Europe. The South American mara, for example, inhabited a niche that was occupied by the English rabbit. You can compare a mara and an English rabbit in **Figure 10** on the next page. Darwin realized that the mara was more similar to other South American species than it was to the English rabbit because it shared a closer ancestor with the South American animals.

Patterns of migration were critical to Darwin when he was developing his theory. Migration patterns explained why, for example, islands often have more plant diversity than animal diversity: the plants are more able to migrate from the closest mainland as seeds, either by wind or on the backs of birds.

Since Darwin's time, scientists have confirmed and expanded Darwin's study of the distribution of plants and animals around the world in a field of study now called **biogeography.** Evolution is intimately linked with climate and geological forces, especially plate tectonics, which helps explain many ancestral relationships and geographic distributions seen in fossils and living organisms today.

English rabbit

Mara

Figure 10 The mara *(Dolichotis patagonum)* exists in a niche similar to that of the English rabbit *(Oryctolagus cuniculus)*.

Adaptation

The five categories discussed in the previous section—the fossil record, comparative anatomy, comparative embryology, comparative biochemistry, and geographic distribution—offer evidence for evolution. Darwin drew on all of these except biochemistry—which was not well developed in his time—to develop his own theory of evolution by natural selection. At the heart of his theory lies the idea that natural selection leads to adaptation.

Types of adaptation

An adaptation is a trait shaped by natural selection that increases an organism's reproductive success. One way to determine how effectively a trait contributes to reproductive success is to measure fitness. **Fitness** is a measure of the relative contribution that an individual trait makes to the next generation. It often is measured as the number of reproductively viable offspring that an organism produces in the next generation. The better an organism is adapted to its environment, the greater its chances of survival and reproductive success. This concept explains the variations Darwin observed in the finches' beaks on the Galápagos Islands. Adaptation means that the distribution of traits in a population can change when conditions change. Because the environments differed on each island, different beak characteristics were selected for.

Natural selection results in populations that are dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. Organisms in a population that have a trait that gives them an advantage will survive and reproduce more successfully than the organisms that don't have that trait. Over time, the number of organisms that have the advantageous trait will eventually be larger than those that do not. Changes in the physical environment, whether due to human activity or naturally occurring, can—and have—contributed to the expansion of some species. Changes in the environment can also have other effects. If an adaptation is not an advantage in a newly-changed environment, the number of organisms in that species will likely decline, and may sometimes go extinct. In other cases, a change in environmental conditions can cause the emergence of new, distinct species as populations diverge, or become different from each other, under different conditions. It is clear why the ability of a species to survive and reproduce in a specific environment is essential to natural selection.

Camouflage Some species have evolved morphological adaptations that allow them to blend in with their environments. This is called **camouflage** (KA muh flahj). Camouflage allows organisms to become almost invisible to predators, as shown in **Figure 11**. As a result, more of the camouflaged individuals survive and reproduce.

Figure 11 It would be easy for a predator to overlook this insect because of the animal's effective yellow camouflage.

Mimicry Another type of morphological adaptation is **mimicry.** In mimicry, one species evolves to resemble another species. You might expect that mimicry would make it difficult for individuals in one species to find and breed with other members of their species, thus decreasing reproductive success. However, mimicry often increases an organism's fitness. Mimicry can occur in a harmless species that has evolved to resemble a harmful species, such as the example shown in **Figure 12**. Sometimes two harmful species mimic each other. Both mimics are protected because predators quickly learn to avoid both species.

Figure 12 Predators avoid the harmless kingsnake because it has color patterns similar to those of the poinsonous coral snake.

Get It?
Compare mimicry and camouflage.

Antimicrobial resistance Species of bacteria that originally were killed by penicillin and other antibiotics have developed drug resistance. For almost every antibiotic, at least one species of resistant bacteria exists. One unintended consequence of the continued development of antibiotics is that some diseases, which were once thought to be contained, such as tuberculosis, have re-emerged in more harmful forms.

Consequences of adaptations

Not all features of an organism are necessarily adaptive. Some features might be consequences of other evolved characteristics. Biologists Stephen Jay Gould and Richard Lewontin made this point in 1979 in a paper claiming that biologists tended to overemphasize the importance of adaptations in evolution.

Spandrel example To illustrate this concept, they used an example from architecture. Building a set of four arches in a square to support a dome means that spaces called spandrels will appear between the arches.

SCIENCE USAGE v. COMMON USAGE

Adaptation

Science usage: a trait shaped by natural selection to increase the survival or reproductive success of an organism

The prehensile tail of monkeys is an adaptation for life in trees.

Common usage: adjustment or change

The movie script is an adaptation of the original play.

Figure 13 Spaces between arches set in a square to support a dome are called spandrels and are often decorative. Some features in organisms might be like spandrels, a consequence of another adaptation.

Spandrels, like the ones shown in **Figure 13**, are often decorative. Because of their appearance, one might think that they exist only for decoration. In reality, they are an unavoidable consequence of arch construction. Gould and Lewontin argued that some features in organisms are like spandrels because even though they are prominent, they do not increase reproductive success. Instead, they likely arose as an unavoidable consequence of prior evolutionary change.

Human example A biological example of a spandrel is the helplessness of human babies. Humans give birth at a much earlier developmental stage than other primates do. This causes them to need increased care early in their lives. Many scientists think that the helplessness of human babies is a consequence of the evolution of big brains and upright posture. To walk upright, humans need narrow pelvises, which means that babies' heads must be small enough to fit through the pelvic opening at birth. In contrast, scientists previously thought that the helplessness of human infants provided an adaptive advantage, such as increased attention from parents and more learning.

Check Your Progress

Summary

- Fossils provide strong direct evidence to support evolution.
- Homologous and vestigial structures indicate shared ancestry.
- Examples of embryological and biochemical traits provide insight into the evolution of species.
- Biogeography can explain why certain species live in certain locations.
- Natural selection gives rise to features that increase reproductive success.

Demonstrate Understanding

1. **Explain** how the scientific theory of evolution is supported by patterns in the fossil record.
2. **Explain** why camouflage and mimicry can increase an organism's fitness.
3. **Explain** how the scientific theory of evolution is supported by molecular biology.
4. **Compare** the morphological evidence and the biochemical evidence supporting evolution.

Explain Your Thinking

5. **Hypothesize** Evidence suggests that the bones in bird wings share a number of features with the bones of dinosaur arms. Based on this evidence, what hypothesis could you make about the evolutionary relationship between birds and dinosaurs?
6. **Apply** Research has shown that if a prescribed dose of an antibiotic is not taken completely, some bacteria might not be killed and the disease might return. How does natural selection explain this phenomenon?

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LESSON 3
SHAPING EVOLUTIONARY THEORY

FOCUS QUESTION

What patterns can be observed in evolution?

Mechanisms of Evolution

Evolutionary theory states that four things must happen in order for the evolution of a species to occur: the number of individuals must be able to increase, there must be genetic variation within the species, individuals must compete for limited resources, and the number of organisms that are better able to survive and reproduce in that environment must increase. At the center of this understanding is that evolution occurs at the population level, with genes as the raw material.

Population genetics

At the turn of the twentieth century, genes had not been discovered. However, the allele was understood to be one form of an inherited character trait, such as eye color, that gets passed down from parent to offspring. Scientists did not understand why dominant alleles would not overpower recessive alleles in a population.

In 1908, English mathematician Godfrey Hardy and German physician Wilhelm Weinberg independently came up with the same solution to this problem. They showed mathematically that evolution will not occur in a population unless allelic frequencies are acted upon by forces that cause change. Without these forces, the allelic frequency remains the same and evolution doesn't occur. This idea, now known as the **Hardy-Weinberg principle,** states that when allelic frequencies remain constant, a population is in genetic equilibrium. This concept is illustrated in **Figure 14**.

Figure 14 According to the Hardy-Weinberg principle, if the number of owls in a population doubles, the ratio of gray to red owls will remain the same.

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COLLECT EVIDENCE

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INVESTIGATE

GO ONLINE to find these activities and more resources.

Applying Practices: Can Scientists Model Natural Selection?

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

Table 3 The Hardy-Weinberg Principle

Condition	Violation	Consequence
The population is very large.	The population is small.	Chance events can lead to changes in population traits.
There is no immigration or emigration.	Organisms move in and out of the population.	The population can lose or gain traits with movement of organisms.
Mating is random.	Mates are selected.	The proportion of the population with a trait over time.
Mutations do not occur.	Mutations occur.	New variations appear in the population with each new generation.
Natural selection does not occur.	Natural selection occurs.	Traits in a population change from one generation to the next.

To illustrate the Hardy-Weinberg principle, consider a population of 100 humans. Forty people are homozygous dominant for earlobe attachment (*EE*). Another 40 people are heterozygous (*Ee*). Twenty people are homozygous recessive (*ee*). In the 40 homozygous dominant people, there are 80 *E* alleles (2 *E* alleles × 40); and in the 20 homozygous recessive people, there are 40 *e* alleles (2 *e* alleles × 20). The heterozygous people have 40 *E* alleles and 40 *e* alleles. Summing the alleles, we have 120 *E* alleles and 80 *e* alleles for a total of 200 alleles. The *E* allele frequency is 120/200, or 0.6. The *e* allele frequency is 80/200, or 0.4.

The Hardy-Weinberg principle states that the allele frequencies in populations should be constant. This often is expressed as $p + q = 1$. For our example, p can represent the *E* allele frequency and q can represent the *e* allele frequency.

Squaring both sides of the equation yields the new equation $p^2 + 2pq + q^2 = 1$. This equation allows us to determine the equilibrium frequency of each genotype in the population: homozygous dominant (p^2), heterozygous ($2pq$), and homozygous recessive (q^2). From the above example, $p = 0.6$, and $q = 0.4$, so $(0.6)(0.6) + 2(0.6)(0.4) + (0.4)(0.4) = 1$. In the example population, the equilibrium frequency for homozygous dominant will be 0.36, the equilibrium frequency of heterozygous will be 0.48, and the equilibrium frequency of homozygous recessive will be 0.16. Note that the sum of these frequencies equals one.

Get It?

Determine when a population is in equilibrium.

Conditions According to the Hardy-Weinberg principle, a population in genetic equilibrium must meet five conditions: there must be no genetic drift, no gene flow, no mutation, mating must be random, and there must be no natural selection. Populations in nature might meet some of these requirements, but hardly any population meets all five conditions for long periods of time. If a population is not in genetic equilibrium, at least one of the five conditions has been violated. These five conditions, listed in **Table 3**, are known mechanisms of evolutionary change.

Genetic drift

Any change in the allelic frequencies in a population that results from chance is called **genetic drift.** Recall that for simple traits, only one of a parent's two alleles passes to the offspring, and that this allele is selected randomly through independent assortment. In large populations, enough alleles "drift" to ensure that the allelic frequency of the entire population remains relatively constant from one generation to the next. In smaller populations, however, the effects of genetic drift become more pronounced, and the chance of losing an allele becomes greater.

Founder effect The founder effect is an extreme example of genetic drift. The **founder effect** can occur when a small sample of a population settles in a location separated from the rest of the population. Because this sample is a random subset of the original population, the sample population carries a random subset of the population's genes. Alleles that were uncommon in the original population might be common in the new population, and the offspring in the new population will carry those alleles. Such an event can result in large genetic variations in the separated populations.

The founder effect is evident in the Amish and Mennonite communities in the United States, in which the people rarely marry outside their own communities. The Old Order Amish have a high frequency of six-finger dwarfism. All affected individuals can trace their ancestry back to one of the founders of the Order.

Bottleneck Another extreme example of genetic drift is a **bottleneck,** which occurs when a population declines to a very low number and then rebounds. The gene pool of the rebound population often is genetically similar to that of the population at its lowest level, that is, it has reduced diversity. Researchers think that cheetahs in Africa experienced a bottleneck 10,000 years ago, and then another one about 100 years ago. Throughout their current range, shown in **Figure 15**, cheetahs are so genetically similar that they appear inbred. Inbreeding decreases fertility, and might be a factor in the potential extinction of this endangered species.

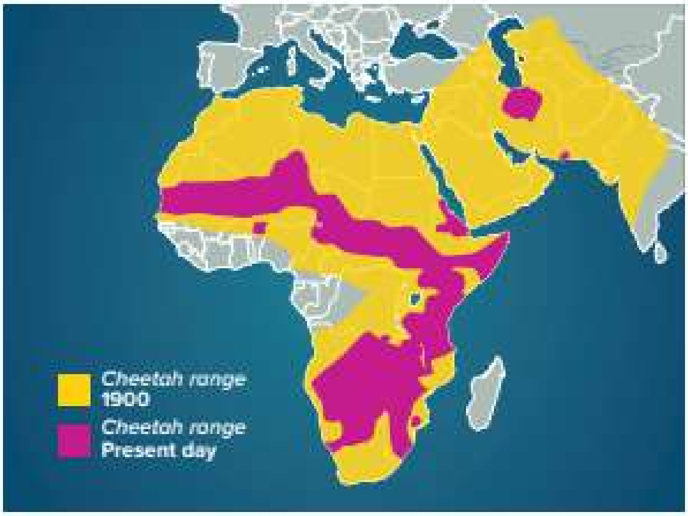


Figure 15 The map shows the present range of cheetahs in Africa. It is believed that cheetahs had a much larger population until a bottleneck occurred.

Apply Concepts *What effect has the bottleneck had on the reproductive rate of cheetahs?*

Gene flow

A population in genetic equilibrium experiences no gene flow. It is a closed system, with no new genes entering the population and no genes leaving the population. In reality, few populations are isolated. The random movement of individuals between populations, or migration, increases genetic variation within a population and reduces differences between populations.

Nonrandom mating

Rarely is mating completely random in a population. Usually, organisms mate with individuals in close proximity. This promotes inbreeding and could lead to a change in allelic proportions favoring individuals that are homozygous for particular traits.

Mutation

Recall that a mutation is a random change in genetic material. The cumulative effect of mutations in a population might cause a change in allelic frequencies and thus violate genetic equilibrium. Although many mutations cause harm or are lethal, occasionally a mutation provides an advantage to an organism. This mutation will then be selected for and become more common in subsequent generations. In this way, mutations provide the raw material upon which natural selection works.

Natural selection

The Hardy-Weinberg principle requires that all individuals in a population be equally adapted to their environment and thus contribute equally to the next generation. As you have learned, natural selection depends on variation in both genetic information and how that information is expressed as traits within a population. Natural selection favors the individuals that are best adapted for survival and reproduction. Over time, the traits the traits that have a positive effect will become more common in the population. Natural selection acts on an organism's phenotype and changes allelic frequencies. **Figure 16** shows three main ways in which natural selection alters phenotypes: through stabilizing selection, directional selection, and disruptive selection. A fourth type of selection, sexual selection, also is considered a type of natural selection.

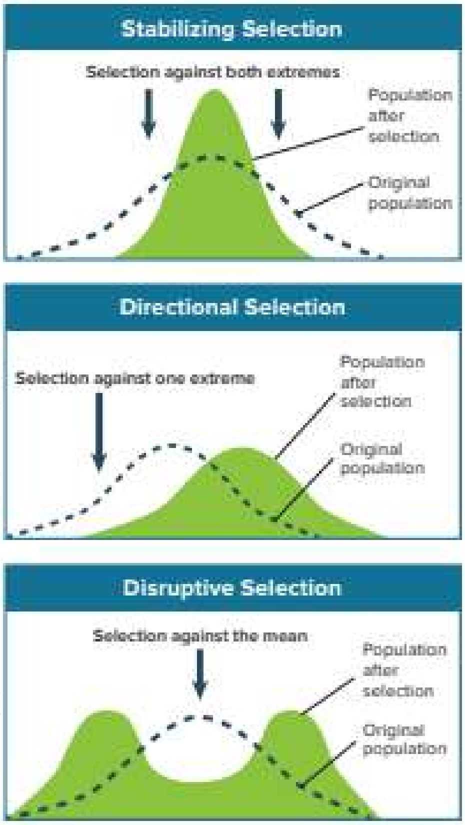


Figure 16 Natural selection can alter allele frequencies of a population in three ways. The bell-shaped curve shown as a dotted line in each graph indicates the trait's original variation in a population. The solid line indicates the outcome of each type of selection pressure.

Get It?
Summarize how mutation violates the Hardy-Weinberg principle.

Stabilizing selection

The most common form of natural selection is **stabilizing selection.** It operates to eliminate extreme expressions of a trait when the average expression leads to higher fitness.

For example, human babies born with below-normal and above-normal birth weights have lower chances of survival than babies born with average weights. Therefore, birth weight varies little in human populations.

Male Pacific field-cricket

Female Pacific field-cricket

Figure 17 Male field crickets can be chirping or silent. Over time, directional selection has caused the population to be made up of mostly silent crickets.

Infer *how natural selection might have caused a change in the frequency of the genotypes.*

Directional selection

If an extreme version of a trait makes an organism more fit, **directional selection** might occur. This form of selection increases the expression of the extreme versions of a trait in a population. One example of directional selection is the evolution of Hawaiian Pacific field-crickets like those shown in **Figure 17**. The male field-crickets that had normal chirping prior to the 1990s are now silent. Why? In the 1990s, the field-cricket was targeted by a parasitic fly. The fly larvae burrowed inside the field cricket and would eat them alive. The flies listened to the chirping of the male field-crickets in order to find them. Since the parasitic flies were so successful at finding the field-crickets, the population had dramatically decreased. However, the silent male field-crickets escaped the attention of the parasitic flies. Male crickets had a mutation that allowed them to remain silent and that trait was passed on. After about 20 generations, the male field-crickets were mostly silent.

The distribution of traits in a population can change when environmental conditions change. For three decades in the latter part of the twentieth century, Peter and Rosemary Grant studied populations of Galápagos finches. The Grants found that during drought years, food supplies dwindled and the birds had to eat the hard seeds that they normally ignored. Birds with the largest beaks were more successful in cracking the tough seed coatings than were birds with smaller beaks. As a result, over the duration of the drought, birds with larger beaks came to dominate the population. In rainy years, however, the directional trend was reversed, and the population's average beak size decreased. Changes in the finches' physical environment contributed to the expansion of some species and the decline of others.

Figure 18 Northern water snakes have two different color patterns, depending on their habitats. Intermediate color patterns would make them more visible to predators.

Disruptive selection Another type of natural selection, **disruptive selection,** is a process that splits a population into two groups. It tends to remove individuals with average traits but retain individuals expressing extreme traits at both ends of a continuum. Northern water snakes, illustrated in **Figure 18**, are an example. Snakes living on the mainland shores inhabit grasslands and have mottled brown skin. Snakes inhabiting rocky island shores have gray skin. Each is adapted to its particular environment. A snake with intermediate coloring would be disadvantaged because it would be more visible to predators.

Sexual selection Another type of natural selection, in which the change in frequency of a trait is based on the ability to attract a mate is called **sexual selection.** This type of selection often operates in populations in which males and females differ significantly in appearance. Usually in these populations, males are the largest and most colorful of the group. The bigger the tail of a male peacock, as shown in **Figure 19**, the more attractive the bird is to females. Males also evolve threatening characteristics that intimidate other males. This is common in species such as elk and deer, where the male keeps a harem of females.

Darwin wondered why some qualities of sexual attractiveness appeared to be the opposite of qualities that might enhance survival. For example, the peacock's tail, while attracting females, is large and cumbersome, and it might make the peacock a more likely target for predators. Although some modern scientists think that sexual selection is not a form of natural selection, others think that sexual selection follows the same general principle: brighter colors and bigger bodies enhance reproductive success, whatever the chances are for individual long-term survival.

Figure 19 Peacocks that have the largest tails tend to attract more peahens. The frequency of this trait increases because of sexual selection.

Figure 20 The map shows the overlapping ranges of the Eastern meadowlark, and the left, and Western meadowlark, on the right. While the two are similar in appearance, their songs separate them behaviorally.

Infer *how different songs prevent the meadowlarks from breeding.*

Reproductive Isolation

Mechanisms of evolution—genetic drift, gene flow, nonrandom mating, mutation, and natural selection—violate the Hardy-Weinberg principle. To what extent each mechanism contributes to the origin of new species is a major topic of debate in evolutionary science today. Most scientists define speciation as the process whereby some members of a sexually reproducing population change so much that they can no longer produce fertile offspring with members of the original population. Two types of reproductive isolating mechanisms prevent gene flow among populations. **Prezygotic isolating mechanisms** operate before fertilization occurs. **Postzygotic isolating mechanisms** operate after fertilization has occurred to ensure that the resulting hybrid remains infertile.

Prezygotic isolation

Prezygotic isolating mechanisms prevent reproduction by making fertilization unlikely. These mechanisms prevent genotypes from entering a population's gene pool through geographic, ecological, behavioral, or other differences. For example, the Eastern meadow lark and the Western meadowlark, pictured in **Figure 20**, have overlapping ranges and are similar in appearance. These two species, however, use different mating songs and do not interbreed. Time is another factor in maintaining a reproductive barrier. Closely related species of fireflies mate at different times of night, just as different species of trout live in the same stream but breed at different times of the year.

Figure 21 The offspring of a male tiger and a female lion is a tigon.

Postzygotic isolation

When fertilization has occurred but a hybrid offspring cannot develop or reproduce, postzygotic isolation has occurred. Postzygotic isolating mechanisms prevent offspring survival or reproduction. A lion and a tiger are considered separate species because even though they can mate, their offspring—like the tigon, shown in **Figure 21**—is often sterile.

Speciation

For speciation to occur, a population must diverge and then be reproductively isolated. Biologists usually recognize two types of speciation: allopatric and sympatric.

Allopatric speciation

In **allopatric speciation,** a physical barrier divides one population into two or more populations. The separate populations eventually will contain organisms that, if enough time has passed, will no longer be able to breed successfully with one another. Most scientists think that allopatric speciation is the most common form of speciation. Small subpopulations isolated from the main population have a better chance of diverging than those living within it. This was the conclusion of biologist Ernst Mayr, who argued as early as the 1940s that geographic isolation was not only important but also was required for speciation.

Geographic barriers can include mountain ranges, channels between islands, wide rivers, and lava flows. The Grand Canyon, pictured in **Figure 22**, is an example of a geographic barrier. The Kaibab squirrel is found on the canyon's north rim, while the Abert squirrel lives on the south rim. Scientists think that the two types of squirrels diverged from an ancestral species and today are reproductively isolated by the width of the canyon. While these animals officially belong to the same species, they demonstrate distinct differences and, in time, they might diverge enough to be classified as separate species.

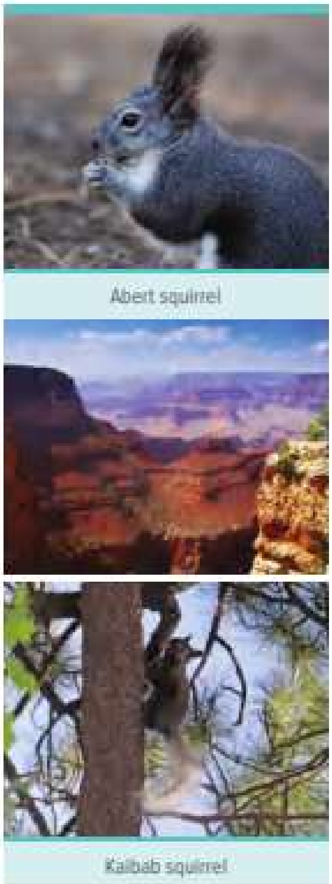


Figure 22 The Grand Canyon is a geographic barrier separating the Abert and Kaibab squirrels.

Sympatric speciation

In **sympatric speciation,** a species evolves into a new species without a physical barrier. The ancestor species and the new species live side-by-side during the speciation process. Evidence of sympatric evolution can be seen in several insect species, including apple maggot flies, which appear to be diverging based on the type of fruit they eat. Scientists think that sympatric speciation happens fairly frequently in plants, especially through polyploidy. Recall that polyploidy is a mutation that increases a plant's chromosome number. As a result, the plant is no longer able to interbreed with the main population.

ACADEMIC VOCABULARY

Isolation
the condition of being separated from others

After infection, a patient is kept in isolation from other patients to prevent the infection from spreading.

CCC CROSSCUTTING CONCEPTS

Cause and Effect Research an example of either allopatric or sympatric speciation other than the ones described on this page. Sketch a model of how this example of speciation works, identifying both the cause and the effect. What evidence from your research supports your model?

Figure 23 More than 300 species of cichlid fishes once lived in Lake Victoria. Their adaptive radiation is remarkable because it is thought to have occurred in less than 14,000 years.

Patterns of Evolution

Many details of the speciation process remain unresolved. Relative to the human life span, speciation is a long process, and first-hand accounts of speciation are expected to be rare. However, evidence of speciation is visible in patterns of evolution.

Adaptive radiation

More than 300 species of cichlid fish, six of which are illustrated in **Figure 23**, once lived in Africa's Lake Victoria. Data show that these species diverged from a single ancestor within the last 14,000 years. This is a dramatic example of a type of speciation called **adaptive radiation.** Adaptive radiation, also called divergent evolution, can occur in a relatively short time when one species gives rise to many species in response to the creation of a new habitat or another ecological opportunity. Likely, a combination of factors caused the explosive radiation of the cichlids, including the appearance of a unique double jaw, which allowed these fish to exploit various food sources. Adaptive radiation often follows large-scale extinctions. The adaptive radiation of mammals occurred following the extinction of dinosaurs at the beginning of the Cenozoic Era. This likely produced the diversity of mammals visible today.

Coevolution

Many species evolve in close relationship with other species. The relationship might be so close that the evolution of one species affects the evolution of other species. This is called coevolution. Mutualism is one form of coevolution. Mutualism occurs when two species benefit each other. For example, flowers and the many pollinating insects that pollinate them have coevolved in an intimate dependency.

Another form of coevolution is often called a coevolutionary arms race. The classic example is a plant, and an insect predator that is dependent on the plant for food. The plant population evolves a chemical defense against the insect population. The insects, in turn, evolve the biochemistry to resist the defense. The plant then steps up the race by evolving new defenses, the insect escalates its response, and the race goes on. Complex coevolutionary relationships like these might reflect thousands of years of evolutionary interaction.

Convergent evolution

Sometimes unrelated species evolve similar traits even though they live in different parts of the world. This is called convergent evolution. Convergent evolution occurs in environments that are geographically far apart but have similar ecology and climate. The mara and rabbit discussed in Lesson 2 provide an example of convergent evolution. The mara and the rabbit are not closely related, but because they inhabit similar niches, they have evolved similarities in morphology, physiology, and behavior. **Table 4** shows examples of convergent evolution between Australian marsupials and the placental mammals on other continents.

Table 4 Convergent Evolution

Niche	Placental Mammals	Australian Marsupials
Burrower	 Mole	 Marsupial mole
Anteater	 Lesser anteater	 Numbat (anteater)
Mouse	 Mouse	 Marsupial mouse
Glider	 Flying squirrel	 Flying phalanger
Wolf	 Wolf	 Tasmanian wolf

Rate of speciation

Evolution is a dynamic process. In some cases, as in a coevolutionary arms race, traits might change rapidly. In other cases, traits might remain unchanged for millions of years. Scientists think that evolution proceeds in small, gradual steps. This is a theory called **gradualism.** A great deal of evidence favors this theory. However, the fossil record contains instances of abrupt transitions. For example, certain species of fossil snails looked the same for millions of years, and then the shell shape changed dramatically in only a few thousand years. The theory of **punctuated equilibrium** attempts to explain such abrupt transitions in the fossil record. According to this theory, rapid spurts of genetic change cause species to diverge quickly; these periods punctuate much longer periods when the species exhibit little change.

The two theories for the tempo of evolution are illustrated in **Figure 24**. The tempo of evolution is an active area of research in evolutionary theory today. Does most evolution occur gradually or in short bursts? Solving this puzzle requires insights from a variety of disciplines using a variety of methods. Evolution offers a complex collection of evidence, and it does not yield easily to simple analysis.

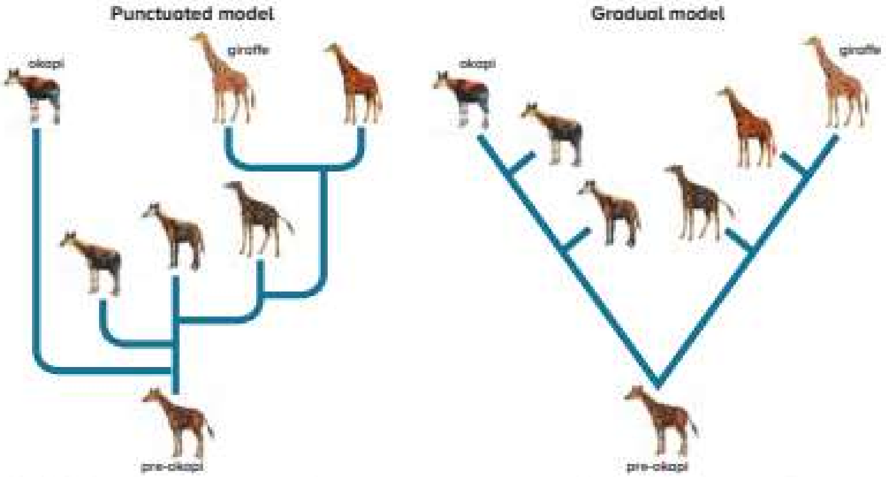


Figure 24 Gradualism and punctuated equilibrium are two competing models describing the tempo of evolution.

Check Your Progress

Summary

- The Hardy-Weinberg principle describes the conditions within which evolution does not occur.
- Speciation often begins in small, isolated populations.
- Selection can operate by favoring average or extreme traits.
- Punctuated equilibrium and gradualism are two models that explain the tempo of evolution.

Demonstrate Understanding

1. **Discuss** genetic drift and gene flow as mechanisms of evolutionary change.
2. **Identify** the conditions of the Hardy-Weinberg principle.
3. **Discuss** factors that can lead to speciation.
4. **Explain** how the pattern of evolution is shown by the many species of finches on the Galápagos Islands is evidence that the distribution of traits in a population can change when conditions change.

Explain Your Thinking

5. **Design an Experiment** Two populations of frogs live separated by the Amazon River. What experiment could be designed to test whether the two populations are one species or two?
6. What type of mathematical results would you expect from the experiment you designed above if the two populations diverged only recently?

LEARNSMART® Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

NATURE OF SCIENCE

Cool Adaptations

You might think that by this millennium, scientists have discovered all the species there are to be discovered. You might think that they know pretty much all there is to know about those species. However, you would be wrong.

Antarctic lakes like this one are home to many hyperspecialized organisms that can withstand extreme cold.

Discovering New Species

Thanks to advanced DNA analysis techniques, new species are still being discovered today. Many of these species, including archaea, bacteria, algae, and fungi, are found in harsh environments, and their ability to survive in those environments is due to their incredible adaptations.

Built for the Cold

Lakes in Antarctica get cold—as cold as −13°C. The only reason they are not frozen solid is because they are supersaturated salt solutions. So you might be surprised to find that these lakes are hotbeds of microbial life. From bacteria to algae, these super cool species would die if you brought them to a room temperature lab.

Organisms that thrive in extreme cold are called psychrophiles. The secret to these microbes surviving in this extreme environment is found in their DNA. By sequencing DNA found in water samples, researchers have discovered more about the adaptations these organisms have that allow them to live in cold temperatures.

One of the adaptations is that the cell membranes of these organisms remain flexible in cold temperatures. Another adaptation that these organisms have is that the proteins in their cells do not stop working when exposed to extreme cold. Like their cell membranes, proteins in these organisms are more flexible than those of organisms that live in warmer temperatures. This flexibility helps the proteins to maintain their shape, and therefore function properly.

Psychrophiles also have slow metabolisms. They perform cellular activities including cell division at much slower rates than their warmer relatives.

The more scientists learn about these species, the more they may understand about species that live in other extreme environments.

COMMUNICATE SCIENTIFIC INFORMATION

Research organisms that live in hydrothermal vents. Write a descriptive essay about the adaptations that enable them to survive.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 DARWIN'S THEORY OF EVOLUTION BY NATURAL SELECTION

- Darwin drew from his observations on the HMS Beagle and other studies to develop his theory of evolution by natural selection.
- Natural selection is based on ideas of excess reproduction, variation, inheritance, and advantages of certain traits in certain environments.
- Darwin reasoned that the process of natural selection eventually could result in the appearance of new species.

- artificial selection
- natural selection
- evolution

Lesson 2 EVIDENCE OF EVOLUTION

- Fossils provide strong direct evidence to support evolution.
- Homologous and vestigial structures indicate shared ancestry.
- Examples of embryological and biochemical traits provide insight into the evolution of species.
- Biogeography can explain why certain species live in certain locations.
- Natural selection gives rise to features that increase reproductive success.

- derived trait
- ancestral trait
- homologous structure
- vestigial structure
- analogous structure
- embryo
- biogeography
- fitness
- camouflage
- mimicry

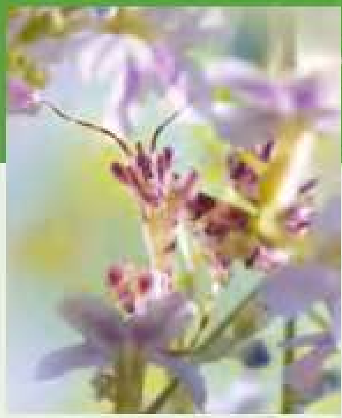
Lesson 3 SHAPING EVOLUTIONARY THEORY

- The Hardy-Weinberg principle describes the conditions within which evolution does not occur.
- Speciation often begins in small, isolated populations
- Selection can operate by favoring average or extreme traits.
- Punctuated equilibrium and gradualism are two models that explain the tempo of evolution.

- Hardy-Weinberg principle
- genetic drift
- founder effect
- bottleneck
- stabilizing selection
- directional selection
- disruptive selection
- sexual selection
- prezygotic isolating mechanism
- postzygotic isolating mechanism
- allopatric speciation
- sympatric speciation
- adaptive radiation
- gradualism
- punctuated equilibrium

THREE-DIMENSIONAL THINKING

Module Wrap-Up



REVISIT THE PHENOMENON

Look for the insect in this photo. Why would an animal try to look like a plant?

CER Claim, Evidence, Reasoning

Explain your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will summarize your evidence and apply it to the project.

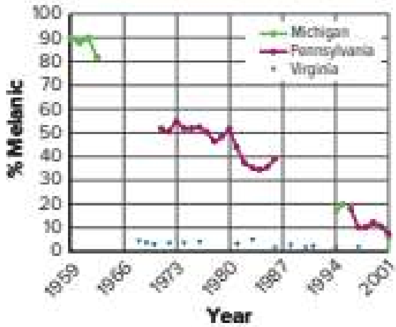
GO FURTHER

SEP Data Analysis Lab

How does pollution affect melanism in moths?

The changing frequencies of light-colored and dark-colored moths have been studied for decades in the United States. The percentage of the melanic, or dark, form of the moth was low prior to the Industrial Revolution. It increased until it made up nearly the entire population in the early 1900s. After anti-pollution laws were passed, the percentage of melanic moths declined, as shown in the graph.

Recent History of Melanism in American Peppered Moths



*Data obtained from: Grant, B. S. and L. L. Wiseman. 2002. Recent history of melanism in American peppered moths. *Journal of Heredity* 93: 86-90.

CER Analyze and Interpret Data

1. **Claim** What is the percent decrease in Pennsylvania melanic moth population?
2. **Evidence, Reasoning** Hypothesize why the percentage of melanic moths might have remained at a relatively low level in Virginia.

POPULATION ECOLOGY

POPULATION ECOLOGY

ENCOUNTER THE PHENOMENON

Why are bee populations declining?

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about the impacts of global resource consumption on populations. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 1: Explore & Explain: Population Characteristics

LESSON 2: Explore & Explain: Human Population Growth

LESSON 1
POPULATION DYNAMICS

FOCUS QUESTION

What are characteristics of populations and how are they determined?

Population Characteristics

All species occur in groups called populations. There are certain characteristics that all populations have, such as population density, spatial distribution, and growth rate. These characteristics are used to classify all populations of organisms, including bacteria, animals, and plants.

Population density

One characteristic of a population is its **population density,** which is the number of organisms per unit area. For example, the population density of cattle egrets, shown with the Cape buffalo in **Figure 1**, is greater near the buffalo than farther away. Near the Cape buffalo, there might be three birds per square meter. Fifty meters from the Cape buffalo, the density of birds might be zero.

Figure 1 The population density of the cattle egrets is greater near the Cape buffalo.

Suggest *the type of dispersion you would expect these birds to have.*

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Applying Practices: Local Ecosystem Dynamics

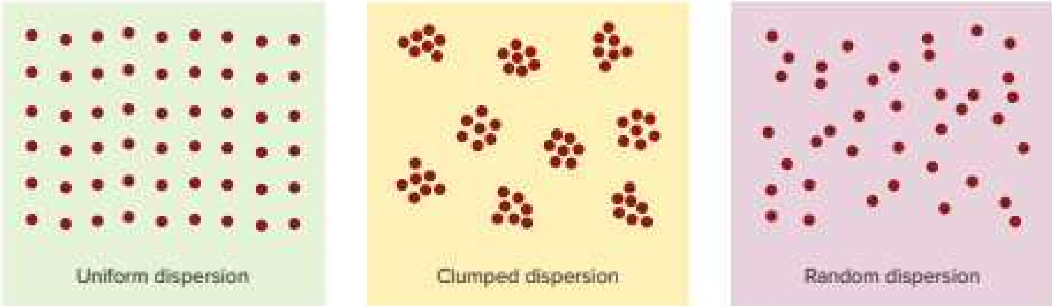
HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.

Figure 2 Visualizing Population Characteristics

Black Bear	American Bison	White-tailed Deer

Spatial distribution

The pattern of spacing of a population within an area; one of the primary factors in the pattern of dispersion for all organisms is the availability of resources such as food.



Population density

The number of organisms per unit area; can be calculated by dividing the number of organisms in the population by the area the population occupies.

Population range

Some species have a very limited population range, or distribution. Other species have a vast distribution. A species might not be able to expand its population range because it cannot survive the abiotic conditions found in the expanded region.

Spatial distribution

Another characteristic of a population is called **dispersion**—the pattern of spacing of a population within an area. **Figure 2** on the previous page shows the three main types of dispersion—uniform, clumped, and random. Black bears are typically dispersed in a uniform arrangement. American bison are dispersed in clumped groups or herds. White-tailed deer are dispersed randomly with unpredictable spacing. The availability of resources such as food and water is one of the main determinants of spatial distribution of a population within its ecosystem.

Population ranges

No population, not even the human population, occupies all habitats in the biosphere. Some species, such as the Hawaiian honeycreeper shown in **Figure 3**, have a very limited population range, or distribution. This songbird is found only on some of the islands of Hawaii. Other species, such as the peregrine falcon shown in **Figure 3**, have a vast distribution. Peregrine falcons are found on all continents except Antarctica. Note the ranges of the animals in **Figure 2.**

Hawaiian honeycreeper | Peregrine falcon

Figure 3 The Hawaiian honeycreeper lives only on some of the Hawaiian islands. The peregrine falcon is found worldwide.

CCC CROSSCUTTING CONCEPTS

Scale, Proportion, and Quantity The coyote lives in almost every habitat in California, with the exception of major city centers. The Department of Fish and Wildlife estimates a population of between 250,000 and 750,000 animals. Why do you think that the estimate is such a wide range of values? Find the area of the state and then determine the range of the estimated population density. What evidence would be needed to determine a more accurate estimate of the coyote population density? Debate with your classmates whether coyotes are a pest or simply just another wild animal looking for suitable habitat.

You may have learned that organisms adapt to the biotic and abiotic factors in their environment. A species might not be able to expand its population range because it cannot survive the abiotic conditions found in the expanded region. A change in temperature range, humidity level, annual rainfall, or sunlight might make a new geographic area uninhabitable for the species. In addition, biotic factors, such as predators, competitors, and parasites, present threats that might make the new location difficult for survival.

Get It?

Describe two reasons why a species might not be able to expand its range.

Population-Limiting Factors

Limiting factors are biotic or abiotic factors that keep a population from continuing to increase indefinitely. Decreasing a limiting factor, such as the available food supply, often changes the number of individuals that are able to survive in a given area. In other words, if the food supply increases a larger population might result, and if the food supply decreases a smaller population would likely result.

Density-independent factors

Any factor in the environment that does not depend on the number of members in a population per unit area is a **density-independent factor.** These factors usually are abiotic and include natural phenomena such as weather events. Weather events that limit populations include drought or flooding, extreme heat or cold, tornadoes, hurricanes, or fires (as shown in **Figure 4**).

Crown fire damage | Managed ground fire damage

Figure 4 A crown fire is a density-independent factor that can limit population growth. However, small ground fires can promote growth in a forest community.

Explain *why these two situations involving fire have different results on the tree populations.*

STEM CAREER Connection

Population Biologist

Why is it important to know the characteristics, such as size, growth, and distribution, of populations? How would you study a population to determine these characteristics? Would you like a job that requires you to be in the field studying organisms in their natural habitat? If these questions interest you, you might be a future population biologist. Population biologists use their findings to predict the future of populations and determine what can be done to lessen negative impacts.

ACADEMIC VOCABULARY

dominant

more powerful, successful, or in control than something else

The hand with which you write and do most other tasks is called your dominant hand.

Figure 4 on the last page shows an example of the effects that fire can have on a population. The ponderosa pines have been damaged by a crown fire, a fire that advances to the tops of the trees. In this example, the fire limits the population of ponderosa trees by killing many of the trees. However, smaller but more frequent ground fires have the opposite effect on the population. By thinning lower growing plants that use up nutrients, a healthier population of mature ponderosa pines is produced.

Populations can be limited by the results of human interference. For example, over the last 100 years, building dams and other human activities on the Colorado River have significantly reduced the river's water flow and changed its temperature. In addition, the introduction of nonnative fish species altered the river's biotic factors. Because of the changes in the river, the number of small fish called humpback chub was reduced. During the 1960s, the number of humpback chub dropped so low that they were in danger of disappearing from the Colorado River altogether. Air, land, and water pollution are the result of human activities that also can limit populations. Pollution reduces the available resources by making some of the resources toxic.

Density-dependent factors

Any factor in the environment that depends on the number of members in a population per unit area is a **density-dependent factor.** Density-dependent factors are often biotic factors such as predation, disease, competition, and parasites.

Predation A study of density-dependent factors was done on the wolf and moose populations in northern Michigan on Isle Royale, located in Lake Superior. The results of this study are shown in **Figure 5**.

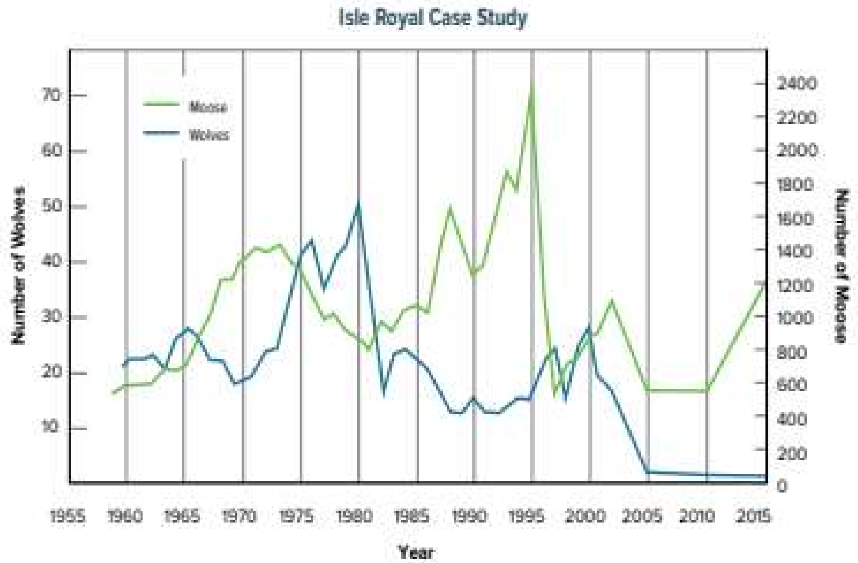


Figure 5 The long-term study of the wolf and moose populations on Isle Royale shows the relationship between the number of predators and prey over time.

Infer *what might have caused the increase in the number of moose between 1990 and 1995.*

Prior to the winter of 1947–48 there were apparently no wolves on Isle Royale. During that winter, a single pair of wolves crossed the ice on Lake Superior, reaching the island. During the next ten years the population of wolves reached about twenty individuals. Notice that the graph in **Figure 5** on the previous page shows that the rise and fall of the numbers of each group was dependent on the other group. For example, follow the wolves' line on the graph. As the number of wolves decreased, the number of moose increased.

Disease Another density-dependent factor is disease. Outbreaks of disease tend to occur when population size has increased and population density is high. When population density is high, disease is transmitted easily from one individual to another because contact between individuals is more frequent. Therefore, the disease spreads easily and quickly through a population. This is just as true for human populations as it is for populations of protists, plants, and other species of animals.

Competition Competition between organisms also increases when density increases. When the population increases to a size where resources such as food or space become limited, individuals in the population must compete for the available resources. Competition can occur within a species or between two different species that use the same resources. For example, the foxes fighting over the squirrel in **Figure 6** also compete with other species, such as coyotes, for the same food source.

Figure 6 A decrease in the food supply can trigger competition between members of the same species.

Competition for insufficient resources might result in a decrease in population density in an area due to starvation or to individuals leaving the area in search of additional resources. As the population size decreases, competition becomes less severe.

Parasites Like disease, parasitic organisms can place limits on a population. The presence of parasites is a density-dependent factor that can negatively affect population growth at higher densities.

Population growth rate

An important characteristic of any population is its growth rate. The **population growth rate** (PGR) explains how fast a given population grows. One of the characteristics of the population ecologists must know, or at least estimate, is natality. The natality of a population is the birthrate, or the number of individuals born in a given time period. Ecologists also must know the mortality—the number of deaths that occur in the population during a given time period.

The number of individuals emigrating or immigrating also is important. **Emigration** (em uh GRAY shun) is the term ecologists use to describe the number of individuals moving away from a population.

Immigration (ih muh GRAY shun) is the term ecologists use to describe the number of individuals moving into a population. In most instances, emigration is about equal to immigration. Therefore, natality and mortality usually are the most important factors in determining the population growth rate.

Some populations tend to remain approximately the same size from year to year. Other populations vary in size depending on conditions within their habitats. To better understand why populations grow in different ways, you should understand two mathematical models for population growth—the exponential growth model and the logistic growth model.

Exponential growth model Look at **Figure 7** to see how a population of mice would grow if there were no limits placed on it by the environment.

Assume that two adult mice breed and produce a litter of two young. Also assume the two offspring are able to reproduce in one month. If all of the offspring survive to breed, the population grows slowly at first. This slow growth period is defined as the lag phase. The rate of population growth soon begins to increase rapidly because the total number of organisms that are able to reproduce has increased. After only two years, the experimental mouse population would reach more than three million mice.

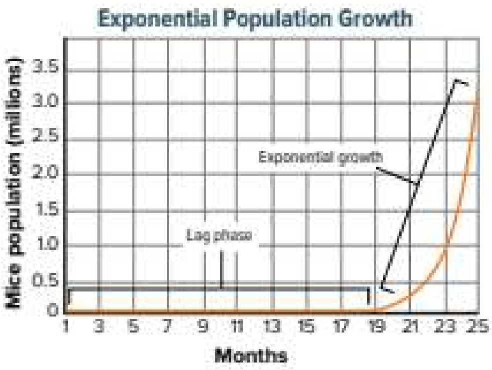


Figure 7 If mice were allowed to reproduce unhindered, the population would grow slowly at first but would accelerate quickly.

Infer *why mice or other populations do not continue to grow exponentially.*

MATH Connection Notice in **Figure 7** that once the mice begin to reproduce rapidly, the graph becomes J-shaped. A J-shaped growth curve illustrates exponential growth. Exponential growth, also called geometric growth, occurs when the growth rate is proportional to the size of the population. All populations grow exponentially until some limiting factor slows the population's growth. It is important to recognize that even in the lag phase, the use of available resources is exponential. Because of this, the resources soon become limited and population growth slows.

Logistic growth model Most populations grow like the model shown in **Figure 8** rather than the model shown in **Figure 7**. Notice that the graphs look exactly the same through some of the time period: the number of individuals begins very low, then increases very rapidly. During this period, competition for resources among individuals in the population is low.

The second graph, however, curves into the S-shape typical of logistic growth. Population growth stops increasing when an environment's carrying capacity has been reached.

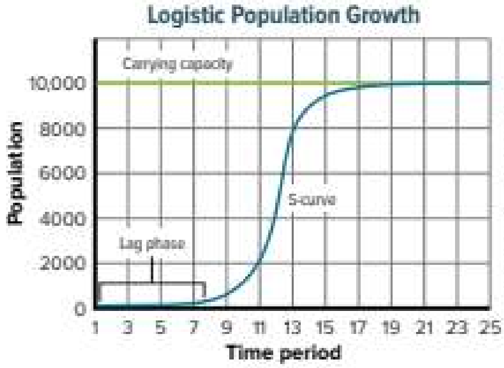


Figure 8 When a population exhibits growth that results in an S-shaped graph, it exhibits logistic growth. The population levels off at a limit called the carrying capacity.

Carrying capacity Ecosystems have limits to the numbers of organisms and populations they can support. The maximum number of individuals in a species that an environment can support for the long term is the **carrying capacity.** You will notice in **Figure 8** on the last page that logistic growth levels off at the line on the graph identified as the carrying capacity.

Carrying capacity is limited by such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. When populations develop in an environment with plentiful resources, there are more births than deaths. The population soon reaches or passes the carrying capacity. As a population nears the carrying capacity, resources become limited.

If a population exceeds the carrying capacity, deaths outnumber births because adequate resources are not available to support all of the individuals. The population then falls below the carrying capacity as individuals die. The concept of carrying capacity is used to explain why many populations tend to stabilize.

Reproductive patterns

The graph in **Figure 8** shows the number of individuals increasing until the carrying capacity is reached. The graph is a useful population model, and can be used to predict how a population's number might change over time.

However, there are several additional factors that must be considered for real populations. Species of organisms vary in the number of births per reproduction cycle, in the age that reproduction begins, and in the life span of the organism. Both plants and animals are placed into groups based on their reproductive factors. However, not all organisms fit under a specific reproductive strategy.

Members of one of the groups are called the *r*-strategists. The rate strategy, or *r*-strategy, is an adaptation for living in an environment where fluctuation in biotic or abiotic factors occur. Fluctuating factors might be availability of food, changing temperatures, or migrating animals. An *r*-strategist is generally a small organism such as a fruit fly, a mouse, or the locusts shown in **Figure 9**. *r*-strategists usually have short life spans and produce many offspring.

The reproductive strategy of an *r*-strategist is to produce as many offspring as possible in a short time period in order to take advantage of some environmental factor. Organisms classified as *r*-strategists typically expend little or no energy in raising their young to adulthood. Populations of *r*-strategists are usually controlled by density-independent factors, and they usually do not maintain a population near the carrying capacity.

Figure 9 Locusts, which are an example of *r*-strategists, produce many offspring in their short lifetimes.

Infer *what specific factors might fluctuate in a locust's environment.*

Just as some environments fluctuate, others are fairly predictable. The elephants in **Figure 10** experience a carrying capacity that changes little from year to year. The carrying-capacity strategy, or *k*-strategy, is an adaptation for living in environments that are fairly stable.

Figure 10 Elephants are *k*-strategists that produce few offspring, but they invest a lot of care in the raising of their offspring.

A *k*-strategist generally is a larger organism that has a long life span, produces few offspring, and whose population reaches equilibrium at the carrying capacity.

The reproductive strategy of a *k*-strategist is to produce only a few offspring that have a better chance of living to reproductive age because of the energy, resources, and time invested in the care for the young. The number of individuals in a population of *k*-strategists usually are controlled by density-dependent factors and not by density-independent factors. For example, a ten-degree change in temperature might be enough to drastically reduce the number of locusts in a population, but it would not likely influence the number of elephants in a population.

Check Your Progress

Summary

- There are population characteristics that are common to all populations of organisms, including plants, animals, and bacteria.
- Populations tend to be distributed randomly, uniformly, or in clumps.
- Population-limiting factors are either density-independent or density-dependent.
- Populations tend to stabilize near the carrying capacity of their environment.

Demonstrate Understanding

1. **Compare and contrast** spatial distribution, population density, and population growth rate.
2. **Summarize** the concepts of carrying capacity and limiting factors, and their effects on reproductive patterns.
3. **Sketch** diagrams showing population dispersion patterns.
4. **Analyze** the impact a nonnative species might have on a native species in terms of population dynamics.

Explain Your Thinking

5. **Design** an experiment that you could perform to determine which population growth model applies to fruit fly populations.
6. **WRITING Connection** Write a newspaper article describing how a weather event, such as drought, has affected a population of animals in your community.

LEARNSMART® Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

LESSON 2

HUMAN POPULATION

FOCUS QUESTION

What factors affect human population growth?

Human Population Growth

The study of human population size, density, distribution, movement, and birth and death rates is **demography** (de MAH gra fee). The graph in **Figure 11** shows demographers' estimated human population on Earth for several thousand years.

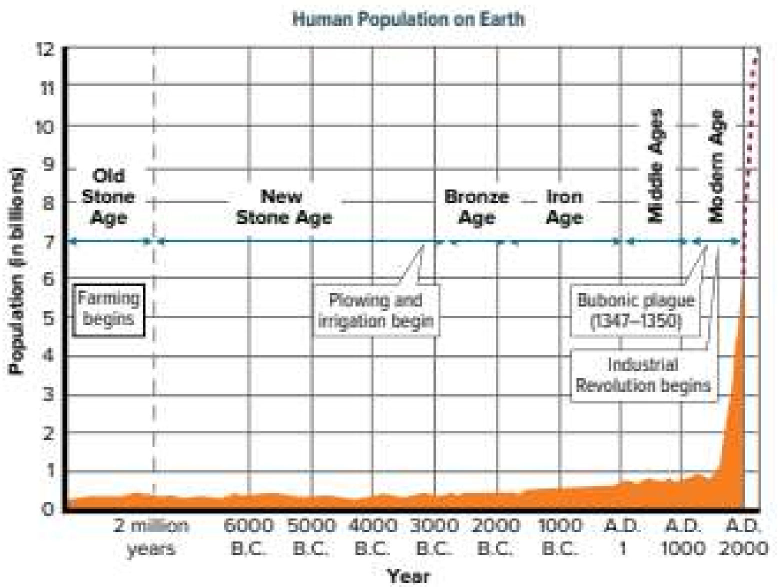


Figure 11 The human population on Earth was relatively constant until recent times, when the population began to grow at an exponential rate.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

BioLab: How can you show a population trend?
Plan and carry out an investigation to determine the cause and effect of population trends.

Quick Investigation: Evaluate Factors
Analyze and interpret data to determine the factors that affect population growth.

Notice **Figure 11** on the last page shows a relatively stable number of individuals over thousands of years—until recently. Notice also the recovery of the human population after the outbreak of the bubonic plague in the 1300s when an estimated one-third of the population of Europe died. Perhaps the most significant feature in this graph is the increase in the population in recent times. In 1804, the population of Earth was an estimated one billion people. Earth reached a milestone in 2011, when our population was recorded at seven billion people. With the current growth rate at just over 83 million people per year we are expected to reach a population of 9.8 billion by 2050.

Technological advances

For thousands of years, environmental conditions kept the size of the human population at a relatively constant number below the environment's carrying capacity. More recently, however, humans have altered the environment in ways that appear to have changed its carrying capacity. Agriculture and domestication of animals have increased the human food supply. Technological advances and medicine have improved the chances of human survival by reducing the number of deaths from parasites and disease. In addition, improvements in shelter have made humans less vulnerable to climatic impacts.

Get It?

Explain the factors that have contributed to an increase in the survival rate of the human population. Have these factors contributed to the homeostasis of the population within its enviroment? Explain.

Human population growth rate

Although the human population is still growing, the rate of its growth has slowed. **Figure 12** shows the percent increase in human population from the late 1940s through 2016. The graph also includes the projected population increase through 2050.

Notice the sharp dip in human population growth in the 1960s. This was due primarily to a famine in China in which about 60 million people died. The graph also shows that human population growth reached its peak at over 2.2 percent in 1963. By 2016, the percent increase in human population growth had dropped to less than 1.2 percent.

Population models predict the overall population growth rate to be below 0.6 percent by 2050. The decline in human population growth is due primarily to diseases such as AIDS and voluntary population control.

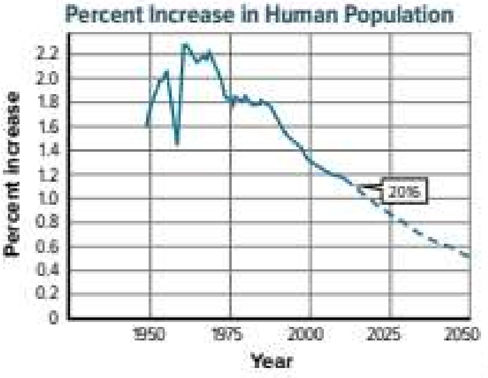


Figure 12 This graph shows the percent increase in the global human population using data from the late 1940s through 2016 and the projected percent increase to 2050.

Determine *the approximate population increase in the year 2025.*

Trends in Human Population Growth

The graph in **Figure 12** on the last page is somewhat deceptive. Population trends can be altered by events such as disease and war. **Figure 13** (next page) shows a few historical events that have changed population trends. **Figure 12** could also easily be misinterpreted because human population growth is not the same in all countries. However, population growth trends are often similar in countries that have similar economies.

For example, one trend that has developed during the previous century is a change in the population growth rate in industrially developed countries such as the United States. An industrially developed country is advanced in industrial and technological capabilities and has a population with a high standard of living. Criteria for determining developed countries include average national income, individual average health and education, and national export and import of goods.

In its early history, the United States had a high birthrate and a high death rate. It was not uncommon for people to have large families and for individuals to die by their early forties. Many children also died before reaching adulthood. Presently, the birthrate in the United States has decreased dramatically and the life expectancy is greater than seventy years. This change in a population from high birth and death rates to low birth and death rates is called a **demographic transition.**

MATH Connection How do population growth rates (PGR) compare in industrially developed countries and developing countries? As an example, we will compare the 2008 populations for the United States and Honduras, a small country in Central America. The calculation for PGR is

$$\frac{\text{birthrate} - \text{death rate} + \text{migration rate}}{10} = \text{PGR (\%)}$$

In our example, we'll have to divide the final answer by 10 to get a percentage because the rates are calculated per 1000. The United States has birthrate 14.1 (per 1000), death rate 8.3 (per 1000), and migration rate 2.9 (per 1000). This gives a PGR of 0.87 percent for the United States. Honduras has birthrate 26.9 (per 1000), death rate 5.4 (per 1000), and migration rate -1.3 (per 1000). This gives a PGR of 2.02 percent for Honduras.

Get It?

Compare the population growth rates in the United States and the United Kingdom, which has a birthrate of 12 (per 1000), death rate 8.8 (per 1000), and migration rate 2.5 (per 1000).

WORD ORIGINS

demography

demo– from the Greek word *demos*; meaning *people*

–ography from the French word *graphie*; meaning *writing*

Figure 13

History of Human Population Trends

Many factors have affected human population growth throughout history.

1 **1347-1351** The bubonic plague kills one-third of Europe's population and 75 million people throughout the world.

2 **1798** The first essay on human population is written by Thomas Malthus, who predicted exponential population growth leading to famine, poverty, and war.

3 **1800** The Industrial Revolution leads to a dramatic population explosion.

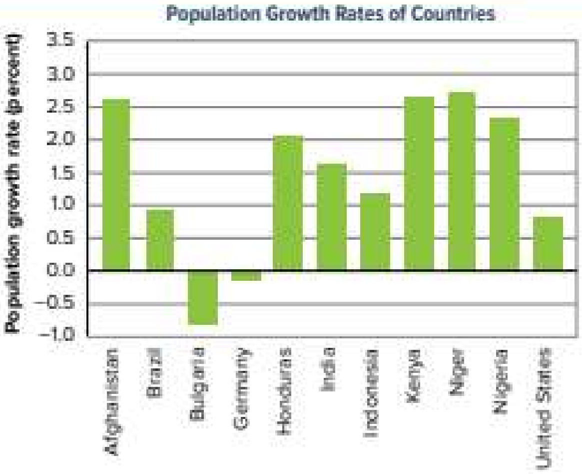
4 **1918** The Spanish flu kills between 50 and 100 million people.

5 **1939-1945** Approximately 58 million people are killed during World War II.

6 **1954** Improved medical care, medicines, and sanitation leads to an increase in human population.

7 **2014** An estimated 1.2 million people die from AIDS-related causes.

Table 1 Population Growth Rates of Countries

Country	Population Growth Rate (percent)	Location
Afghanistan	2.63	
Brazil	0.98	
Bulgaria	−0.81	
Germany	−0.04	
Honduras	2.02	
India	1.58	
Indonesia	1.18	
Kenya	2.76	
Niger	2.88	
Nigeria	2.38	
United States	0.88	

Population growth models predict that the total number of people added to the world population in developing countries will be greater than the total number of people added in the industrially developed countries. For example, between now and 2050, the developing country Niger—shown in **Table 1**—will be one of the fastest growing countries. Assuming that the growth rate remains the same, its population is expected to expand from 13 to 53 million people. The industrially developed country Bulgaria is expected to have a population decline from seven to five million people in the same time period.

Zero population growth

Another trend that populations can experience is zero population growth. **Zero population growth** (ZPG) occurs when births plus immigration equals deaths plus emigration for a generation. This will mean that the population has stopped growing, because births and deaths occur at the same rate. Once the world population reaches ZPG, the age structure eventually should be more balanced with numbers at pre-reproductive, reproductive, and post-reproductive ages being approximately equal.

Zero population growth is a goal of many countries and societies. Many population planners and environmentalists believe that ZPG will contribute to the sustainability of Earth's ecosystems.

CCC CROSSCUTTING CONCEPTS

Scale, Proportion, and Quantity Carefully study the data presented in **Table 1.** Research to find the current population of each of these countries. Assuming that the growth rate remains the same, determine what the population of these countries will be in 10 years. Select a country that you think has a problematic trend and prepare a report for its government summarizing the population trend for the next decade. Use your evidence to identify potential problems and suggest solutions for these problems.

STUDY TIP

Interactive Reading As you read, write three questions about human population dynamics. The questions should begin with why, how, where, or when. Ask a partner the questions about the content in the module.

Age structure

Another important characteristic of any population is its age structure. A population's **age structure** is the number of males and females in each of three age groups: pre-reproductive stage, reproductive stage, and post-reproductive stage. Humans are considered to be pre-reproductive before age 20 even though they are capable of reproduction at an earlier age. The reproductive years are considered to be between 20 and 44, and the post-reproductive years are after age 44.

Analyze the age structure diagrams for three different representative countries in **Figure 14**. The age structure diagrams are typical of many countries in the world. Notice the shape of the overall diagram for a country that is rapidly growing, one that is growing slowly, and one that has reached negative growth. The age structure for the world's human population looks more like that of a rapidly growing country.

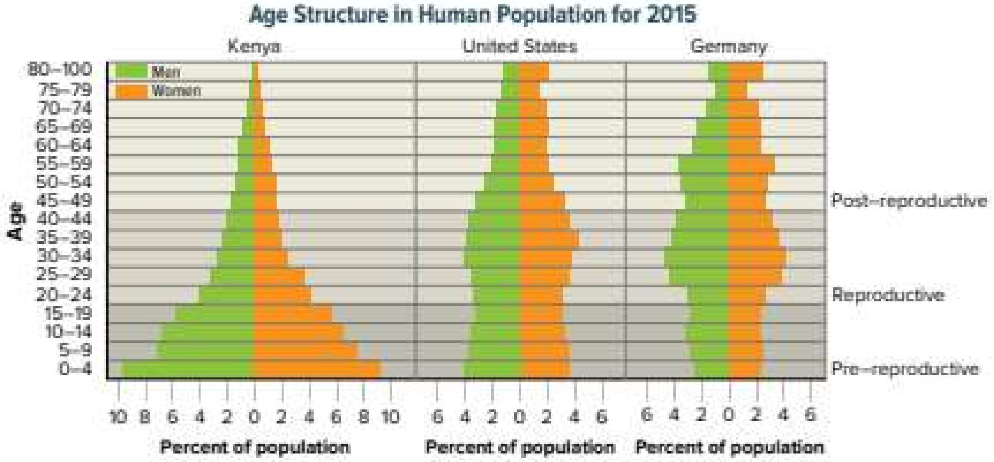


Figure 14 The relative numbers of individuals in pre-reproductive, reproductive, and post-reproductive years are shown for three representative countries.

Get It?

Compare and contrast the age structures of the countries shown in **Figure 14**.

Earth's carrying capacity for humans

Calculating population growth rates is not just a mathematical exercise. Scientists are concerned about the human population reaching or exceeding the carrying capacity. As you learned in Lesson 1, all populations are limited by the carrying capacity of their ecosystems, and the human population is no exception. Many scientists suggest that human population growth needs to be reduced. In many countries, voluntary population control is occurring through family planning. Unfortunately, if the human population continues to grow—as most populations do— and areas become overcrowded, disease and starvation will occur. However, technology has allowed humans to increase the carrying capacity of Earth, at least temporarily. It might be possible for technology and planning to keep the human population at or below Earth's carrying capacity.

Another important factor in keeping the human population at or below the carrying capacity is the amount of resources from the biosphere that are used by each person. Currently, individuals in industrially developed countries use far more resources than those individuals in developingv countries, as shown in **Figure 15**. This graph shows the estimated amount of land required to support a person through his or her life, including land used for production of food, forest products and housing, and the additional forest land required to absorb the carbon dioxide produced by the burning of fossil fuels. Countries such as India are becoming more industrialized, and they have a high growth rate. These countries are adding more people and are increasing their use of resources. At some point, the land needed to sustain each person on Earth might exceed the amount of land that is available. At that time the human population will likely have exceeded Earth's carrying capacity.

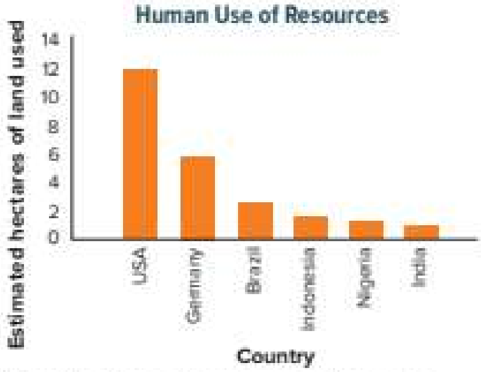


Figure 15 The amount of resources used per person varies around the world.

Check Your Progress

Summary

- Human population growth rates vary in industrially developing countries and industrialized countries.
- Zero population growth occurs when the birthrate and immigration rate of a population equals the death rate and the emigration rate.
- The age structure of the human population is a contributing factor to population growth in some countries.
- Earth has an undefined carrying capacity for the human population.

Demonstrate Understanding

1. **Describe** the change in human population growth over time.
2. **Describe** the differences between the age structure graphs of nongrowing, slowly growing, and rapidly growing countries.
3. **Assess** the consequences of exponential population growth of any population.
4. **Summarize** why the human population began to grow exponentially in the Modern Age.

Explain Your Thinking

5. **Analyze** how a newly emerging disease might affect the population size in an industrially developing and in an already developed country.
6. **MATH Connection** Construct an age-structure diagram using the following percentages: 0–19 years: 44.7; 20–44 years: 52.9; 45 years and over: 2.4. Which type of growth is this country experiencing?

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STEM AT WORK

As Easy (or Not) as 1, 2, 3

Biologists and other scientists often count populations of organisms as part of their work in the field. There are several different methods scientists can use to determine or estimate a population count.

In mark-recapture sampling, scientists often insert a passive integrated transponder into an animal to record information on its growth, movements, and survival.

Complete Counts, Sampling, and Indirect Counts

With a *complete count*, scientists count every member of a population. They can use an airplane to fly over a population and take photographs of its members, or they can walk across an area and count every population member they see. With *sampling*, scientists count a small number of population members and use that number to estimate the total population. With an *indirect count*, scientists count signs left by a population—such as scat, nests, and dens—instead of counting the actual members of the population.

Quadrat sampling is used with plant species, which do not move, or with animal species that move very slowly. Scientists count all members of a population in a specific area (called a quadrat) and then extrapolate to estimate the total population. In *transect sampling*, scientists "draw" lines across an area instead of marking off a quadrat. They walk the lines and count the plants or animals they see along the lines. They use those numbers to estimate the total population.

Mark-recapture

Mark-recapture is a sampling method used with animals. Scientists capture members of a population, tag them, and release them.

Later, scientists recapture population members. They count the number of untagged and already-tagged animals. They then use these numbers to determine a ratio (tagged to untagged animals) and extrapolate that to an estimation of the total population.

PLAN AND CONDUCT AN INVESTIGATION

Work with a partner to conduct a quadrat sampling population count on an area of one square meter. Record your data in a table. Discuss how to use your data to estimate the total population.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 POPULATION DYNAMICS

- There are population characteristics that are common to all populations of organisms, including plants, animals, and bacteria.
- Populations tend to be distributed randomly, uniformly, or in clumps.
- Population limiting factors are either density-independent or density-dependent.
- Populations tend to stabilize near the carrying capacity of their environment.

- population density
- dispersion
- density-independent factor
- density-dependent factor
- population growth rate (PGR)
- emigration
- immigration
- carrying capacity

Lesson 2 HUMAN POPULATION

- Human population growth rates vary in industrially developing countries and industrialized countries.
- Zero population growth occurs when the birthrate and immigration rate of a population equals the death rate and the emigration rate.
- The age structure of the human population is a contributing factor to population growth in some countries.
- Earth has an undefined carrying capacity for the human population.

- demography
- demographic transition
- zero population growth (ZPG)
- age structure

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

Why are bee populations declining?

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will summarize your evidence and apply it to the project.

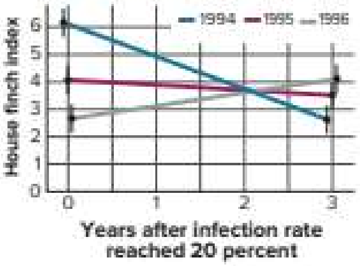
GO FURTHER

SEP Data Analysis Lab

Do parasites affect the size of a host population?

In 1994, the first signs of a serious eye disease caused by the bacterium *Mycoplasma gallisepticum* were observed in house finches that were eating in backyard bird feeders. Volunteers collected data at the beginning of three different years on the number of finches infected with the parasite and the total number of finches present.

House Finches and *Mycoplasma gallisepticum* Infection



*Data obtained from: Gregory, R., et al. 2000. Parasites take control. *Nature* 406: 33–34.

Data and Observations The graph shows the abundance of house finches in areas where the infection rate was at least 20 percent of the house finch population. It also shows the changes in the population over the three years following the initial count.

CER Analyze and Interpret Data

1. **Compare** the data from the three years.
2. **Claim, Evidence, Reasoning** Explain why the house finch abundance stabilized in 1995 and 1996.
3. **Infer** whether the parasite is effective in limiting the size of house finch populations. Explain.

THE IMMUNE SYSTEM

ENCOUNTER THE PHENOMENON

Why would this scientist need all this protection?

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

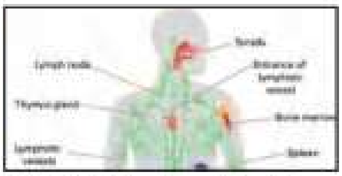
Make Your Claim Use your CER chart to make a claim about why this scientist would need all this protection. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 1: Explore & Explain: The Immune System: Diseases



LESSON 2: Explore & Explain: The Immune System: Specific Immunity

LESSON 1

INFECTIOUS DISEASES

FOCUS QUESTION

What are infectious diseases?

Pathogens Cause Infectious Disease

What do a cold and athlete's foot have in common? They are both examples of an infectious disease. An **infectious disease** is a disease that is caused by a pathogen passed from one organism to another, disrupting homeostasis in the organism's body. Agents called **pathogens** are the cause of infectious diseases. Some, but not all, types of bacteria, viruses, protozoans, fungi, and parasites are pathogens.

Many types of these organisms present in the world around us do not cause infectious diseases. Your body benefits from organisms, such as certain types of bacteria and protozoans, that normally live in your intestinal and reproductive tracts. Other bacteria live on your skin, especially in the shafts of your hair follicles. These organisms keep pathogens from thriving and multiplying on your body.

Germ Theory and Koch's Experiments

Before the invention of the microscope, people thought "something" passed from a sick person to a well person to cause an illness. Then, scientists discovered microorganisms and Louis Pasteur demonstrated that microorganisms from the air are able to grow in nutrient solutions. With the knowledge gained from these and other discoveries, doctors and scientists began to develop the germ theory. The germ theory states that some microorganisms are pathogens. However, scientists were not able to clearly demonstrate this theory until Robert Koch developed his postulates.

Identification of the first disease pathogen

In the late 1800s, Robert Koch, a German physician, was studying anthrax (AN thraks)–a deadly disease that affects cattle and sheep and can also affect people.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

BioLab: Forensics: How do you find Patient Zero?
Plan and carry out an investigation to determine patterns that indicate who is patient zero.

Revisit the Encounter the Phenomenon Question
What information from this lesson can help you answer the Module question?

Koch isolated bacteria, like those in **Figure 1**, from the blood of cattle that had died from anthrax. After growing the bacteria in the laboratory, Koch injected the bacteria into healthy cattle. These animals developed the disease anthrax. He then isolated bacteria from the blood of newly infected cattle and grew the bacteria in the laboratory. The characteristics of the two sets of cultures were identical, indicating that the same type of bacteria caused the illness in both sets of cattle. Thus, Koch demonstrated that the bacteria he originally isolated were the cause of anthrax.

Color-Enhanced SEM Magnification: unavailable

Figure 1 These rodlike bacteria cause the disease anthrax.

Get It?

Explain how Koch proved the germ theory correct.

Koch's postulates

Koch established and published experimental steps known as **Koch's postulates,** which are rules for demonstrating that an organism causes a disease. These steps are followed today to identify a specific pathogen as the agent of a specific disease. Follow the steps in **Figure 2** as you read each of the four postulates.

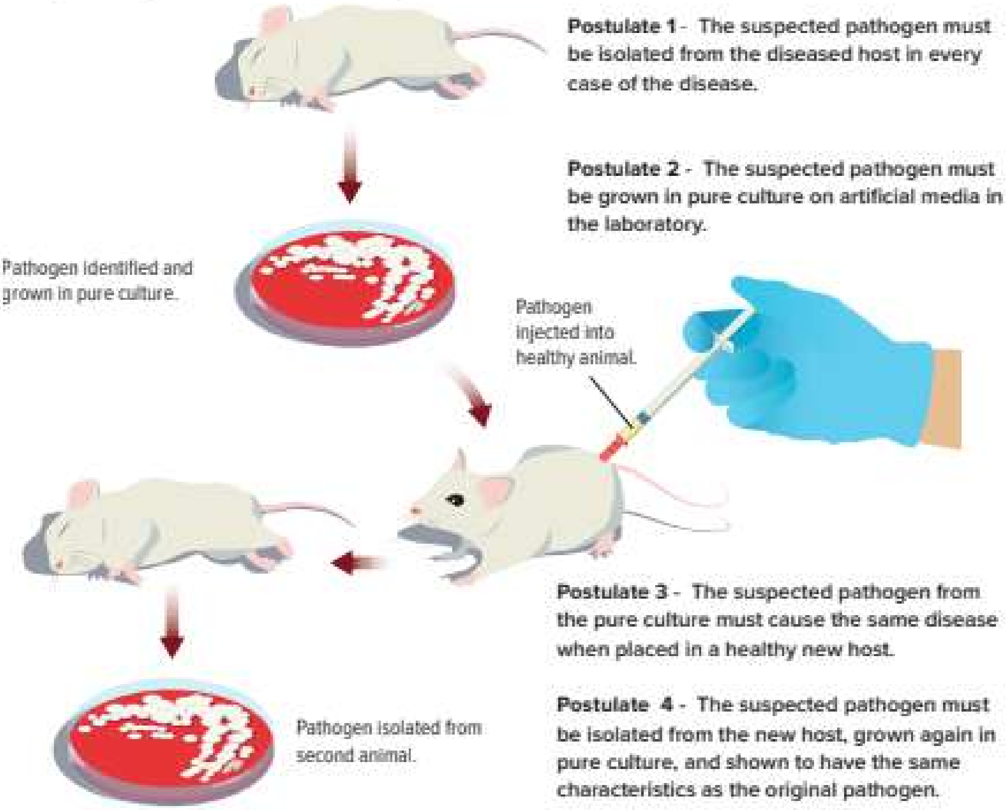


Figure 2 Koch's postulates demonstrate that a specific pathogen causes a specific disease.

Infer *what Koch demonstrated when he isolated the same bacteria from the cattle the second time.*

Some exceptions to Koch's postulates do exist. Some pathogens, such as the pathogen that is thought to cause syphilis (SIH fuh lus), cannot be grown in pure culture on artificial media. Artificial media are the nutrients that the bacteria need to survive and reproduce. Pathogens are grown on this media in the laboratory. Also, in the case of viruses, cultured cells are needed because viruses cannot be grown on artificial media.

Spread of Disease

Although there are a large number of microorganisms, only a few cause disease. Some might cause mild diseases, such as the common cold. Others cause serious diseases, such as meningitis, an infection of the coverings of the brain and spinal cord. **Table 1** lists some human infectious diseases. For a pathogen to spread, it must have both a reservoir and a way to spread. A disease **reservoir** is a source of the pathogen in the environment. Reservoirs might be animals, people, or inanimate objects, such as soil.

Human reservoirs

Humans are the main reservoir for pathogens that affect humans. Many pathogens might be passed on to other hosts before the person even knows he or she has the disease. An individual that is symptom-free but capable of passing the pathogen is called a carrier. Pathogens that cause colds, the flu, and sexually transmitted diseases, such as HIV, can be passed on without the person knowing he or she is infected.

Animal reservoirs

Other animals also are reservoirs of pathogens that can be passed to humans. Influenza and rabies are examples of human diseases listed in **Table 1** that are caused by pathogens passed to humans from other animals. Influenza can infect pigs. Rabies is found in domestic dogs and many wild animals, such as bats, skunks, and raccoons.

Table 1 Human Infectious Diseases

Disease	Cause	Affected Organ System	How Disease is Spread
Tetanus	Bacterium	Nervous system	Soil in deep puncture wound
Strep throat	Bacterium	Respiratory system	Droplets/direct contact
Lyme disease	Bacterium	Skeletal and nervous systems	Vector (tick)
Chicken pox	Virus	Skin	Droplets/direct contact
Rabies	Virus	Nervous system	Animal bite
Influenza (the flu)	Virus	Respiratory system	Droplets/direct contact
Hepatitis B	Virus	Liver	Direct contact with exchange of body fluids
Giardia	Protozoan	Digestive tract	Contaminated water
Malaria	Protozoan	Blood and liver	Vector (mosquito)
Athlete's foot	Fungus	Skin	Direct contact or contaminated objects

Other reservoirs

Some bacteria normally found in the soil, such as tetanus bacteria, can cause disease in humans. The tetanus bacteria can cause a serious infection if it contaminates a deep wound in the body. Contamination of wounds by bacteria was a major cause of death during wars before the development of antibiotics and vaccinations.

Contaminated water or food is another reservoir of pathogens for human disease. One of the main purposes of sewage treatment plants is the safe disposal of human feces, which prevents contamination of the water supply by pathogens. Contaminated water used in growing or preparing food can transfer pathogens. Food also can become contaminated through contact with humans or insects such as flies.

Transmission of pathogens

Pathogens are transmitted to humans in four main ways: direct contact, indirectly through the air, indirectly through touching contaminated objects, or by organisms called vectors that carry pathogens. **Figure 3** illustrates some of the ways pathogens can be transmitted to humans.

Figure 3 Diseases can be transmitted to humans in various ways.

Identify *ways to prevent contracting diseases if contact cannot be avoided.*

Direct contact Direct contact with other humans is one of the major modes of transmission of pathogens. Diseases such as colds, infectious mononucleosis (mah noh new klee OH sus) (commonly referred to as mono, or the "kissing disease"), herpes (HUR peez), and sexually transmitted diseases are caused by pathogens passed through direct contact, even if the person is a carrier.

Indirect contact Some pathogens can be passed through the air. When a person with an infectious disease sneezes or coughs, pathogens can be passed along with the tiny mucus droplets. These droplets then can spread pathogens to another person or to an object.

Many organisms can survive on objects handled by humans. Cleansing of dishes, utensils, and countertops with detergents, as well as careful hand-washing help prevent the spread of diseases that are passed in this manner. As a result, there are various food rules that restaurants must abide by that are based on preventing the spread of disease.

Vectors Certain diseases can be transmitted by vectors. The most common vectors are arthropods, which include biting insects such as mosquitoes and ticks. Recall from **Table 1** on the previous page that Lyme disease and malaria are diseases that are passed to humans by vectors. The Zika virus is another exmple of a disease that can be passed to humans by a vector. The Zika virus, which is currently spreading across South America and North America, is transmitted to humans by infected mosquitoes. The mosquitoes become infected when they bite a person who is already infected with the Zika virus. The West Nile virus, cases of which were reported in 47 states in 2016, is transmitted from horses and other mammals to humans by mosquitoes. Flies can transmit pathogens by landing on infected materials, such as feces, and then landing on materials handled or eaten by humans.

Get It?
Describe how diseases are spread to humans.

Symptoms of Disease

When you become ill with a disease such as the flu, why do you feel aches and pains, and why do you cough and sneeze? The pathogen, such as the influenza virus or bacteria, has invaded some of the cells of your body. The virus multiplies in the cells and leaves the cells either by exocytosis, or by causing the cell to burst. Thus, the virus damages tissues and even kills some cells. When pathogenic bacteria invade the body, harmful chemicals or toxins might be produced. The toxins can be carried throughout the body via the bloodstream and damage various parts of the body.

CCC CROSSCUTTING CONCEPTS

Patterns Koch's research established the idea that some microorganisms cause infectious diseases. Summarize the historical evidence that lead to the germ theory. Present your summary in the form of a news report that starts with the following sentence: "People have known for some time that 'something' passes from a sick person to a well person to cause an illness."

SCIENCE USAGE v. COMMON USAGE

carrier

Science usage: person who spreads germs while remaining well

Typhoid fever was spread by a carrier known as "Typhoid Mary."

Common usage: a person or corporation in the transportation business

Freight is shipped by carriers.

Toxins produced by some pathogens can affect specific organ systems. The tetanus bacteria produce a potent toxin that causes spasms in voluntary muscles. The disease botulism (BAH chuh lih zum) usually is caused when a person consumes food in which the botulism bacteria have grown and produced a toxin. This toxin paralyzes nerves. The toxin from the botulism bacteria can cause disease in humans even when no bacteria are present.

Some types of bacteria, some protozoans, and all viruses invade and live inside cells, causing damage. Because the cells are damaged, they might die, causing symptoms in the host. Some disease symptoms, such as coughing and sneezing, are triggered by the immune system, as discussed later in this module. For a closer look at research on the immune system, examine **Figure 4**, on the next page.

Get It?

Describe what happens when a person consumes food that contains botulism bacteria.

Disease Patterns

As outbreaks of diseases spread, certain patterns are observed. Agencies such as community health departments, the Centers for Disease Control and Prevention (CDC), and the World Health Organization (WHO) continually monitor disease patterns to help control the spread of diseases. The CDC, with headquarters in Atlanta, Georgia, receives information from doctors and medical clinics and publishes a weekly report about the incidence of specific diseases, as shown in **Figure 5**. The WHO similarly watches disease incidence throughout the world.

TABLE 2. Reported cases of notifiable diseases,* by geographic division and area – United States, 2014

Area	Total resident population (in thousands)	Lyme disease
UNITED STATES	318,856	33,461
NEW ENGLAND	14,681	11,292
Connecticut	3,597	2,360
Maine	1,330	1,401
Massachusetts	6,745	5,304
New Hampshire	1,327	724
Rhode Island	1,055	904
Vermont	627	599
MID. ATLANTIC	41,471	14,509
New Jersey	8,938	3,286
New York (Upstate)	11,255	2,887
New York City	8,491	849
Pennsylvania	12,787	7,487
E.N. CENTRAL	46,740	1,950
Illinois	12,881	233
Indiana	6,597	110
Michigan	9,910	127
Ohio	11,594	119

Figure 5 The Centers for Disease Control and Prevention publish reports on the incidence of certain diseases.

Infer *how these reports are helpful in understanding disease patterns.*

Some diseases, such as the common cold, are known as **endemic diseases** because small numbers of incidents are continually found within the population. Sometimes, a particular disease will have a large outbreak in an area and afflict many people, causing an **epidemic.** In 2003, there was an epidemic of severe acute respiratory syndrome (SARS). If an epidemic is widespread throughout a large region, such as a country, continent, or the entire globe, it is described as **pandemic.** HIV is an example of a pandemic. Influenza has led to several pandemics throughout history, including the Spanish flu in 1918, the Asian flu in 1957, and the Hong Kong flu in 1968. Each of the these flu pandemics killed millions of people worldwide.

Get It?

Compare and contrast an epidemic and a pandemic.

Figure 4

Immunology Through Time

For centuries, scientists have struggled to learn about the human immune system. Today, scientists are working to stop HIV, a virus that has attacked the immune system of over 40 million people worldwide.

1 **1796** Edward Jenner discovers that a patient vaccinated with the cowpox virus is immune to smallpox.

2 **1908** Elie Metchnikoff observes phagocytosis, and Paul Ehrlich describes antibodies. They share a Nobel Prize for their discoveries.

3 **1981** The first clinical description of acquired immunodeficiency syndrome (AIDS) is established.

4 **1984** Luc Montagnier and Robert Gallo independently announce the discovery of the virus that causes AIDS.

5 **1985** Flossie Wong-Staal and her team clone HIV, enabling scientists to create a test to determine whether or not a person has HIV.

6 **1999** Dr. Beatrice Hahn hypothesizes that humans most likely were exposed to HIV from a chimp.

7 **2009** Treatments for HIV/AIDS that use a combination of targeted chemotherapy and highly active retroviral treatments seek out and destroy HIV/AIDS infected cells.

8 **2015** Around 2 million people have started antiretroviral therapy for HIV bringing the total to 17 million people.

Treating and Fighting Diseases

A medical professional may prescribe a drug to help the body fight a disease. One type of prescription drug is an **antibiotic** (an ti bi AH tihk), which is a substance that can kill or inhibit the growth of microorganisms. Penicillin is secreted by the fungus *Penicillium*, which is shown in **Figure 6**. This fungus secretes the chemical penicillin to kill competing bacteria that grow on the fungal food source. Penicillin was isolated, purified, and first used in humans during World War II. Many other fungal secretions are used as antibiotics, such as erythromycin, neomycin, and gentamicin. Synthetic antibiotics also have been developed by pharmaceutical companies.

Figure 6 Penicillin, a widely used antibiotic, is secreted by the mold called *Penicillium*, shown growing on these oranges.

Determine *why many strengths and varieties of penicillin and other antibiotics are needed.*

Chemical agents also are used in the treatment of protozoan and fungal diseases. Some antiviral drugs are used to treat herpes infections, influenza in the elderly, and HIV infections. Most viral diseases are handled by the body's built-in defense system—the immune system.

Get It?

Explain the history of the use of penicillin as an antibiotic.

HEALTH Connection Over the last 60 years, the widespread use of antibiotics has caused many bacteria to become resistant to particular antibiotics. Natural selection occurs when organisms with favorable variations survive, reproduce, and pass their variations to the next generation. Bacteria in a population might have a trait that enables them to survive when a particular antibiotic is present. These bacteria can reproduce quickly and pass on the variation. Because reproduction can occur so rapidly in bacteria, the number of antibiotic-resistant bacteria in a population can increase quickly, too.

Problems resulting from antibiotic resistance

Antibiotic resistance of bacteria has presented the medical community with problems when treating certain diseases. For example, penicillin was used effectively for many years to treat gonorrhea (gah nuh REE uh), a sexually transmitted disease, but now most strains of gonorrhea bacteria are resistant to penicillin. As a result, new drug therapies are needed to treat gonorrhea. **Figure 7**, on the next page, shows the increase in gonorrhea resistance from 1980—1990.

Another treatment problem is with staphylococcal disease—it is acquired in high-density living conditions, which can result in skin infections, pneumonia (noo MOH nyuh), or meningitis. These staphylococci are often strains of bacteria that are resistant to many current antibiotics and can be difficult to treat.

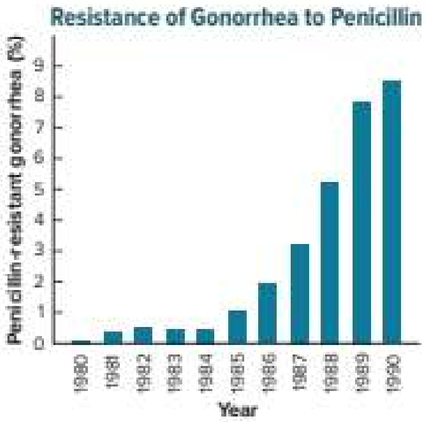


Figure 7 The graph shows the reported incidence of penicillin-resistant gonorrhea in the U.S. from 1980–1990.

For example, MSRA, or methicillin-resistant *Staphylococcus aureus*, is a type of bacteria that is a common cause of infections in hospitals and other healthcare facilities. It is spread by direct contact, usually from the contaminated hands of healthcare providers.

Streptococcus pneumonia is another bacterium that has become resistant to antibiotics. This bacterium causes pneumonia, sinus infections, and infections in the bloodstream. The bacterium that causes tuberculosis, a respiratory infection, can be resistant to the initial antibiotics used to treat the infection. In these cases, different medications are used to treat the infection, but it takes more time and can be more expensive. Scientists are continually researching solutions to treat antibiotic-resistant bacteria.

Check Your Progress

Summary

- Pathogens, such as bacteria, viruses, protozoans, and fungi, cause infectious diseases.
- Koch's postulates describe the accepted procedure for demonstrating that a particular pathogen causes a specific disease.
- Pathogens are found in disease reservoirs and are transmitted to humans by direct and indirect methods.
- The symptoms of disease are caused by invasion of the pathogen and the response of the host immune system.
- Treatment of infectious disease includes the use of antibiotics and antiviral drugs.

Demonstrate Understanding

1. **Compare** the mode of transmission of the common cold with that of malaria.
2. **Summarize** some symptoms of a bacterial infectious disease.
3. **Define** infectious disease and give three examples of infectious diseases.
4. **Illustrate** Koch's postulates for a bacterial infectious disease in a rabbit by drawing a graphic organizer or a concept map.
5. **Analyze** why the CDC calls hand-washing a "do-it-yourself" vaccine.

Explain Your Thinking

6. **Evaluate** the following scenario: Two days after visiting a pet shop and observing green parrots in a display cage and fish in an aquarium, a student developed a fever, became ill, and was diagnosed with parrot fever. What might be the disease reservoir and possible transmission method?
7. **Analyze** how the widespread use of antibiotics to treat infectious diseases has played a role in the development of antibiotic-resistant bacteria. How are scientists dealing with this issue?

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LESSON 2
THE IMMUNE SYSTEM

FOCUS QUESTION
How do nonspecific and specific immunity compare?

Nonspecific Immunity

At the time of birth, the body has a number of defenses in the immune system that fight off pathogens. These defenses are nonspecific because they are not aimed at a specific pathogen. They protect the body from any pathogen that the body encounters.

The nonspecific immunity provided by the body helps to prevent disease. Nonspecific immunity also helps to slow the progression of the disease while the specific immunity begins to develop its defenses. Specific immunity is the most effective immune response, but nonspecific immunity is the first line of defense.

Barriers

Like the strong walls of a fort, barriers are used by the body to protect against pathogens. These barriers are found in areas of the body where pathogens might enter.

Skin barrier The first major line of defense is the unbroken skin and its secretions. Skin contains layers of living cells covered by many layers of dead skin cells. By forming a barrier, the layers of dead skin cells help protect against invasion by microorganisms. Of the many different types of bacteria that normally live on the skin, most have little or no effect on our health. Many of the bacteria that live symbiotically on the skin digest skin oils to produce acids that inhibit many pathogens. **Figure 8** shows bacteria that are normally found on the skin and protect the skin from attack.

SEM Magnification: unavailable

Staphylococcus epidermidis

Figure 8 These bacteria are found on human skin and provide protection from pathogens.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE
Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE
GO ONLINE to find these activities and more resources.

CCC **Identify Crosscutting Concepts**
Create a table of the crosscutting concepts and fill in examples you find as you read.

Review the News
Obtain information from a current news story about the immune system. Evaluate your source and communicate your findings to your class.

Chemical barriers Saliva, tears, and nasal secretions contain the enzyme lysozyme. Lysozyme breaks down bacterial cell walls, which kills pathogens.

Another chemical defense is mucus, which is secreted by many inner surfaces of the body. It acts as a protective barrier, blocking bacteria from sticking to the inner epithelial cells. Cilia also line the airway. Their beating motion sends any bacteria caught in the mucus away from the lungs. When the airway becomes infected, extra mucus is secreted, which triggers coughing and sneezing to help move the infected mucus out of the body.

A third chemical defense is the hydrochloric acid secreted in your stomach. In addition to digestion, stomach acid kills many microorganisms found in food that could cause disease.

Get It?

Compare and contrast the different types of barriers of the immune system.

Nonspecific responses to invasion

Even if an enemy gets through the walls of a town's fort, defense doesn't end. Similarly, the body has nonspecific immune responses to pathogens that get beyond its barriers.

Cellular defense If foreign microorganisms enter the body, the cells of the immune system, shown in **Table 2**, on the next page, defend the body. One method of defense is phagocytosis. White blood cells, especially neutrophils and macrophages, are phagocytic. Recall that phagocytosis is the process by which phagocytic cells surround and internalize the foreign microorganisms. The phagocytes then release digestive enzymes and other harmful chemicals from their lysosomes, destroying the microorganism.

A series of about 20 proteins that are found in the blood plasma are called complement proteins. **Complement proteins** enhance phagocytosis by helping the phagocytic cells bind better to pathogens and activating the phagocytes. Some complement proteins can form a complex in the plasma membrane of a pathogen. This complex forms a pore, which aids in the destruction of the pathogen, as shown in **Figure 9**.

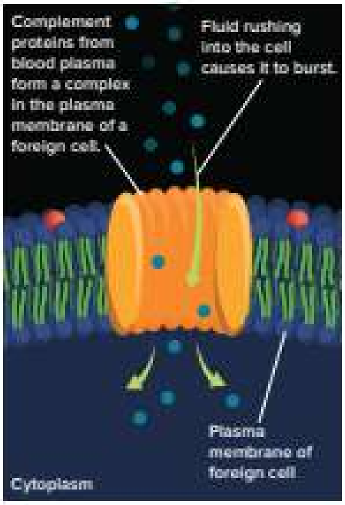


Figure 9 For some pathogens, complement proteins can form a pore in the plasma membrane of the invading cell.

Interferon When a virus enters the body, another cellular defense helps prevent the virus from spreading. Virus-infected cells secrete a protein called **interferon.** Interferon binds to neighboring cells and stimulates these cells to produce antiviral proteins which can prevent viral replication in these cells.

Inflammatory response Another nonspecific response, the inflammatory response, is a complex series of events that involves many chemicals and immune cells that help enhance the overall immune response. When pathogens damage tissue, chemicals are released by both the invader and cells of the body. These chemicals attract phagocytes to the area, increase blood flow to the infected area, and make blood vessels more permeable to allow white blood cells to escape into the infected area.

This response aids in the accumulation of white blood cells in the area. Some of the pain, heat, and redness experienced during an infectious disease are the result of the inflammatory response.

Table 2 Cells of the Immune System

Type of Cell	Example	Function
Neutrophils	LM Magnification: 800× 	Phagocytosis: blood cells that ingest bacteria
Macrophages		Phagocytosis: blood cells that ingest bacteria and remove dead neutrophils and other debris
Lymphocytes	LM Magnification: 1600× 	Specific immunity (antibodies and killing of pathogens): blood cells that produce antibodies and other chemicals

Specific Immunity

Pathogens sometimes get past the nonspecific defense mechanisms. In this event, the body has a second line of defense that attacks the pathogens. Specific immunity is more effective and involves the tissues and organs found in the lymphatic system.

Lymphatic system

The lymphatic system, shown in **Figure 10**, includes organs and cells that filter lymph and blood, destroy foreign microorganisms, and absorb fat. Lymph is the watery part of the blood (the plasma) that leaks out of capillaries to bathe all the cells in the body. This clear fluid, containing oxygen, nutrients, and white blood cells, circulates among the tissue cells, is collected by lymphatic vessels, and is returned to the circulatory system via the veins near the heart.

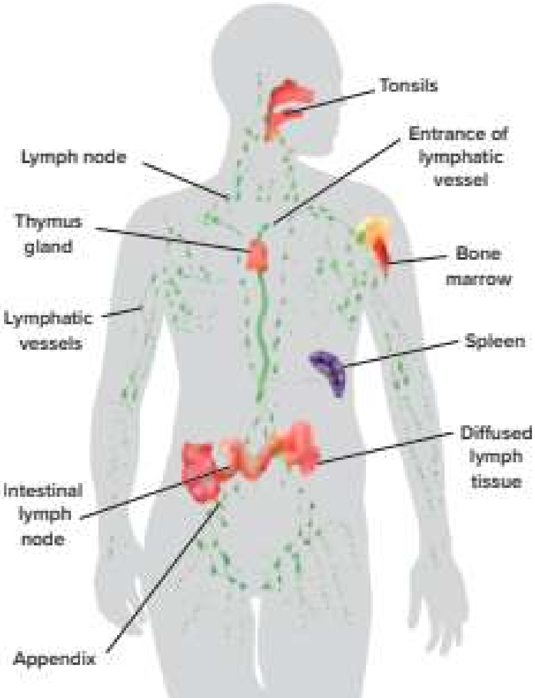


Figure 10 The lymphatic system contains the organs involved in the specific immune response.

Identify *the lymphatic organ where T cells mature.*

Lymphatic organs

The organs of the lymphatic system contain lymphatic tissue, lymphocytes, a few other cell types, and connective tissue. **Lymphocytes** are a type of white blood cell that is produced in red bone marrow. The lymphatic organs include the lymph nodes, tonsils, spleen, thymus (THI mus) gland, and diffused lymphatic tissue found in mucous membranes of the intestinal, respiratory, urinary, and genital tracts.

The lymph nodes filter the lymph and remove foreign materials from the lymph. The tonsils form a protective ring of lymphatic tissue between the nasal and oral cavities. This helps protect against bacteria and other harmful materials in the nose and mouth.

The spleen stores blood and destroys damaged red blood cells. It also contains lymphatic tissue that responds to foreign substances in the blood. The thymus gland, which is located above the heart, plays a role in activating a special kind of lymphocyte called T cells. T cells are produced in the bone marrow, but they mature in the thymus gland.

B Cell Response

B lymphocytes, often called **B cells,** are located in all lymphatic tissues and can be thought of as antibody factories. **Antibodies** are proteins produced by B lymphocytes that specifically react with a foreign antigen. An antigen is a substance foreign to the body that causes an immune response; it can bind to an antibody or T cell. When a portion of a pathogen is presented by a macrophage, B cells produce antibodies. Follow along in **Figure 11** on the next page as you learn about how B cells are activated to produce antibodies.

When a macrophage surrounds, internalizes, and digests a pathogen, it takes a piece of the pathogen, which is called a processed antigen, and displays it on its membrane, as illustrated in **Figure 11**. In the lymphatic tissues, such as the lymph nodes, the macrophage, with the processed antigen on its surface, binds to a type of lymphocyte called a **helper T cell.** This process activates the helper T cell. This lymphocyte is called a "helper" because it activates antibody secretion in B cells and another type of T cell, which will be discussed later, that aids in killing microorganisms:

- The activated helper T cell reproduces, binds processed antigens, and attaches to a B cell.
- The new helper T cells continue the process of binding antigens, attaching to B cells, and reproducing.
- Once an activated helper T cell binds to a B cell holding an antigen, the B cell begins to manufacture antibodies that specifically bind to the antigen.
- The antibodies can enhance the immune response by binding to microorganisms, making them more susceptible to phagocytosis and, by initiating the inflammatory response, helping promote the nonspecific response.

CCC CROSSCUTTING CONCEPTS

Structure and Function As you have learned, there are several components of the immune system spread throughout the body; these components act together to protect the body from pathogens. The lymphatic system responds when other defenses have failed. Using the evidence presented in this lesson, create a chart that summarizes the functions of the various components of the lymphatic system.

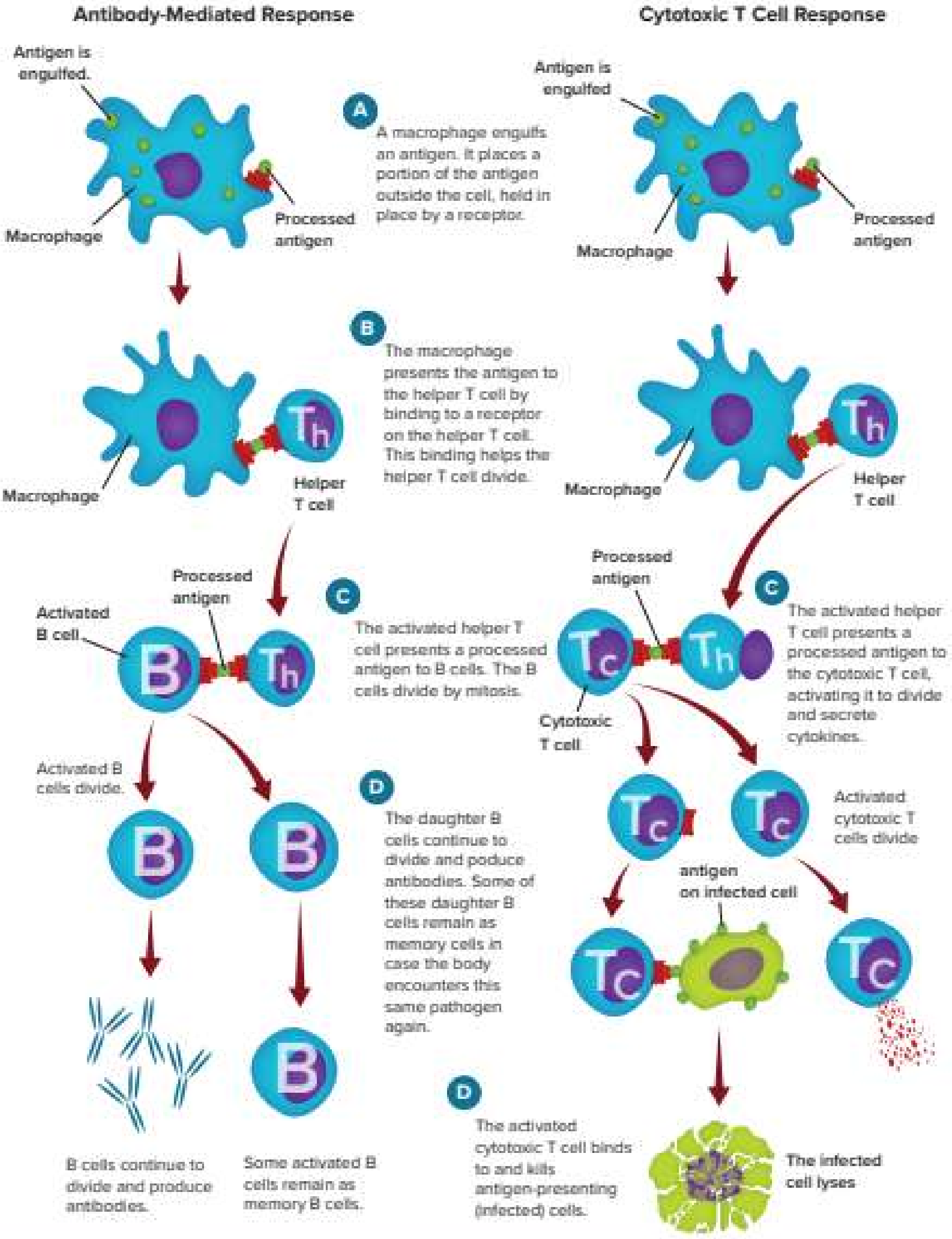
WORD ORIGIN

thymus

comes from the Greek word *thymos*, meaning *warty excrescence*

Figure 11 Visualizing Specific Immune Responses

Specific immune responses involve antigens, phagocytes, B cells, helper T cells, and cytotoxic T cells. The antibody-mediated response involves antibodies produced by B cells and memory B cells. The cytotoxic T cell response results in cytotoxic T cell activation.



B cells make many combinations of antibodies by using DNA that codes for the production of various heavy and light protein chains that make up antibodies, as shown in **Figure 12.** Any heavy chain can combine with any light chain. If a B cell can make 16,000 different kinds of heavy chains and 1200 kinds of light chains, it can make 19,200,000 different types of antibodies (1200 × 16,000).

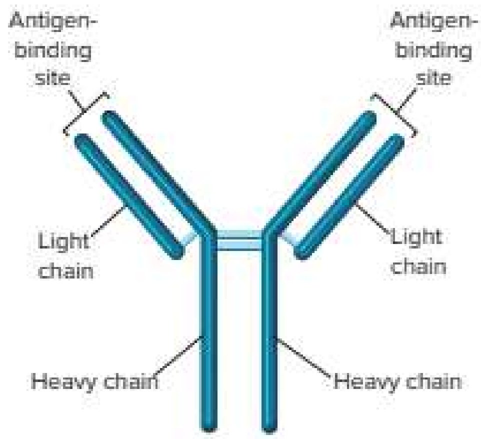


Figure 12 Antibodies are made up of two types of protein chains—heavy and light chains.

T Cell Response

Once helper T cells are activated by the presentation of an antigen by macrophages, helper T cells can also bind to and activate a group of lymphocytes called cytotoxic T cells. Activated **cytotoxic T cells** destroy pathogens and release chemicals called cytokines. Cytokines stimulate the cells of the immune system to divide and recruit immune cells to an area of infection. Cytotoxic T cells bind to pathogens, release a chemical attack, and destroy the pathogens. Multiple target cells can be destroyed by a single cytotoxic T cell. **Figure 11**, on the previous page, summarizes the activation of cytotoxic T cells.

Get It?

Summarize the role that lymphocytes play in immunity.

Passive and Active Immunity

The body's first response to an invasion by a pathogen is called the primary response. For example, if the viral pathogen that causes chicken pox enters the body, nonspecific and specific immune responses eventually defeat the foreign virus and the body is cleared of the pathogen.

One result of the specific immune response is the production of memory B and T cells. **Memory cells** are long-living cells that are exposed to the antigen during the primary immune response. These cells are ready to respond rapidly if the body encounters the same pathogen later. Memory cells protect the body by reducing the likelihood of developing the disease if exposed again to the same pathogen.

STEM CAREER Connection

Immunologist

The immune system in humans is a very robust system. However, even the immune system occasionally needs outside help from a specialist, called an immunologist, who understands malfunctioning of the system. An immunologist manages a variety of immune system problems ranging from the very common, such as asthma, to the less common, such as the autoimmune diseases. Immunology is a specialty requiring additional study beyond the normal medical training.

ACADEMIC VOCABULARY

passive

not active; acted upon

The passive monkey stared lazily at the zoo visitors.

Passive immunity

Sometimes temporary protection against an infectious disease is needed. This type of temporary protection occurs when antibodies are made by other people or animals and are transferred or injected into the body. For example, passive immunity occurs between a mother and her child. Antibodies produced by the mother are passed through the placenta to the developing fetus and through breast milk to the infant child. These antibodies can protect the child until the infant's immune system matures.

Antibodies developed in humans and animals that are already immune to a specific infectious disease are used to treat some infectious diseases in others. These antibodies are injected into people who have been exposed to that particular infectious disease. Passive immune therapy is available for people who have been exposed to hepatitis A and B, tetanus, and rabies. Antibodies also are available to inactivate snake and scorpion venoms.

Active immunity

Active immunity occurs after the immune system is exposed to disease antigens and memory cells are produced. Active immunity can result from having an infectious disease or immunization. **Immunization,** also called vaccination, is the deliberate exposure of the body to an antigen so that a primary response and immune memory cells will develop. **Table 3** lists some of the common immunizations offered in the United States. Immunizations contain killed or weakened pathogens, which are incapable of causing the disease.

Most immunizations include more than one stimulus to the immune system, given after the first immunization. These booster shots increase the immune response, providing further protection from the disease-causing organism.

Get It?

Describe the difference between passive immunity and active immunity.

Table 3 Common Immunization

Immunization	Disease	Contents
DPT	Diphtheria (D), tetanus (T), pertussis (P) (whooping cough)	D: inactivated toxin, T: inactivated toxin, P: inactivated bacteria
Polio	Poliomyelitis	Inactivated virus
MMR	Measles, mumps, rubella	All three inactivated viruses
Varicella	Chicken pox	Inactivated virus
HIB	Haemophilus influenzae (flu) type b	Portions of bacteria cell wall covering
HBV	Hepatitis B	Subunit of virus

Why are immunizations effective in preventing disease? The characteristics of the secondary immune response, which is the response to a second exposure to an antigen, enable immunizations to be effective in preventing disease. Study the graph in **Figure 13.** Note that the secondary response to the antigen has a number of different characteristics. First, the response is more rapid than the primary response, as shown by the greater steepness in the portion of the curves plotted in red. Second, the overall response, both B and T cell response, is greater during the second exposure. Lastly, the overall memory lasts longer after the second exposure.

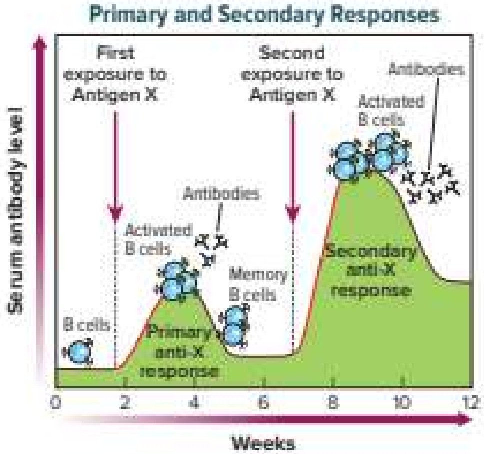


Figure 13 This graph shows the difference between the primary and secondary immune responses to exposure to an antigen.

Analyze *the differences between the primary and secondary immune responses.*

Get It?

Analyze how immunizations help prevent disease.

Immune System Failure

Defects in the immune system can result in an increased likelihood of developing infectious diseases as well as certain types of cancers. Some diseases can affect the immune system's effectiveness. One such disease called acquired immunodeficiency syndrome (AIDS) results from an infection by human immunodeficiency virus (HIV). AIDS is a serious health problem worldwide.

In 2015, approximately 18,303 AIDS cases were diagnosed in the U.S. In 2014, 6,721 people died of AIDS in the U.S. In 2015, an estimated 36 million people globally were living with HIV infection.

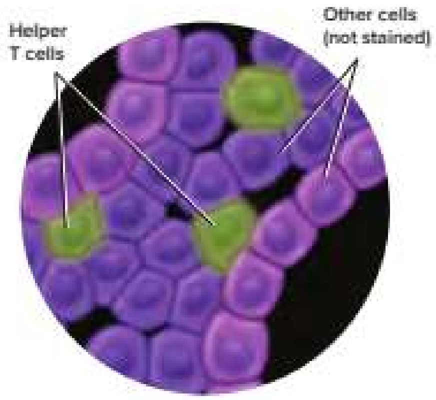


Figure 14 Helper T cells have receptors on the surface that are used to identify them in the laboratory.

Recall the important role that helper T cells play in specific immunity. T cells are also called $CD4^+$ cells because these cells have a receptor on the outside of their plasma membrane. This $CD4^+$ receptor is used by medical professionals to identify these cells, as illustrated in **Figure 14.**

HIV is an RNA virus that infects helper T cells. The helper T cells become HIV factories, producing new viruses that are released and infect other helper T cells. Over time, the number of helper T cells in an infected person decreases, making the person less able to fight disease. HIV infection usually has an early phase during the first six to twelve weeks while viruses are replicating in helper T cells.

The patient suffers symptoms such as night sweats and fever, but these symptoms are reduced after about eight to ten weeks. Then, the patient exhibits few symptoms for a period of time as long as ten years but is capable of passing the infection through sexual intercourse or blood products.

HIV is a secondary immunodeficiency disease, which means that the immune system of a previously healthy person fails. Without antiviral drug therapy, the patient usually dies from a secondary infection from another pathogen after about ten years of being infected with HIV. Current antiviral drug therapy is aimed at controlling the replication of HIV in the body. Resistant strains, expensive drugs, and side effects are all issues that patients face. Researchers and health care providers are working to meet these needs and continue the search for a cure.

Get It?

Summarize how the immune system protects and attempts to maintain a healthy balance in the body.

Check Your Progress

Summary

- The nonspecific immune response includes the skin barrier, secreted chemicals, and cellular pathways that activate phagocytosis.
- The specific immune response involves the activation of B cells, which produce antibodies, and T cells, which include helper T cells and cytotoxic T cells.
- Passive immunity involves receiving antibodies against a disease.
- Active immunity results in immune memory against a disease.
- HIV attacks helper T cells, causing an immune system failure.

Demonstrate Understanding

1. **Compare** specific and nonspecific immune responses.
2. **Describe** the steps involved in activating an antibody response to an antigen.
3. **Identify** ways passive and active immunity can be acquired.
4. **Describe** the structure and function of the immune system.
5. **Infer** why the destruction of helper T cells in HIV infection is so devastating to specific immunity.

Explain Your Thinking

6. **Hypothesize** what happens when an HIV strain mutates such that viral-replication drugs are no longer effective.
7. **Evaluate** the effects of severe combined immune deficiency on a child born without T cell immunity.
8. **MATH Connection** Antibodies are made of two light protein chains and two heavy protein chains. If the molecular weight of a light chain is 25,000 and the molecular weight of a heavy chain is 50,000, what is the molecular weight of an antibody?

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LESSON 3

NONINFECTIOUS DISORDERS

FOCUS QUESTION

Should you worry about catching a noninfectious disease? Why or why not?

Genetic Disorders

Not all diseases or body disorders are caused by pathogens. Some diseases, such as albinism, sickle cell anemia, Huntington's disease, and hemophilia, are caused by the inheritance of genes that do not function properly in the body. There are also disorders, such as Down syndrome and Turner syndrome, that result from abnormal chromosome numbers. Many diseases are complex and have both an environmental and a genetic cause.

Coronary artery disease (CAD) is an example of a condition with environmental and genetic origins. This cardiovascular disease can result in blockage of arteries, shown in **Figure 15**, that deliver oxygenated blood to the heart muscle. There is a genetic component that increases a person's risk of developing CAD. Environmental factors such as diet and inactivity contribute to the development of this complex disease. Families with a history of CAD have a two to seven times greater risk of having CAD than families without a history of CAD. The exact genetic factors, however, are not known.

Figure 15 When blood cannot flow through a coronary artery, such as the diseased artery shown here, a heart attack or sudden death can result.

Get It?
Summarize the factors that cause coronary artery disease.

Degenerative Diseases

Diseases that are the result of the body wearing out or of the natural aging process are referred to as **degenerative** (dih JEH nuh ruh tihv) **diseases.**

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Compare Cancerous and Healthy Cells
Analyze and interpret data to determine the differences in the structure of healthy cells to diseased cells.

CCC **Identify Cross Cutting Concepts**
Create a table of the crosscutting concepts and fill in examples you find as you read.

However, a degenerative condition, such as degenerative arthritis, could occur sooner than would be expected if the person is genetically predisposed to the disease or if the person's joints have experienced an increased amount of wear and tear. Degenerative arthritis is common; most people have it by age 70. It is found in almost all vertebrate animals. Arteriosclerosis (ar tir ee oh skluh ROH sus), which is a hardening of the arteries, is another example of a degenerative disease. Because degenerative diseases also have a genetic component, some individuals might be more likely to develop such a disease because of their genetic makeup.

Metabolic Diseases

Metabolic disease results from an error in a biochemical pathway. Some metabolic diseases result in the inability to digest specific amino acids or to regulate body processes. The condition known as phenylketonuria (PKU) is an inherited disorder that creates the inability to break down part of a protein called phenylalanine. When the pancreas does not make the proper amount of insulin and glucose does not enter body cells normally, the condition is known as Type 2 diabetes. This results in high glucose levels in the bloodstream, which causes damage to many organs including the kidneys and the retinas of the eyes. Metabolic diseases can have a genetic component but also can involve environmental factors such as diet.

Cancer

Cancer is characterized by abnormal cell growth. Normally, certain regulatory molecules in the body control the beginning and end of the cell cycle. If this control is lost, abnormal cell growth results that could lead to various types of tumors, as shown in **Figure 16.** The abnormal cells can interfere with normal body functions and can travel throughout the body. Cancer can develop in any body tissue or organ, including the blood cells. Cancer in the blood cells is called leukemia. Both genetic and environmental factors have been shown to cause cancer.

Figure 16 Cancer is due to an abnormal increase in cell division in the body, resulting in a tumor such as this skin tumor.
Infer *why this growth is so life-threatening.*

HISTORY Connection Cancer is a disease that has affected humans since ancient times. Egyptian mummies show evidence of bone cancer, and ancient Greek scientists described different kinds of cancer. Medieval manuscripts have reported details about cancer.

Inflammatory Diseases

Inflammatory diseases, such as allergies and autoimmunity, are diseases in which the body produces an inflammatory response to a common substance. Recall from Lesson 2 that infectious diseases also result in an inflammatory response. However, the inflammatory response in an infectious disease enhances the overall immune response. This inflammatory response is a result of the immune system removing bacteria or other microorganisms from the body. In inflammatory disease, the inflammatory response is not helpful to the body.

Allergies

Certain individuals might have an abnormal reaction to environmental antigens. A response to environmental antigens is called an **allergy.** These antigens are called allergens and include things such as plant pollens, dust, dust mites, and various foods, as shown in **Table 4.** An individual becomes sensitized to the allergen and has a localized inflammatory response with swollen itchy eyes, stuffy nose, sneezing, and sometimes a skin rash. These symptoms are the result of a chemical called histamine, released by certain white blood cells. Antihistamine medications can help alleviate these symptoms.

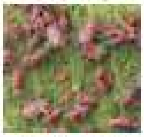
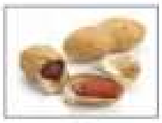
Get It?

Explain how allergies are related to the immune system.

Severe allergic reactions to particular allergens can result in **anaphylactic** (an uh fuh LAK tik) **shock,** which causes a massive release of histamine. In anaphylactic shock, the smooth muscles in the bronchioles contract, which restricts air flow into and out of the lungs.

Common allergens that cause severe allergic reactions are bee stings, penicillin, peanuts, and latex, which is used to make balloons and surgical gloves. People who are extremely sensitive to these allergens require prompt medical treatment if exposed to these agents, because anaphylactic reactions are life-threatening. Allergies and anaphylactic reactions are known to have an inherited component.

Table 4 Common Allergens

Allergen	Example	Description
Dust mite	Color-enhanced SEM, magnification ×44 	Dust mites are found in mattresses, pillows, and carpets. Mites and mite feces are allergens.
Plant pollen	Color-enhanced SEM, magnification ×1000 	Different parts of the country have very different pollen seasons. People can react to one or more pollens, and a person's pollen allergy season might be from early spring to late fall.
Animal dander	Color-enhanced SEM, magnification ×100 	Dander is skin flakes. Cat and dog allergies are the most common, but people also are allergic to pets such as birds, hamsters, rabbits, mice, and gerbils.
Peanut		Allergic reaction to peanuts can result in anaphylactic shock. Peanut allergy is responsible for more fatalities than any other type of allergy.
Latex		Latex comes from the milky sap of the rubber tree, found in Africa and Southeast Asia. The exact cause of latex allergy is unknown.

Autoimmunity

During the development of the immune system, the immune system learns not to attack proteins produced by the body. However, some people develop autoimmunity (aw toh ih MYOON ih tee) and do form antibodies to their own proteins, which injures their cells. **Figure 17** shows the hands of a person with rheumatoid arthritis—a form of arthritis in which antibodies attack the joints. Degenerative arthritis, the form of arthritis that you read about earlier in the section on degenerative diseases, is not caused by autoimmunity.

Rheumatic fever and lupus (LEW pus) are other examples of autoimmune disorders. Rheumatic fever is an inflammation in which antibodies attack the valves of the heart. This can lead to damage to the heart valves and cause the valves to leak or not close properly as blood moves through the heart. Lupus is a disorder in which autoantibodies are formed and attack healthy tissue. As a result, many organs are vulnerable to attack by the body's own immune system.

Figure 17 The large knobs and deformaties of these fingers are due to rheumatoid arthritis, an autoimmune disease.

Check Your Progress

Summary

- Noninfectious disorders often have both a genetic and an environmental component.
- The inflammatory response to an infectious disease enhances the immune response, but the inflammatory response to an inflammatory disease is not helpful to the body.
- Allergies are due to an overactive immune response to allergens found in the environment.
- Anaphylactic shock is a severe hypersensitivity to particular allergens.
- Autoimmunity results in an immune attack on body cells.

Demonstrate Understanding

1. **Identify** the type of noninfectious disease shown in **Figure 15.**
2. **Explain** the role of allergens in allergies.
3. **Create** a diagram demonstrating the process of anaphylactic shock.
4. **Categorize** the following diseases into the categories used in this section: sickle cell disease, Type 2 diabetes, vertebral degeneration, autoimmunity, and leukemia.

Explain Your Thinking

5. **Hypothesize** several causes of chronic bronchitis (inflammation of the bronchioles) found in coal miners.
6. **Create** a plan that limits a child's exposure to cat dander when the child is found to be allergic to that allergen.
7. **WRITING Connection** Create a pamphlet listing common allergens and explaining the symptoms of allergies.

LEARNSMART® Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

NATURE OF SCIENCE

Taking the Bite Out of the Zika Virus

The Zika virus was first identified in 1947, but was not considered to be a significant health threat until 2007. Its increased danger to humans changed the way that scientists study the Zika virus.

The Zika virus is mostly spread from person to person by the *Aedes aegypti* mosquito.

The Changing Nature of Zika Study

There are over 200 viruses known to infect humans. Some viruses are fatal, while others cause only mild symptoms, so the study of viruses is a consistent challenge to the scientific community. Scientists must be prepared to change the way they think about a virus if its impact on the human population changes.

For most people, infection with Zika causes symptoms like fever, eye inflammation, joint swelling, and pain. In more severe cases, Zika is associated with Guillain-Barre syndrome, an autoimmune disorder in which the body attacks its own nerve cells, causing muscle pain and weakness. Zika can pose a grave danger to pregnant women, who can pass the virus to their unborn children. This can lead to severe birth defects.

The first confirmed human cases of Zika were in the early 1950s, and its symptoms were officially described in the early 1960s. Since Zika's symptoms were mild, and the number of cases small, scientists were not concerned about developing a vaccine. The number of confirmed cases remained low but by the early 2000s small outbreaks of Zika had begun to appear outside of Africa and Asia. Cases were confirmed in North and South America by 2015. It was time for the scientific community to change their approach.

What happens next?

Recently, scientists have discovered that the Zika virus, like HIV, infects white blood cells, suppressing the mother's immune system so that the virus can cross the placenta. They hope to use this information to help generate a vaccine. Other scientists are focusing on how to prevent mosquito populations from increasing, a problem tied to climate change and urbanization. A solution to the problem will require the combined work of the entire global scientific community.

COMMUNICATE SCIENTIFIC INFORMATION

Create an information sheet for the general public that explains the Zika virus and gives tips people can use in order to protect themselves from it.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 INFECTIOUS DISEASES

- Pathogens, such as bacteria, viruses, protozoans, and fungi, cause infectious diseases.
- Koch's postulates describe the accepted procedure for demonstrating that a particular pathogen causes a specific disease.
- Pathogens are found in disease reservoirs and are transmitted to humans by direct and indirect methods.
- The symptoms of disease are caused by invasion of the pathogen and the response of the host immune system.
- Treatment of infectious disease includes the use of antibiotics and antiviral drugs.

- infectious disease
- pathogen
- Koch's postulates
- reservoir
- endemic disease
- epidemic
- pandemic
- antibiotic

Lesson 2 THE IMMUNE SYSTEM

- The nonspecific immune response includes the skin barrier, secreted chemicals, and cellular pathways that activate phagocytosis.
- The specific immune response involves the activation of B cells, which produce antibodies, and T cells, which include helper T cells and cytotoxic T cells.
- Passive immunity involves receiving antibodies against a disease.
- Active immunity results in immune memory against a disease.
- HIV attacks helper T cells, causing an immune system failure.

- complement protein
- interferon
- lymphocyte
- B cell
- antibody
- helper T cell
- cytotoxic T cell
- memory cell
- immunization

Lesson 3 NONINFECTIOUS DISORDERS

- Noninfectious disorders often have both a genetic and an environmental component.
- The inflammatory response to an infectious disease enhances the immune response, but the inflammatory response to an inflammatory disease is not helpful to the body.
- Allergies are due to an overactive immune response to allergens found in the environment.
- Anaphylactic shock is a severe hypersensitivity to particular allergens.
- Autoimmunity results in an immune attack on body cells.

- degenerative disease
- metabolic disease
- allergy
- anaphylactic shock

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

Why would this scientist need all this protection?

CER Claim, Evidence, Reasoning

Explain your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will apply your evidence from this module and complete your project.

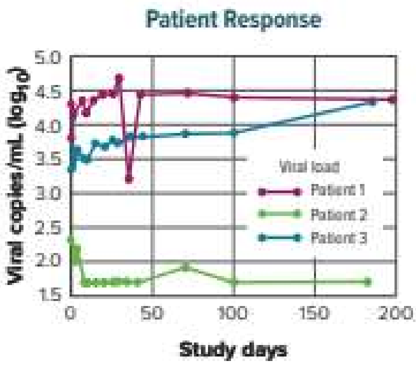
GO FURTHER

SEP Data Analysis Lab

Is passive immune therapy effective for HIV infection?

The standard treatment for a patient with an HIV infection is antiviral drug therapy. Unfortunately, the side effects and increasing prevalence of drug-resistant viruses create a need for additional therapies. One area being studied is passive immune therapy.

Data and Observations The graph shows HIV patient responses to passive immune therapy. The number of viral copies/mL is a measure of the amount of virus in the patient's blood.



*Data obtained from: Stiegler G., et al. 2002. Antiviral activity of the neutralizing antibodies 2F5 and 2F12 in asymptomatic HIV-1-infected humans: a phase I evaluation. *AIDS* 16: 2019–2025.

CER Analyze and Interpret Data

1. **Compare** the patient responses to passive immune therapy.
2. **Claim, Evidence, Reasoning** Explain whether the researchers can conclude if passive immune therapy is effective.

CELLULAR ENERGY

ENCOUNTER THE PHENOMENON

Why would a farmer grow lettuce in a greenhouse?

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about why a farmer would grow plants in a greenhouse. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 2: Explore & Explain: Overview of Photosynthesis

LESSON 3: Explore & Explain: Overview of Cellular Respiration

LESSON 1

HOW ORGANISMS OBTAIN ENERGY

FOCUS QUESTION

Lettuce plants can't eat, so how do they obtain energy?

Transformation of Energy

Many chemical reactions and processes in your cells are ongoing, even when you might not think that you are using any energy. Macromolecules are assembled and broken down, substances are transported across cell membranes, and genetic instructions are transmitted. All of these cellular activities require **energy**—the ability to do work. **Figure 1** on the next page shows some of the major advancements in the study of cellular energy. **Thermodynamics** is the study of the flow and transformation of energy in the universe.

Laws of thermodynamics

The first law of thermodynamics is the law of conservation of energy, which states that energy can be converted from one form to another, but it cannot be created nor destroyed. For example, the stored energy in food is converted to chemical energy when you eat and to mechanical energy when you run or kick a ball.

The second law of thermodynamics states that energy cannot be converted without the loss of usable energy. The energy that is "lost" is generally converted to thermal energy. Entropy (EN truh pee) is the measure of disorder, or unusable energy, in a system. Therefore, the second law of thermodynamics can also be stated as "entropy increases." One example of the second law of thermodynamics is evident in food chains. Recall that at each step in a food chain, the amount of usable energy that is available to the next trophic level decreases.

Autotrophs and heterotrophs

All organisms need energy to live. Directly or indirectly, nearly all the energy for life comes from the Sun. Some organisms make their own food, while others must obtain it from other organisms. Organisms can be classified based on how they get the energy they need to live.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

CCC **Identify Crosscutting Concepts**

Create a table of the crosscutting concepts and fill in examples you find as you read.

Review the News

Obtain information from a current news story about cellular energy, photosynthesis, and cellular respiration. Evaluate your source and communicate your findings to your class.

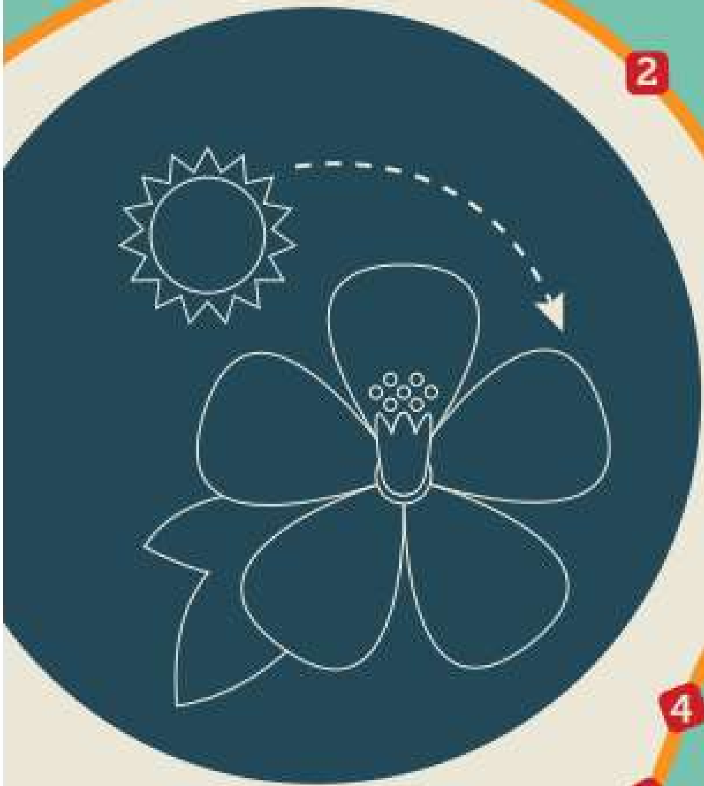


Figure 1

Understand Cellular Energy

Scientific discoveries have led to a greater understanding of photosynthesis and cellular respiration.

1 **1772** Joseph Priestley determines that plants take in carbon dioxide and emit oxygen.

2 **1844** Hugo von Mohl first observes chloroplasts in plant cells.

3 **1881-1882** Chloroplasts are shown to be the organelles responsible for photosynthesis.

4 **1937** Hans Krebs discovers the citric acid cycle, which is later renamed the Krebs cycle.

5 **1948** Eugene Kennedy and Albert Lehninger discover that mitochondria are responsible for cellular respiration.

6 **1981** Melvin Calvin, James Bassham, and Andrew Benson discover the light-independent reactions of photosynthesis, or the Calvin cycle.

7 **2008** Exploring the mitochondria of fruit flies and mice, Jaime Miquel provides the first evidence that mitochondrial breakdown causes aging.

8 **2009** Research shows that defects in mitochondria may be linked to diseases such as Parkinson's and Alzheimer's.

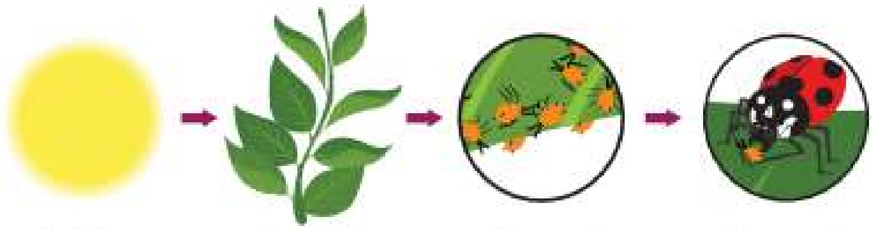


Figure 2 Almost all the energy in living organisms originates from the Sun, and energy flows from autotrophs to heterotrophs.

Autotrophs make their own food. Chemoautotrophs use inorganic substances such as hydrogen sulfide as a source of energy. Photoautotrophs, such as the plant in **Figure 2**, convert light energy from the Sun into chemical energy. Heterotrophs, such as the aphids and the ladybug in **Figure 2**, ingest food to obtain energy.

Metabolism

All of the chemical reactions in a cell are referred to as the cell's **metabolism.** As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. A series of chemical reactions in which the product of one reaction is the substrate for the next reaction is called a metabolic pathway. There are two main types of metabolic pathways: catabolic (ka tuh BAH lik) pathways and anabolic (a nuh BAH lik) pathways. Catabolic pathways release energy by breaking down larger molecules into smaller molecules. Anabolic pathways use the energy released by catabolic pathways to build larger molecules from smaller molecules. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another.

Energy continually flows between organisms. **Photosynthesis** is the anabolic pathway in which light energy is converted to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. The energy stored in glucose is transferred to other organisms when the molecules are consumed as food.

Cellular respiration is a catabolic pathway in which organic molecules are broken down to release energy. In cellular respiration, oxygen is used to break down organic molecules, producing carbon dioxide and water. Notice the cyclical nature of these processes in **Figure 3**.

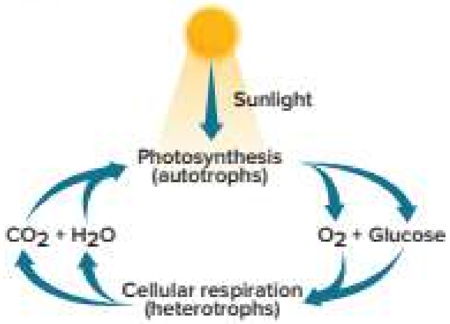


Figure 3 Photosynthesis and cellular respiration provide most of the energy for life processes.

ATP: The Unit of Cellular Energy

CHEMISTRY Connection Energy exists in many forms, such as mechanical energy and chemical energy. In organisms, chemical energy stored in biological molecules can be converted to other forms. For example, chemical energy is converted to mechanical energy when muscles contract. **Adenosine triphosphate** (uh DEN uh seen • tri FAHS fayt)—ATP—is the most important biological molecule that provides chemical energy.

ATP structure

ATP is a multipurpose storehouse of chemical energy that can be used by cells in a variety of reactions. Although other carrier molecules transport energy within cells, ATP is the most abundant energy-carrier molecule in cells and is found in all types of organisms. ATP plays an important role in energy transfers within cells. As shown in **Figure 4**, ATP is a nucleotide made of an adenine base, a ribose sugar, and three phosphate groups.

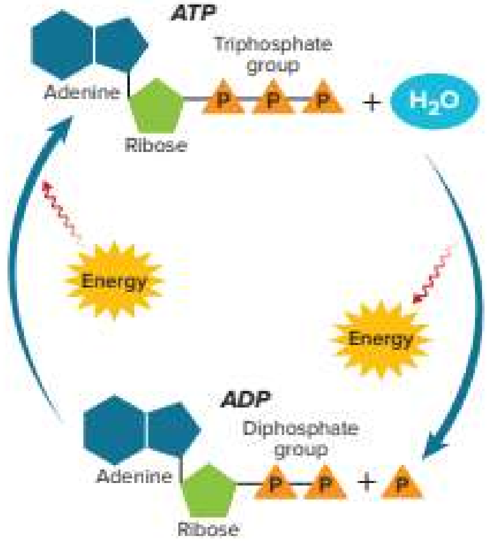


Figure 4 The breakdown of ATP releases energy for powering cellular activities in organisms.

ATP function

ATP releases energy when the bond between the second and third phosphate groups is broken, forming a molecule called adenosine diphosphate (ADP) and a free phosphate group, as shown in **Figure 4**. Energy is stored in the phosphate bond formed when ADP receives a phosphate group and becomes ATP. As shown in **Figure 4**, ATP and ADP can be interchanged by the addition or removal of a phosphate group. Sometimes ADP becomes adenosine monophosphate (AMP) by losing an additional phosphate group. There is less energy released in this reaction, so most of the energy reactions in the cell involve conversions between ATP and ADP.

Check Your Progress

Summary

- The laws of thermodynamics govern the flow and transformation of energy in organisms.
- Some organisms produce their own food, whereas others obtain energy from the food they ingest.
- Cells store and release energy through coupled anabolic and catabolic reactions.
- The energy released from the breakdown of ATP drives cellular activities.

Demonstrate Understanding

1. **Identify** the major source of energy for living organisms and the main process by which that energy is captured and stored on Earth.
2. **Describe** an example of the first law of thermodynamics.
3. **Compare and contrast** anabolic and catabolic pathways.
4. **Connect** the role of adenosine triphosphate (ATP) to energy transfers within a cell.

Explain Your Thinking

5. **Write** an essay describing the laws of thermodynamics. Use examples related to biology to support your ideas.
6. **Cite evidence** to support the argument that photosynthesis and cellular respiration provide most of the energy for life processes.

LEARNSMART Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

LESSON 2
PHOTOSYNTHESIS

FOCUS QUESTION

What do lettuce plants need to survive?

Overview of Photosynthesis

Recall the first law of thermodynamics, which states that energy can be converted from one form to another, but it cannot be created nor destroyed. Photosynthesis is a complex chemical process that converts energy from one form to another. It is the main way that solar energy is captured and stored on Earth. Along with cellular respiration, it provides most of the energy for life processes.

Most autotrophs, including plants, make organic compounds, such as sugars, by a process called photosynthesis. Recall that a basic function of photosynthesis is the conversion of light energy into chemical energy. The products and reactants of photosynthesis are identified in the overall chemical reaction for photosynthesis, which is shown below.

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

Photosynthesis occurs in two phases. Phase one of photosynthesis consists of reactions called the light-dependent reactions. First, light energy is captured, or absorbed, by organelles called chloroplasts. It is then converted into chemical energy, which is stored in ATP and NADPH molecules.

Phase two of photosynthesis consists of a series of reactions called the light-independent reactions. In phase two, molecules of ATP and NADPH that were formed in the phase one light-dependent reactions are used to make glucose, a form of sugar.

Once glucose is produced, it can be joined to other simple sugars to form complex carbohydrates, such as starch. The glucose molecules that are formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules such as proteins, lipids, or DNA used, for example, to form new cells.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Observe Chloroplasts

Draw a pictorial model of the structure of a chloroplast.

BioLab: Do different wavelengths of light affect the rate of photosynthesis?

Plan and carry out an investigation to determine the effect of different colors of light on the rate of photosynthesis.

Phase One: Light Reactions

The absorption of light is the first step in photosynthesis. Plants have organelles that capture, or absorb, light energy. Once the energy is captured, two energy storage molecules, NADPH and ATP, are produced. These molecules are used in the light-independent reactions.

Chloroplasts

Large organelles called chloroplasts capture light energy in photosynthetic organisms. In plants, chloroplasts are found mainly in the cells of leaves. As shown in **Figure 5**, chloroplasts are disk-shaped organelles that contain two main compartments essential to photosynthesis. The first compartment is called the thylakoid (THI la koyd). **Thylakoids** are flattened, saclike membranes that are arranged in stacks. The stacks of thylakoids are called **grana** (singular, granum). The light-dependent reactions take place within the thylakoids. The second important compartment within the chloroplast is called the **stroma,** the fluid-filled space that is outside the grana. The stroma, shown in **Figure 5,** is the location of the light-independent reactions that take place in phase two of photosynthesis.

Get It?

Apply Look back at the photo at the beginning of the module. What cellular structures in the plants absorb the light that passes into the greenhouse?

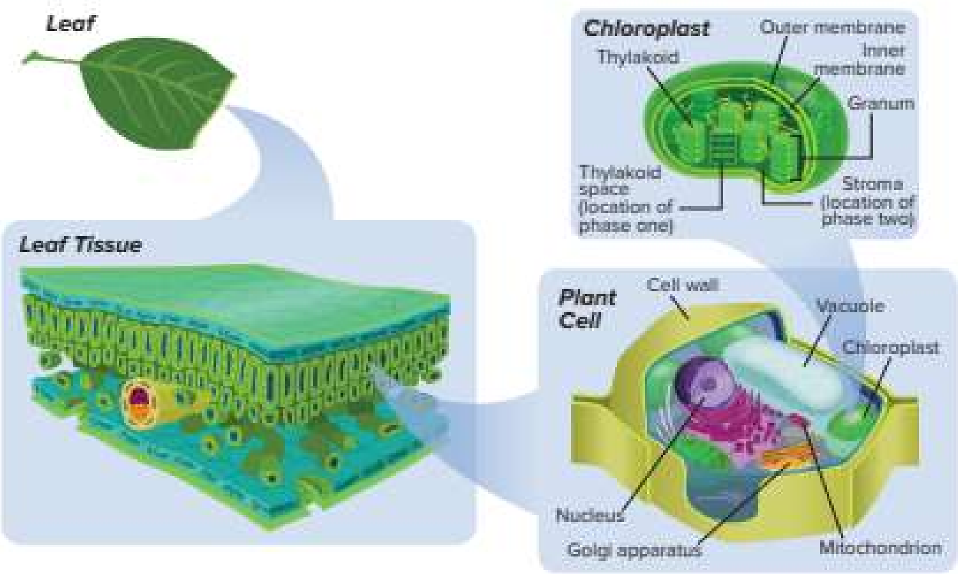


Figure 5 Photosynthesis occurs inside pigmented organelles called chloroplasts.
Identify *the location of the stroma and thylakoids within a plant cell.*

Pigments

Light-absorbing colored molecules called **pigments** are found in the thylakoid membranes. Pigments absorb specific wavelengths of light energy, as illustrated in **Figure 6**. Different pigments absorb different wavelengths of light.

The major light-absorbing pigments in plants are chlorophylls. There are several types of chlorophylls, but the two most common types are chlorophyll *a* and chlorophyll *b*. The structure of chlorophyll can differ from one molecule to another, enabling distinct chlorophyll molecules to absorb light at unique areas of the visible spectrum. In general, chlorophylls absorb light energy most strongly in the violet-blue region of the visible light spectrum and reflect light in the green region of the spectrum. This is why plant parts that contain chlorophyll appear green to the human eye.

Get It?

Explain why many plant parts appear green in color.

In addition to chlorophylls, most photosynthetic organisms contain accessory pigments that allow plants to trap additional light energy from other areas of the visible spectrum. One such group of accessory pigments is the carotenoids (kuh ROH tuh noydz). Carotenoids, such as ß-carotene (beta-carotene), absorb light mainly in the blue and green regions of the spectrum, while reflecting most light in the yellow, orange, and red regions, as shown in **Figure 6**. Carotenoids are the pigments that produce the colors of carrots and sweet potatoes.

Chlorophylls are more abundant than other pigments in leaves, and thus hide the colors of the other pigments. However, autumn in certain parts of the United States can bring out shades of yellow, red, and orange as the leaves turn colors, as shown in **Figure 7**. As trees prepare to lose their leaves before winter, the chlorophyll molecules break down, revealing the colors of the other pigments.

Absorption Spectrum of Photosynthetic Pigments

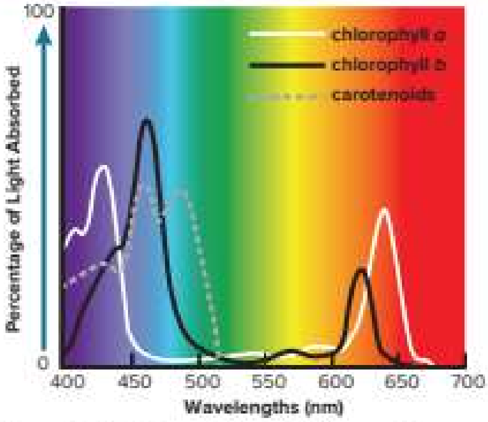


Figure 6 Colorful pigments found in the leaves of trees differ in their ability to absorb specific wavelengths of light.

Hypothesize *the effect on light absorption if a plant did not have chlorophyll b.*

Figure 7 When chlorophyll breaks down in the leaves of some trees, the other pigments become visible.

Electron transport

The structure of the thylakoid membrane is the key to efficient energy transfer during electron transport. Thylakoid membranes have a large surface area, which provides the space needed to hold large numbers of electron-transporting molecules and two types of protein complexes called photosystems. Photosystem I and photosystem II contain light-absorbing pigments and proteins that play important roles in the light reactions.

Follow along in **Figure 8** on the next page as you continue to read about electron transport.

- First, the light energy excites electrons in photosystem II. The light energy also causes a water molecule to split, releasing an electron into the electron transport system, a hydrogen ion (H^+)—also called a proton—into the thylakoid space, and the release of oxygen (O_2) as a waste product. This breakdown of water is essential for photosynthesis to occur.
- The excited electrons move from photosystem II to an electron-acceptor molecule in the thylakoid membrane.
- Next, the electron-acceptor molecule transfers the electrons along a series of electron-carriers to photosystem I.
- In the presence of light, photosystem I transfers the electrons to a protein called ferrodoxin. The electrons lost by photosystem I are replaced by electrons shuttled from photosystem II.
- Finally, ferrodoxin transfers the electrons to the electron carrier **$NADP^+$,** forming the energy-storage molecule NADPH.

Chemiosmosis ATP is produced in conjunction with electron transport by the process of chemiosmosis, the mechanism by which ATP is produced as a result of the flow of electrons down a concentration gradient. The breakdown of water is essential to this process, not only for providing the electrons that initiate the electron transport chain, but also for providing the protons (H^+) necessary to drive ATP synthesis during chemiosmosis.

The protons (H^+) released during electron transport accumulate in the interior of the thylakoid, creating a concentration gradient. As a result of a high concentration of H^+ in the thylakoid interior and a low concentration of H^+ in the stroma, H^+ protons diffuse down their concentration gradient out of the thylakoid interior into the stroma through ion channels spanning the membrane, as shown in **Figure 8.** These channels are enzymes called ATP synthases. As H^+ moves through ATP synthases, ATP is formed in the stroma.

Get It?

Summarize the function of water during chemiosmosis.

ACADEMIC VOCABULARY

transport
to carry something from one place to another

$NADP^+$ molecules transport electrons during photosynthesis.

CCC CROSSCUTTING CONCEPTS

Energy and Matter With a partner, review the information about electron transport on this page and in **Figure 8**. Write a paragraph that cites evidence from the text and figure to describe the energy flow within this system.

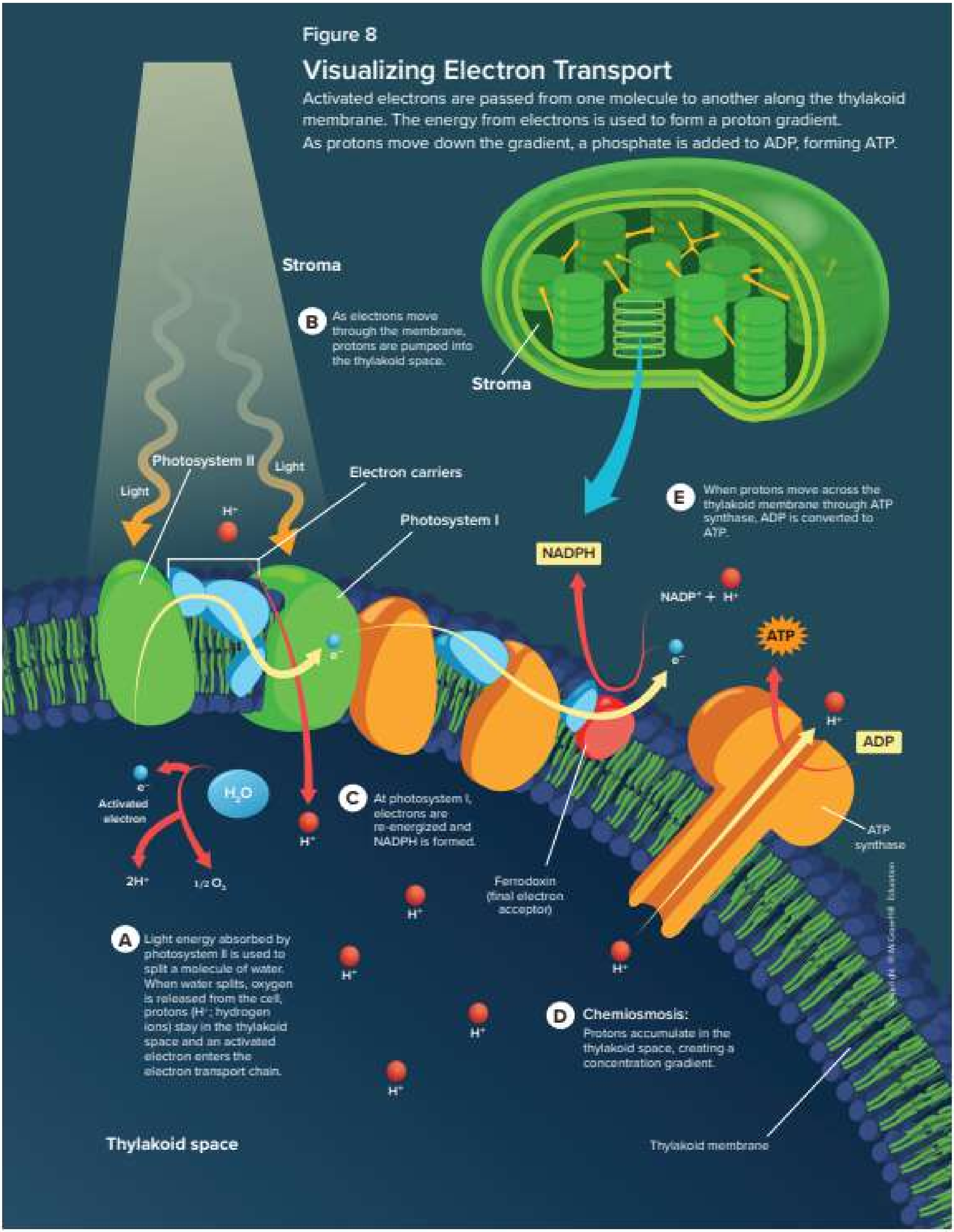


Figure 8

Visualizing Electron Transport

Activated electrons are passed from one molecule to another along the thylakoid membrane. The energy from electrons is used to form a proton gradient. As protons move down the gradient, a phosphate is added to ADP, forming ATP.

Phase Two: The Calvin Cycle

Although NADPH and ATP provide cells with large amounts of energy, these molecules are not stable enough to store chemical energy for long periods of time. Thus, there is a second phase of photosynthesis called the **Calvin cycle,** in which energy is stored in organic molecules such as glucose. The reactions of the Calvin cycle are also referred to as the light-independent reactions. Follow along in **Figure 9** as you learn the steps of the Calvin cycle.

- In the first step of the Calvin cycle, six carbon dioxide (CO_2) molecules combine with six 5-carbon compounds to form twelve 3-carbon molecules called 3-phosphoglycerate (fahs foh GLI suh rayt) (3-PGA). The joining of carbon dioxide with other organic molecules is called carbon fixation.
- In the second step, the chemical energy stored in ATP and NADPH is transferred to the 3-PGA molecules to form high energy molecules called glyceraldehyde 3-phosphates (G3P). ATP supplies the phosphate groups for forming G3P molecules, while NADPH supplies hydrogen ions and electrons.
- In the third step, two G3P molecules leave the cycle to be used for the production of glucose and other organic compounds.
- In the final step of the Calvin cycle, an enzyme called **rubisco** converts the remaining ten G3P molecules into 5-carbon molecules called ribulose 1, 5-bisphosphates (RuBP). These molecules combine with new carbon dioxide molecules to continue the cycle.

Because rubisco converts inorganic carbon dioxide molecules into organic molecules that can be used by the cell, it is considered one of the most important biological enzymes. Plants use the sugars formed during the Calvin cycle both as a source of energy and as building blocks for complex carbohydrates, including cellulose, which provides structural support for plants.

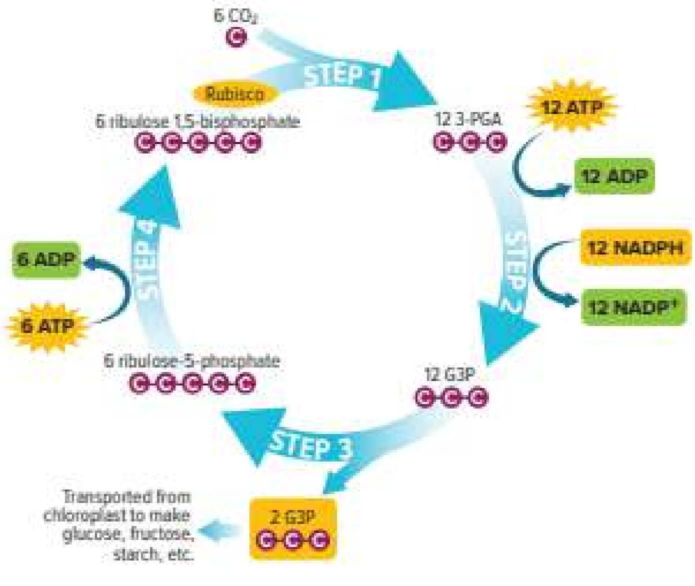


Figure 9 The Calvin cycle joins carbon dioxide with organic molecules inside the stroma of the chloroplast.

Determine *the compound in which energy is stored at the end of the Calvin cycle.*

Alternative Pathways

The environment in which an organism lives can impact its ability to carry out photosynthesis. Environments with insufficient water or carbon dioxide can decrease the ability of a photosynthetic organism to convert light energy into chemical energy. For example, plants in hot, dry environments are subject to excessive water loss that can lead to decreased photosynthesis. Many plants in extreme climates have alternative photosynthesis pathways to maximize energy conversion.

C_4 plants One adaptive pathway that helps plants maintain photosynthesis while minimizing water loss is the C_4 pathway. The C_4 pathway occurs in plants such as sugarcane and corn. These plants are called C_4 plants because they fix carbon dioxide into four-carbon compounds instead of three-carbon molecules during the Calvin cycle. C_4 plants also have significant structural modifications in the arrangement of cells in the leaves. In general, C_4 plants keep their stomata (plant cell pores) closed during hot days, while the four-carbon compounds are transferred to special cells where CO_2 enters the Calvin cycle. This allows for sufficient carbon dioxide uptake, while simultaneously minimizing water loss.

CAM plants Another adaptive pathway used by some plants to maximize photosynthetic activity is called crassulacean (KRAH soo lay shun) acid metabolism (CAM photosynthesis). The CAM pathway occurs in water-conserving plants that live in deserts, salt marshes, and other environments where access to water is limited. CAM plants, such as cacti, orchids, and pineapples allow carbon dioxide to enter the leaves only at night, when the atmosphere is cooler and more humid. At night, these plants fix carbon dioxide into organic compounds. During the day, carbon dioxide is released from these compounds and enters the Calvin cycle. This pathway allows for sufficient carbon dioxide uptake while minimizing water loss.

Check Your Progress

Summary

- Plants contain chloroplasts with light-absorbing pigments that convert light energy into chemical energy.
- Photosynthesis is a two-phase process that consists of light reactions and the Calvin cycle.
- In the light reactions, autotrophs trap and convert light energy into chemical energy in the form of NADPH and ATP.
- In the Calvin cycle, chemical energy in ATP and NADPH is used to synthesize carbohydrates such as glucose.

Demonstrate Understanding

1. **Summarize** how light energy is converted to stored chemical energy during photosynthesis.
2. **Identify** two other molecules that can be assembled in living things by recombining the chemical elements in glucose with other elements in the cell.
3. **Explain** why water is essential for the light reactions.
4. **Summarize** the steps in the Calvin cycle.
5. **Diagram** and explain electron transport.

Explain Your Thinking

6. **Predict** how environmental factors such as light intensity and carbon dioxide levels can affect rates of photosynthesis.
7. **WRITING Connection** **Research** the effects of global warming on photosynthesis. Write an article summarizing your findings.

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LESSON 3

CELLULAR RESPIRATION

FOCUS QUESTION

How does your body get energy from eating lettuce?

Overview of Cellular Respiration

Organisms obtain energy in a process called cellular respiration, during which the bonds of food and oxygen molecules are broken and energy transfers from one set of interacting molecules to another. New compounds (ATP) form that can transport energy to muscles. Energy needed to maintain body temperature despite ongoing energy transfer to the environment is released. Cellular respiration is summarized in the equation and **Figure 10**.

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

Cellular respiration has two main parts. Glycolysis is an anaerobic process. **Anaerobic processes** do not require oxygen. **Aerobic respiration** includes the Krebs cycle and electron transport and is an aerobic process. **Aerobic processes** require oxygen.

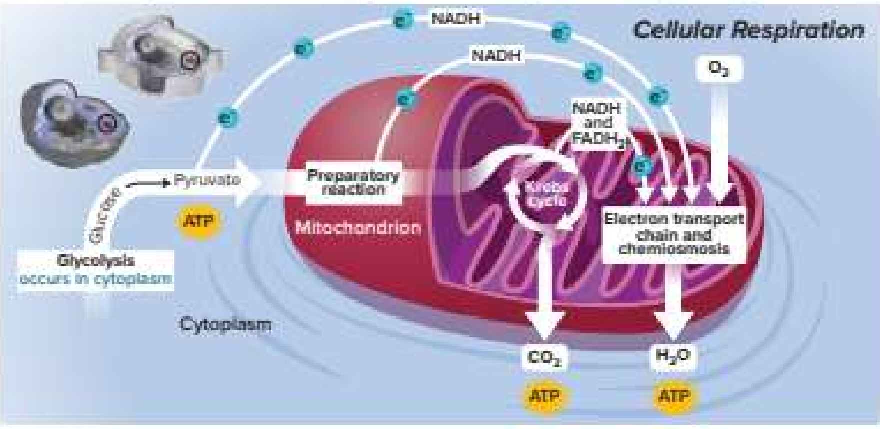

Figure 10 Cellular respiration occurs in the mitochondria, the energy powerhouse organelles of a cell.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Applying Practices: Modeling the Carbon Cycle

HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

Glycolysis

Glucose is broken down in the cytoplasm through the process of **glycolysis.** Two molecules of ATP and two molecules of NADH are formed for each molecule of glucose that is broken down. Follow along with **Figure 11** as you read about the steps of glycolysis. First, two phosphate groups, derived from two molecules of ATP, are joined to glucose. Notice that some energy, two ATP, is required to start the reactions that will produce energy for the cell. The 6-carbon molecule is then broken down into two 3-carbon compounds. Next, two phosphates are added and electrons and hydrogen ions (H^+) combine with two NAD^+ molecules to form two NADH molecules. NAD^+ is similar to NADP, an electron carrier used during photosynthesis. Last, the two 3-carbon compounds are converted into two molecules of pyruvate. At the same time, four molecules of ATP are produced.

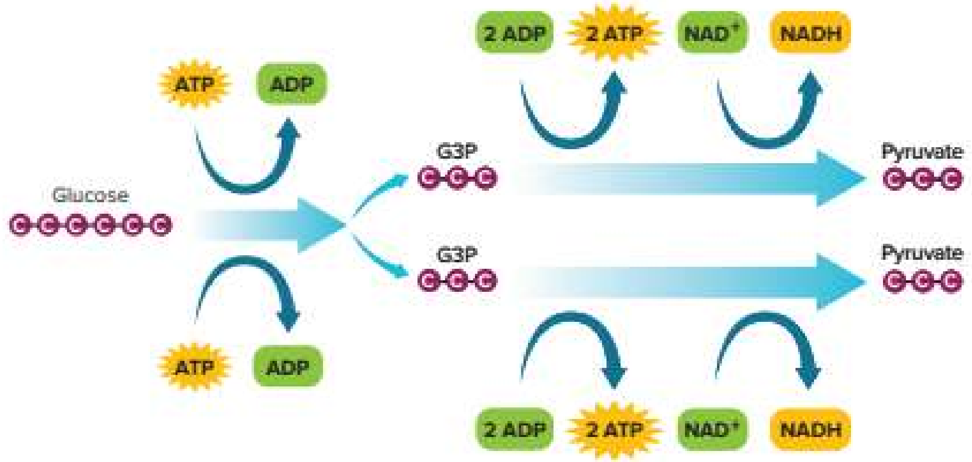

Figure 11 Glucose is broken down during glycolysis inside the cytoplasm of cells.

Krebs Cycle

Glycolysis has a net result of two ATP and two pyruvate molecules. Most of the energy from the glucose is still contained in the pyruvate. In the presence of oxygen, pyruvate is transported into the mitochondrial matrix, where it is eventually converted to carbon dioxide. The series of reactions in which pyruvate is broken down into carbon dioxide is called the **Krebs cycle,** or the tricarboxylic acid (TCA) cycle. This cycle also is referred to as the citric acid cycle.

WORD ORIGINS

glycolysis

comes from the Greek words *glykys*, meaning *sweet* and *lysis*, meaning *to rupture or break*

CCC CROSSCUTTING CONCEPTS

Energy and Matter With a partner, develop a model based on **Figure 12** that illustrates the energy transfer that occurs during glycolysis. Then, explain your model to another pair of students, citing evidence that energy moves from place to place, but is not created nor destroyed during this process.

Preparatory reaction

Prior to the Krebs cycle, the three-carbon pyruvate first reacts with coenzyme A (CoA) to form a two-carbon intermediate called acetyl CoA and carbon dioxide (CO_2). NAD^+ is converted to NADH. Carbon dioxide is given off by the cell. Since there are two molecules of pyruvate for every preparatory reaction, it results in the production of two carbon dioxide molecules and two NADH molecules. Acetyl CoA then moves to the mitochondrial matrix.

Steps of the Krebs cycle

Follow along in **Figure 12** as you continue reading about the steps of the Krebs cycle.

- The Krebs cycle begins with acetyl CoA combining with a 4-carbon compound to form a 6-carbon compound known as citric acid.
- Citric acid is then broken down in the next series of steps, releasing two molecules of carbon dioxide and generating one ATP, three NADH, and one $FADH_2$. FAD is another electron carrier similar to NAD^+ and $NADP^+$.
- Finally, acetyl CoA and citric acid are generated and the cycle continues.

Recall that two molecules of pyruvate are formed during glycolysis, resulting in two "turns" of the Krebs cycle for each glucose molecule. The net yield from the Krebs cycle is six carbon dioxide molecules, two ATP, eight NADH, and two $FADH_2$. Ten NADH and two $FADH_2$ move on to play a significant role in the next stage of aerobic respiration.

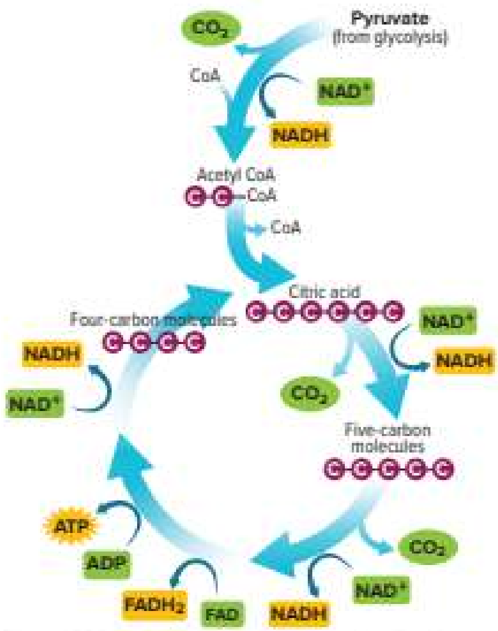

Figure 12 Pyruvate is broken down into carbon dioxide during the Krebs cycle inside the mitochondria of cells.

Trace *Follow the path of carbon molecules that enter and leave the Krebs cycle.*

STUDY TIP

Clarifying Statement Work with a partner to read the text and discuss unfamiliar words and difficult concepts. Write a clarifying statement to summarize the Krebs cycle.

STEM CAREER Connection

Greenhouse Technician

Do you have a "green thumb"? A greenhouse technician makes sure the conditions in a greenhouse are just right for plants to carry out photosynthesis and cellular respiration. This career requires knowledge of the science of plant processes and the technology of greenhouse design. It might involve growing food crops or plants used for decorative purposes.

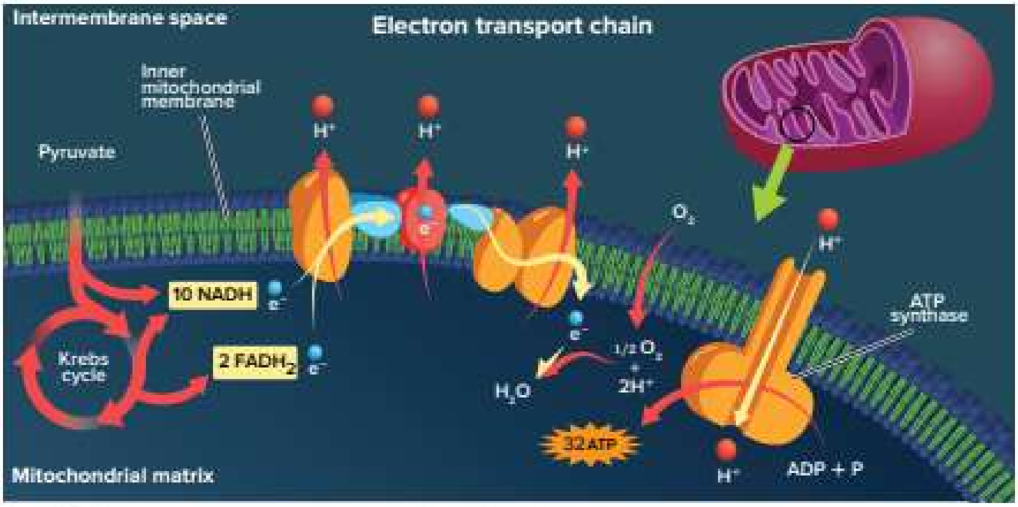

Figure 13 Electron transport occurs along the mitochondrial membrane.

Compare and contrast *electron transport in cellular respiration and photosynthesis.*

As shown in **Figure 13**, electrons move along the mitochondrial membrane from one protein to another.

- The start of the electron transport chain begins with the ten NADH molecules and the two $FADH_2$ molecules releasing electrons. The released electrons move along the mitochondrial membrane from one protein to another. The energy carriers are converted to NAD^+ and FAD, and H^+ ions are released into the mitochondrial matrix.
- The H^+ ions are pumped into the intermembrane space through the proteins in the inner mitochondrial membrane. This creates an increase in the concentration of H^+ ions in the intermembrane space.
- As a result of high concentration in the intermembrane space and a low concentration in the mitochondrial matrix, the H^+ ions diffuse down their concentration gradient back across the inner mitochondrial membrane and into the mitochondrial matrix through ATP synthase proteins in chemiosmosis. As the H^+ ions move through the ATP synthase, ADP is converted into ATP in the mitochondrial matrix.
- Oxygen is the final electron acceptor in the electron transport system in cellular respiration. The H^+ ions and electrons are transferred to oxygen to form water.

Overall, electron transport produces 32 ATP. Each NADH molecule produces three ATP and each group of three $FADH_2$ produces two ATP. In eukaryotes, one molecule of glucose yields 36 ATP under ideal conditions.

Prokaryotic cellular respiration Some prokaryotes also undergo aerobic respiration. Because prokaryotes do not have mitochondria, there are differences in the process. The main difference involves the use of the prokaryotic cellular membrane as the location of electron transport. In eukaryotic cells, pyruvate is transported to the mitochondria. In prokaryotes, this movement is unnecessary, saving the prokaryotic cell two ATP, and increasing the net total of ATP produced to 38.

Anaerobic Respiration

Some cells can function for a short time when oxygen is low. Some prokaryotes are anaerobic organisms--they live without oxygen. In some cases these cells continue to produce ATP through glycolysis. However, there are problems with solely relying on glycolysis for energy. Glycolysis provides only two net ATP for each molecule of glucose, and a cell has a limited amount of NAD^+. Glycolysis stops when NAD^+ is used up. The anaerobic pathway that follows glycolysis is anaerobic respiration, or fermentation. **Fermentation** occurs in the cytoplasm and regenerates the cell's supply of NAD^+ while producing a small amount of ATP. There are two types of fermentation.

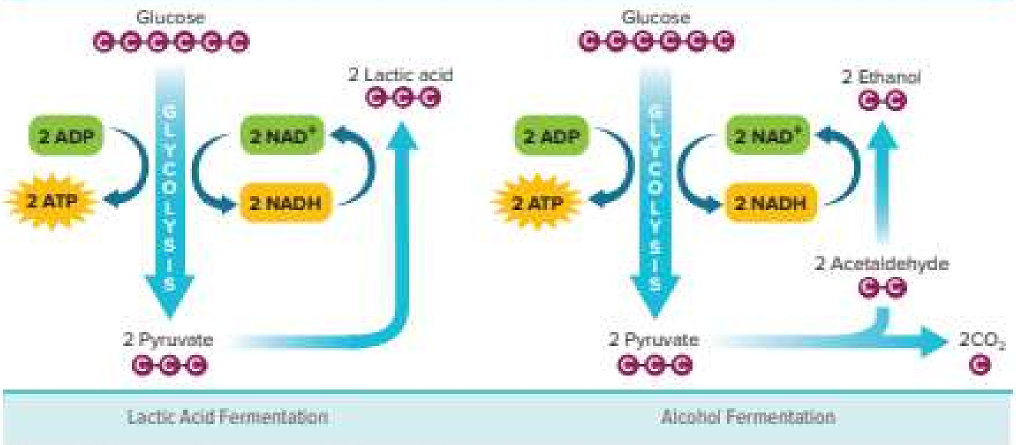

Figure 14 When oxygen is absent or in limited supply, fermentation can occur.
Identify *the reactants and products of lactic acid fermentation and alcohol fermentation.*

HEALTH Connection **Lactic acid fermentation** In lactic acid fermentation, enzymes convert the pyruvate made during glycolysis to lactic acid, as shown in **Figure 14**. This involves the transfer of high energy electrons and protons from NADH. Skeletal muscles produce lactic acid when the body cannot supply enough oxygen, such as during periods of strenuous exercise. When lactic acid concentration in muscle cells increases, muscles become fatigued and sore.

Alcohol fermentation Alcohol fermentation occurs in yeast and some bacteria. **Figure 14** shows the chemical reaction that occurs during alcohol fermentation when pyruvate is converted to ethyl alcohol and carbon dioxide. Similar to lactic acid fermentation, NADH donates electrons during this reaction and NAD^+ is regenerated.

SCIENCE USAGE v. COMMON USAGE

concentration

Science usage: the relative amount of a substance dissolved in another substance

The concentration of hydrogen ions is greater on one side of the membrane than on the other.

Common usage: the directing of close, undivided attention

The student's concentration was focused on the exam.

Photosynthesis and Cellular Respiration

Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. **Figure 15** shows the interrelated, cyclical nature of photosynthesis and cellular respiration. The products of photosynthesis are oxygen and glucose, the reactants needed for cellular respiration. The products of cellular respiration, which are carbon dioxide and water, are the reactants for photosynthesis.

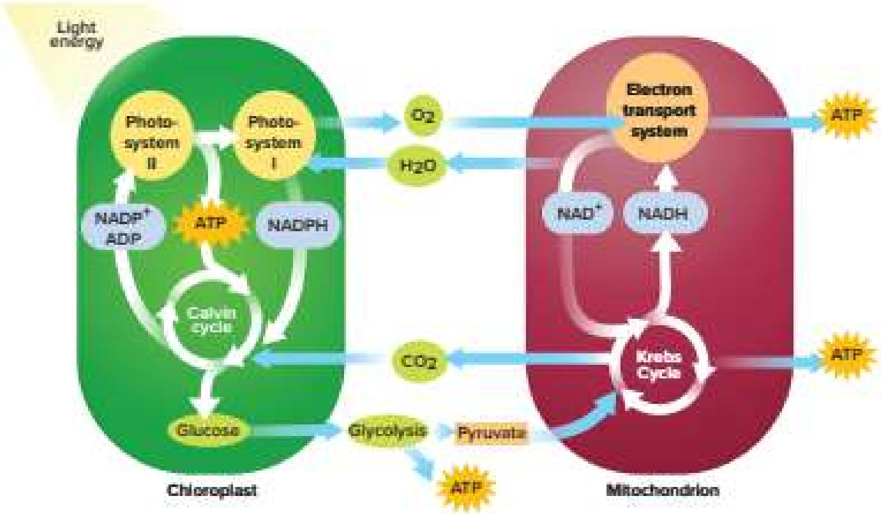

Figure 15 Photosynthesis and cellular respiration form a cycle.

Check Your Progress

Summary

- Many living organisms use cellular respiration to break down glucose.
- The stages of cellular respiration are glycolysis, the Krebs cycle, and electron transport.
- NADH and $FADH_2$ are important electron carriers for cellular respiration.
- In the absence of oxygen, cells can sustain glycolysis by fermentation.

Demonstrate Understanding

1. **Summarize** the stages of cellular respiration and explain its relationship to body temperature.
2. **Identify** how many carbons from one glucose molecule enter one round of the Krebs cycle.
3. **Explain** how high-energy electrons are used in electron transport.
4. **Explain** how energy drives the cycling of matter in photosynthesis and cellular respiration.

Explain Your Thinking

5. **MATH Connection** How many ATP, NADH, and $FADH_2$ are produced in each step of cellular respiration? How is the number of ATP produced different from the net ATP available?
6. **Compare and contrast** the two types of fermentation.

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SCIENTIFIC BREAKTHROUGHS

Faster Photosynthesis: The New Frontier of Food

The need for food for the world's growing population is a global challenge. Crop yields have been vastly improved over the years. However, the rate of photosynthesis has always limited crop production. Recently, scientists have investigated ways to increase the rate of photosynthesis. The more food molecules plants produce and store, the greater the amount of biomass produced and the higher the crop yield.

Some of the research on increasing the efficiency of photosynthesis was done using tobacco plants, because it is relatively easy to alter their genes. Successful results in tobacco plants can lead to work with food crops.

Plants and light

Although plants require light, they have a protective mechanism that keeps them from absorbing too much light when it is very sunny. As the amount of incoming light decreases, plants shut off the protective mechanism, a process that takes up to several hours. During that time, the rate of photosynthesis is limited.

Genetic engineering and photosynthesis

Genetic engineering was used to increase the efficiency of photosynthesis. The goal was to develop a plant that could more quickly turn off its protective mechanism when the amount of incoming light decreased.

Scientists inserted extra copies of three genes that code for proteins involved in shutting off the protective mechanism. They grew the genetically-engineered plants, and compared the amount of biomass produced to a control group. Their data showed that quickly shutting off the protective mechanism increased the rate of photosynthesis and resulted in plants that were up to 20 percent larger.

Scientists are investigating additional ways to modify photosynthesis to increase crop yield and produce a sustainable food supply for the world's growing human population.

APPLY SCIENTIFIC PRINCIPLES AND EVIDENCE

Create an explanation of how the use of genetic engineering to improve the efficiency of photosynthesis could have a global impact on humans. Use evidence and reasoning in your scientific explanation.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 HOW ORGANISMS OBTAIN ENERGY

- The laws of thermodynamics control the flow and transformation of energy in organisms.
- Some organisms produce their own food, whereas others obtain energy from the food they ingest.
- Cells store and release energy through coupled anabolic and catabolic reactions.
- The energy released from the breakdown of ATP drives cellular activities.

- energy
- thermodynamics
- metabolism
- photosynthesis
- cellular respiration
- adenosine triphosphate (ATP)

Lesson 2 PHOTOSYNTHESIS

- Plants contain chloroplasts with light-absorbing pigments that convert light energy into chemical energy.
- Photosynthesis is a two-phase process that consists of light reactions and the Calvin cycle.
- In the light reactions, autotrophs trap and convert light energy into chemical energy in the form of NADPH and ATP.
- In the Calvin cycle, chemical energy in ATP and NADPH is used to synthesize carbohydrates such as glucose.

- thylakoid
- granum
- stroma
- pigment
- $NADP^+$
- Calvin cycle
- rubisco

Lesson 3 CELLULAR RESPIRATION

- Many living organisms use cellular respiration to break down glucose.
- The stages of cellular respiration are glycolysis, the Krebs cycle, and electron transport.
- NADH and $FADH_2$ are important electron carriers for cellular respiration.
- In the absence of oxygen, cells can sustain glycolysis by fermentation.

- anaerobic process
- aerobic respiration
- aerobic process
- glycolysis
- Krebs cycle
- fermentation

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

Why would a farmer grow lettuce in a greenhouse?

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will summarize your evidence and apply it to the project.

GO FURTHER

SEP Data Analysis Lab

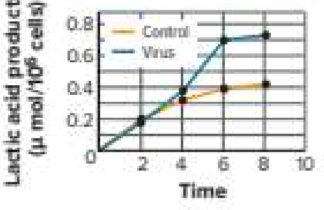
How does viral infection affect cellular respiration?

Infection by viruses can significantly affect cellular respiration and the ability of cells to produce ATP. To test the effect of viral infection on the stages of cellular respiration, cells were infected with a virus, and the amount of lactic acid and ATP produced were measured.

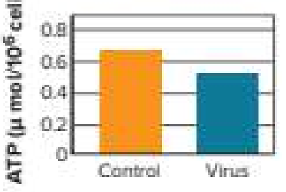
CER Analyze and Interpret Data

1. **Claim** Analyze how the virus affected lactic acid production in the cells.
2. **Evidence** Calculate after 8 hours, by what percentage was the lactic acid higher in the virus group than in the control group? By what percentage was ATP production decreased?
3. **Reasoning** Infer why having a virus such as the flu might make a person feel tired.

Effect of Viral Infection on Lactic-Acid Production



Effect of Viral Infection on ATP Production



*Data obtained from: El-Bacha, T., et al. 2004. Mayaro virus infection alters glucose metabolism in cultured cells through activation of the enzyme 6-phosphofructo 1-kinase. *Molecular and Cellular Biochemistry* 266: 191–198.

Credits