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Grade 10 ASP Biology
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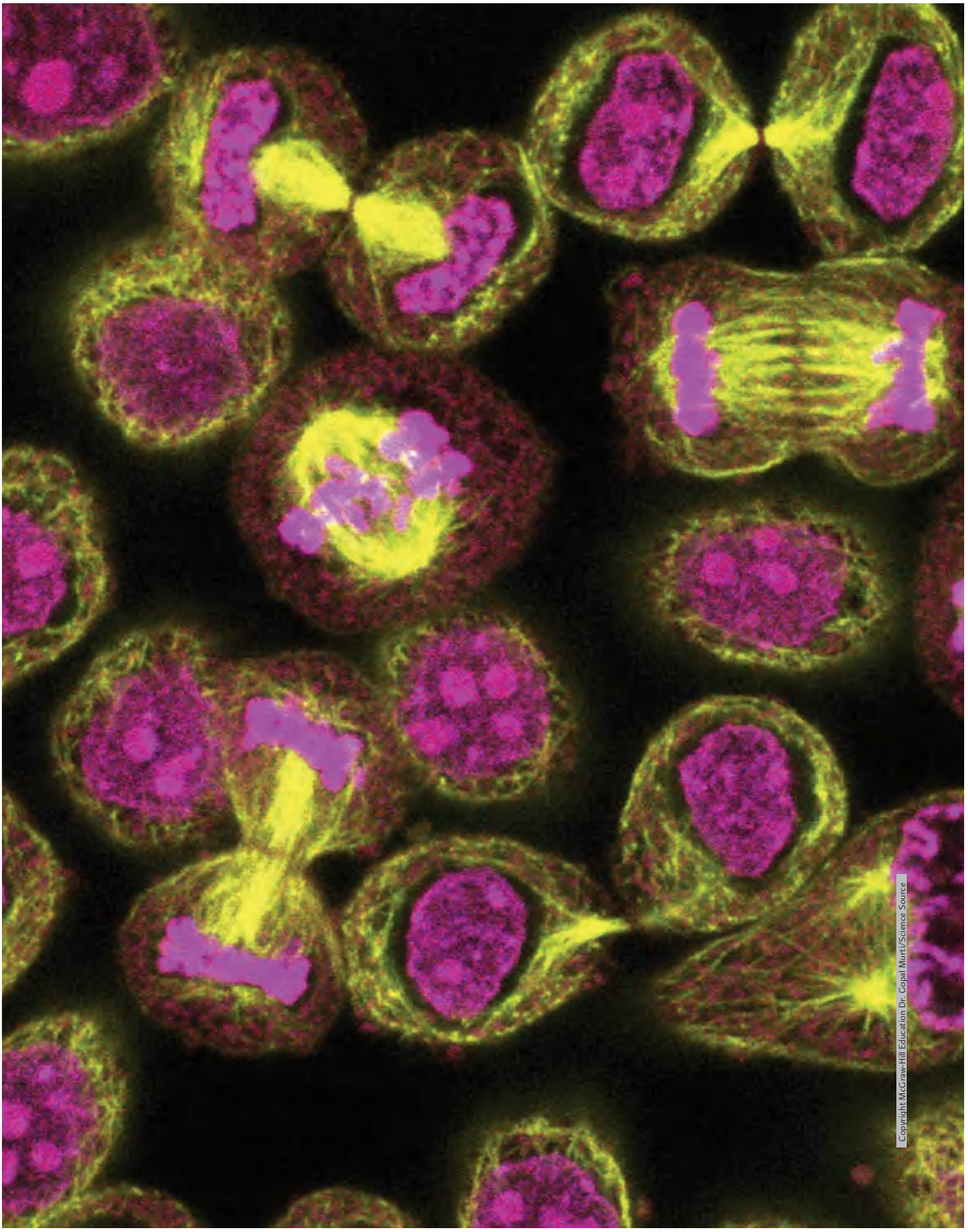
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CELLULAR REPRODUCTION AND SEXUAL REPRODUCTION

ENCOUNTER THE PHENOMENON

Why do some of these cells look so different from each other?

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 some of the cells look so different from each other. 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 Cell Cycle

LESSON 2: Explore & Explain: Meiosis I and II

LESSON 1

CELLULAR REPRODUCTION

FOCUS QUESTION

What are the primary stages of the cell cycle?

Cell Size Limitations

Most cells are less than 100 µm (100×10^{-6} m) in diameter, which is smaller than the period at the end of this sentence. Why are most cells so small? Why don't cells grow continually larger? This lesson explores and investigates several factors that influence cell size.

Ratio of surface area to volume

The key factor that limits the size of a cell is the ratio, or mathematical comparison, of its surface area to its volume. The surface area of the cell refers to the area covered by the plasma membrane. The plasma membrane is the structure through which all nutrients and waste products must pass. The volume of the cell refers to the space taken up by all of the inner contents of the cell, including the organelles in the cytoplasm and the nucleus.

MATH Connection To illustrate the ratio of surface area to volume, think about a small cube, which has six sides. Imagine each side of the cube is one micrometer (µm) in length. This is approximately the size of a bacterial cell. To calculate the surface area of the cube, multiply its length times its width times the number of sides it has (1 µm × 1 µm × 6 sides), which equals 6 μm^2. To calculate the volume of the cube, multiply its length times its width times its height (1 µm × 1 µm × 1 µm), which equals 1 μm^3. So the cube has a surface area of 6 μm^2 and a volume of 1 μm^3. The ratio of surface area to volume of this small cube is 6:1. Now, examine what happens to this ratio when the cube gets bigger.

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.

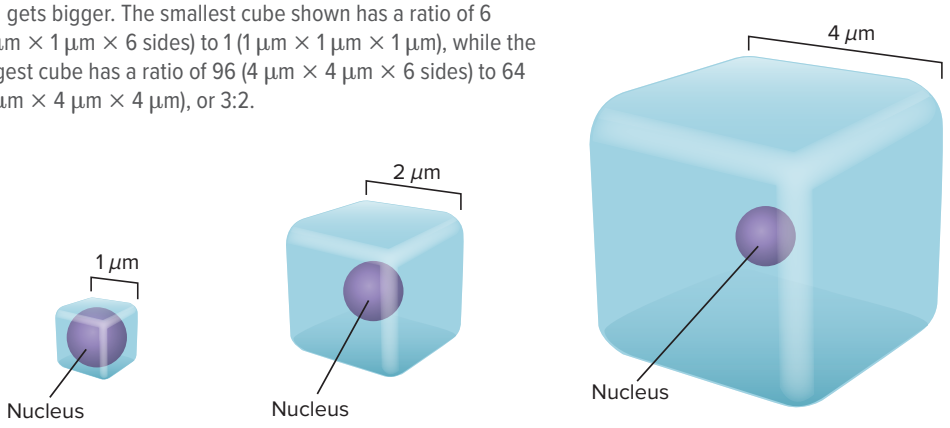
INVESTIGATE

GO ONLINE to find these activities and more resources.

BioLab: How long does each phase of the cell cycle last?
Plan and carry out an investigation to determine how long cells spend in each stage of the cell cycle.

BioLab: Does sunlight affect mitosis in yeast?
Plan and carry out an investigation to determine effects of UV damage on the cell cycle.

Figure 1 The ratio of surface area to volume decreases as a cell gets bigger. The smallest cube shown has a ratio of 6 (1 µm × 1 µm × 6 sides) to 1 (1 µm × 1 µm × 1 µm), while the largest cube has a ratio of 96 (4 µm × 4 µm × 6 sides) to 64 (4 µm × 4 µm × 4 µm), or 3:2.



If the cubic cell grows to 2 µm per side, as represented in **Figure 1**, the surface area becomes 24 μm^2 and the volume is 8 μm^3. The ratio of surface area to volume is now 3:1, which is less than it was when the cell was smaller. If the cell continues to grow, the ratio of surface area to volume will continue to decrease, as shown by the third cube in **Figure 1**. As the cell grows, its volume increases much more rapidly than the surface area. This means that the cell might have difficulty supplying nutrients and expelling enough waste products. By remaining small, cells have a higher ratio of surface area to volume and can sustain themselves more easily.

Get It?

Explain why a high ratio of surface area to volume benefits a cell.

Transport of substances Another task that can be managed more easily in a small cell than in a large cell is the movement of substances. Recall that the plasma membrane controls cellular transport because it is selectively permeable. Once inside the cell, substances move by diffusion or by motor proteins pulling them along the cytoskeleton.

Diffusion over large distances is slow and inefficient because it relies on random movement of molecules and ions. Similarly, the cytoskeleton transportation network, shown in **Figure 2**, becomes less efficient for a cell if the distance to travel becomes too large. Small cell size maximizes the ability of diffusion and motor proteins to transport nutrients and waste products. Small cells maintain more efficient transport systems.

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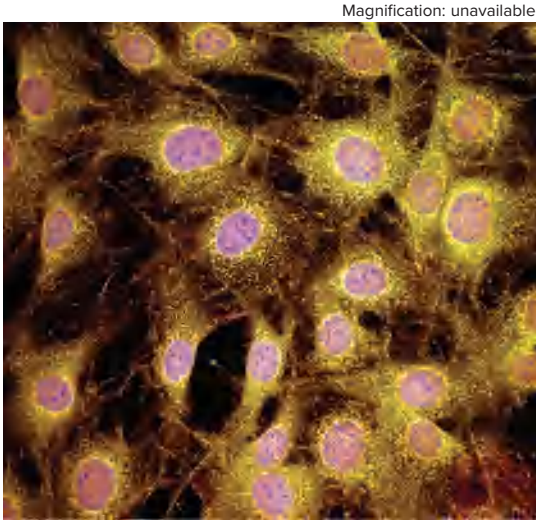


Figure 2 In order for the cytoskeleton to be an efficient transportation railway, the distances that substances have to travel within a cell must be limited.

Cellular communication The need for signaling proteins to move throughout the cell also limits cell size. In other words, cell size affects the ability of the cell to communicate instructions for cellular functions. If the cell becomes too large, it becomes almost impossible for cellular communications, many of which involve movement of substances and signals to various organelles, to take place efficiently. For example, the signals that trigger protein synthesis might not reach the ribosome fast enough for protein synthesis to occur to sustain the cell.

Chromosomes

If a DNA strand 140 million nucleotides long was laid out in a straight line, it would be about five centimeters long. How does all of this DNA fit into a microscopic cell? In prokaryotes, the DNA molecule is contained in the cytoplasm and consists mainly of a ring of DNA and associated proteins. In eukaryotes, the DNA strand is wound up in a tight coil called a chromosome.

Chromatin and chromosomes

DNA is found in the nucleus of eukaryotic cells. DNA can take two forms in the nucleus. **Chromatin** (KROH muh tun) is the relaxed form of DNA. However, the DNA is not relaxed at all times. **Chromosomes** (KROH muh sohmz) are condensed structures that contain the DNA that are visible during mitosis. Chromosomes are passed from generation to generation of cells.

Eukaryotic DNA is organized into chromosomes. Human chromosomes range in length from 51 million to 245 million base pairs. The phosphate groups in DNA create a negative charge, which attracts the DNA to the positively charged histone proteins and forms a **nucleosome.** The nucleosomes group together into chromatin fibers, which supercoil to make up the structure recognized as a chromosome, shown in **Figure 3**.

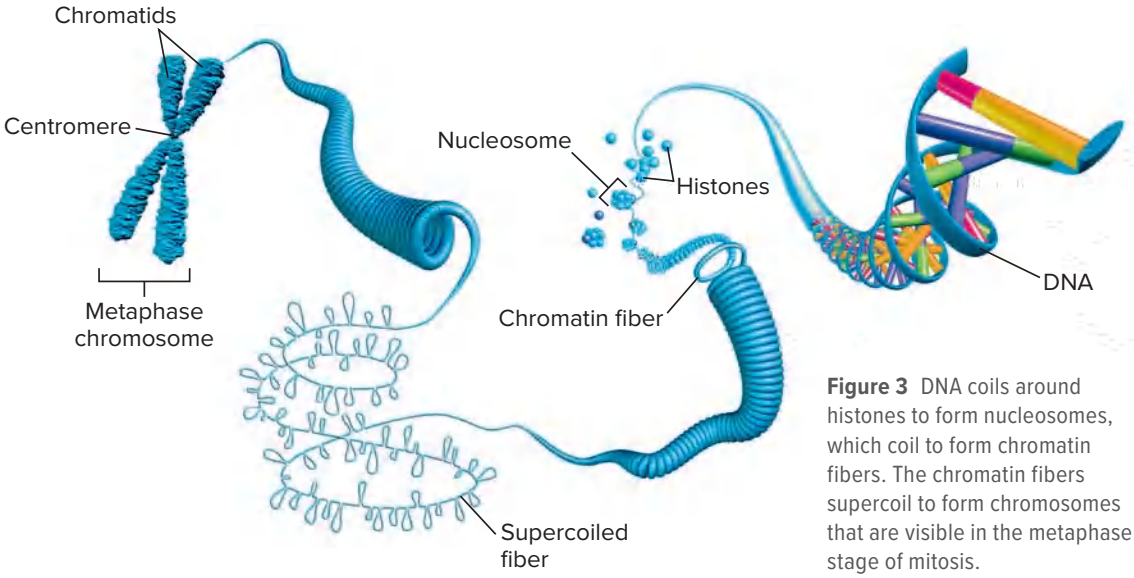


Figure 3 DNA coils around histones to form nucleosomes, which coil to form chromatin fibers. The chromatin fibers supercoil to form chromosomes that are visible in the metaphase stage of mitosis.

The Cell Cycle

Cells reproduce by a cycle of growing and dividing called the **cell cycle.** Cellular reproduction allows your body to grow and heal certain injuries. Each time a cell goes through one complete cell cycle, it becomes two cells. The duration of the cell cycle varies. Some eukaryotic cells might complete the cycle in as few as eight minutes, while other cells might take up to one year. For most normal, actively dividing animal cells, the cell cycle takes about 12–24 hours. There are three main stages of the cell cycle.

Interphase

Interphase is the stage during which the cell grows, develops into a mature, functioning cell, duplicates the DNA in its nucleus, and prepares for division. Interphase is divided into three stages as shown in **Figure 4**: G_1, S, and G_2, also called Gap 1, synthesis, and Gap 2. When these activities are completed, the cell begins mitosis.

Gap 1 (G_1) The first stage of interphase, G_1, is the period immediately after a cell divides. During G_1, a cell is growing, carrying out normal cell functions, and preparing to replicate DNA. Some cells, such as muscle and nerve cells, exit the cell cycle at this point and do not divide again.

Synthesis (S) The second stage of interphase, S, is the period when a cell copies its DNA in preparation for cell division.

Gap 2 (G_2) The G_2 stage follows the S stage and is the period when the cell prepares for the division of its nucleus. A protein that makes microtubules for cell division is synthesized at this time. During G_2, the cell also takes inventory and makes sure it is ready to continue with mitosis.

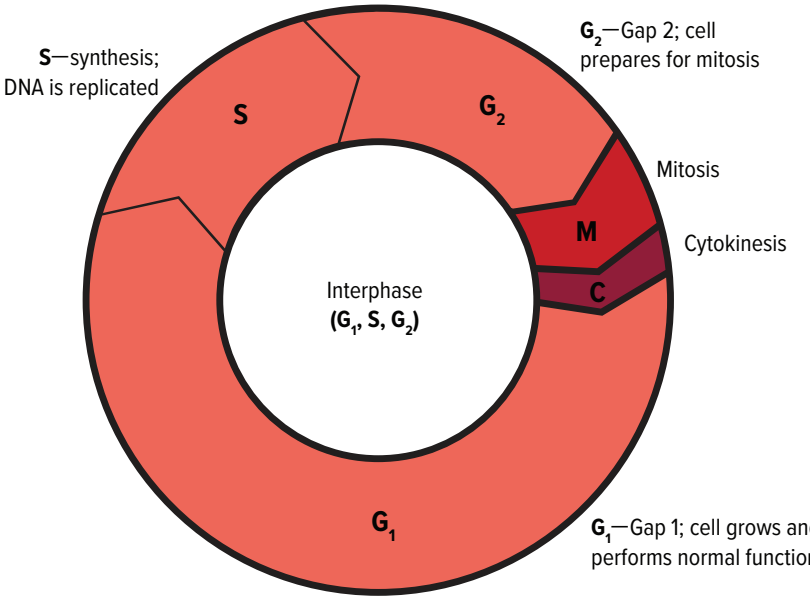


Figure 4 The cell cycle involves three stages—interphase, mitosis, and cytokinesis. Interphase is divided into three substages.

Hypothesize *why cytokinesis represents the smallest amount of time that a cell spends in the cell cycle.*

Mitosis

Mitosis (mi TOH sus) is the stage of the cell cycle during which the cell's nucleus and nuclear material divide. During mitosis, the cell's replicated genetic material separates and the cell prepares to split into two cells. The key activity of mitosis is the accurate separation of the cell's replicated DNA. This enables the cell's genetic information to pass into the new cells intact, resulting in two daughter cells that are genetically identical. In multicellular organisms, the process of mitosis increases the number of cells as a young organism grows to its adult size.

Organisms also use mitosis to replace damaged cells. Recall the last time you were accidentally cut. The body's process of healing the cut involves generating new skin cells. These new cells are produced by your existing skin cells. Under the scab, the existing skin cells divided by mitosis and cytokinesis to create new skin cells that filled the gap in the skin caused by the injury. Mitosis is also important for maintaining chromosome number in organisms that undergo asexual reproduction.

Get It?

Explain the role of mitosis in the processes of growth and repair.

The stages of mitosis

Mitosis is divided into four stages: prophase, metaphase, anaphase, and telophase. The stages occur in the same order during each mitotic division.

Prophase The first and longest of the four stages is called **prophase.** In this stage, the cell's chromatin condenses to form chromosomes. At this point, each chromosome is a single structure containing the genetic material that was replicated during interphase.

In prophase, the chromosomes are shaped like an X, as shown in **Figure 5**. Each half of this X is called a sister chromatid. **Sister chromatids** are structures that contain identical copies of DNA.

SEM Magnification: unavailable

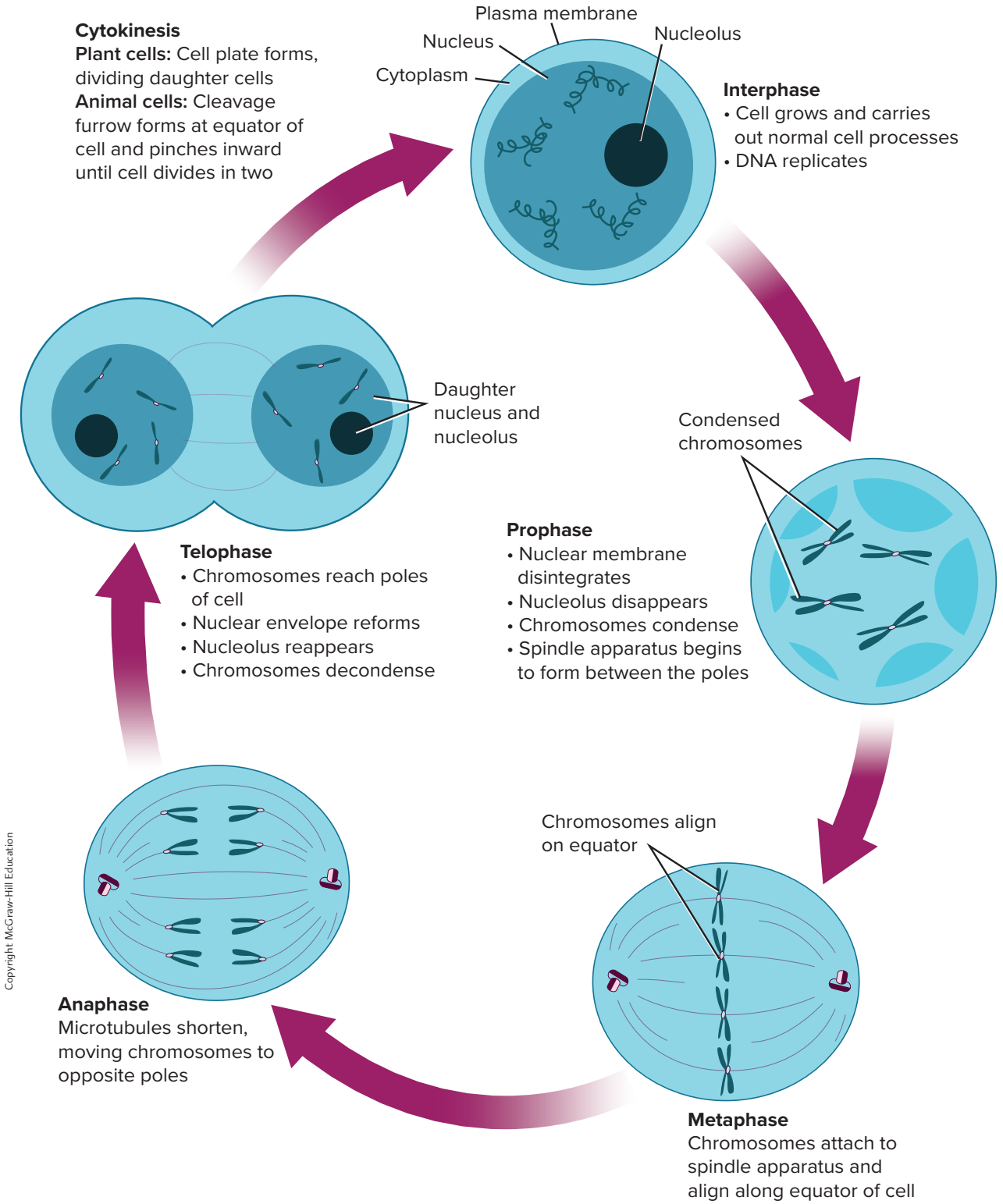
Figure 5 Chromosomes in prophase are actually sister chromatids that are attached at the centromere.

The structure at the center of the chromosome where the sister chromatids are attached is called the **centromere.** A centromere is important because it ensures that a complete copy of the replicated DNA will become part of the daughter cells at the end of the cell cycle.

Locate prophase in the cell cycle diagram illustrated in **Figure 6** on the next page, and note the position of the sister chromatids in the nucleus. As you continue to read about the stages of mitosis in this lesson, refer to **Figure 6** to follow the chromatids through metaphase, anaphase, and telophase. Use the diagram to track the changes that occur as the cell moves through the cell cycle.

Figure 6 Visualizing the Cell Cycle

The cell cycle begins with interphase. Mitosis follows, occurring in four stages—prophase, metaphase, anaphase, and telophase. Mitosis is followed by cytokinesis, then the cell cycle repeats with each new cell.



As prophase continues, the nucleolus starts to disappear. Microtubule structures called spindle fibers form in the cytoplasm. In animal cells and most protist cells, centrioles migrate to the ends, or poles, of the cell. Coming out of the centrioles are aster fibers, which have a starlike appearance. The whole structure, including the spindle fibers, centrioles, and aster fibers, is called the **spindle apparatus** and is shown in **Figure 7**. The spindle apparatus is important in moving and organizing the chromosomes before cell division. Centrioles are not part of the spindle apparatus in plant cells.

Get It?

Summarize the role of the spindle apparatus during cell division.

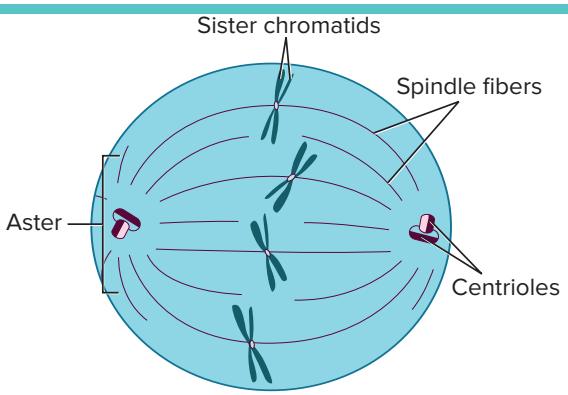


Figure 7 In animal cells, the spindle apparatus is made of spindle fibers, centrioles, and aster fibers.

Near the end of prophase, the nuclear envelope disappears. The spindle fibers attach to the sister chromatids of each chromosome on both sides of the centromere and then attach to opposite poles of the cell. This arrangement ensures that each new cell receives one complete copy of the DNA.

Metaphase During the second stage of mitosis, **metaphase,** the sister chromatids are pulled by motor proteins along the spindle apparatus toward the center of the cell and they line up in the middle, or equator, of the cell, as shown in **Figure 8**. Metaphase is one of the shortest stages of mitosis, but when completed successfully, it ensures that the new cells receive the correct chromosomes.

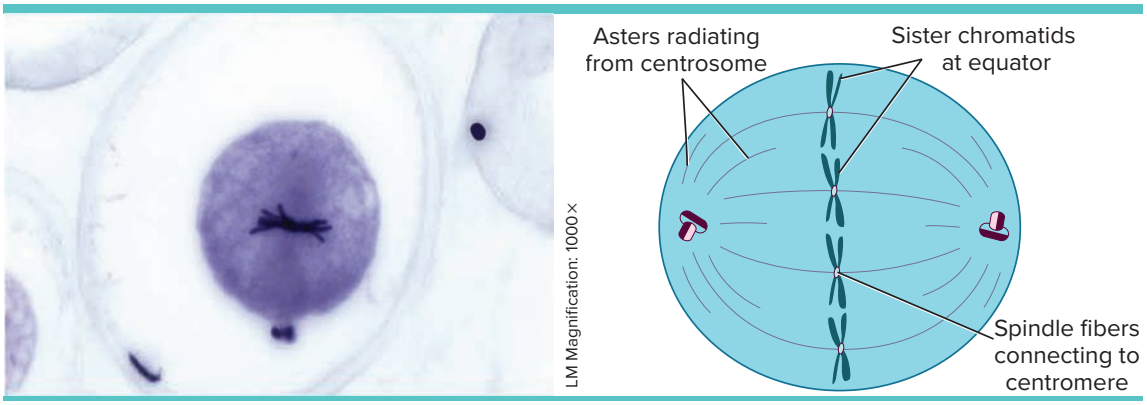


Figure 8 In metaphase, the chromosomes align along the equator of the cell.

Infer *why the chromosomes align along the equator.*

Anaphase The chromatids are pulled apart during **anaphase,** which results in the separation of replicated DNA. In anaphase, microtubules of the spindle apparatus shorten, which pulls at the centromeres. The sister chromatids separate into two identical chromosomes. At the end of anaphase, the microtubules, with the help of motor proteins, move the chromosomes toward the poles of the cell.

Telophase The last stage of mitosis is called **telophase.** Telophase is the stage of mitosis during which the chromosomes arrive at the poles of the cell and begin to relax, or decondense. As shown in **Figure 9**, two new nuclei are formed, each with a complete set of DNA. Two new nuclear membranes begin to form and the nucleoli reappear. Structures used for mitosis are recycled by the cell to build parts of the cytoskeleton.

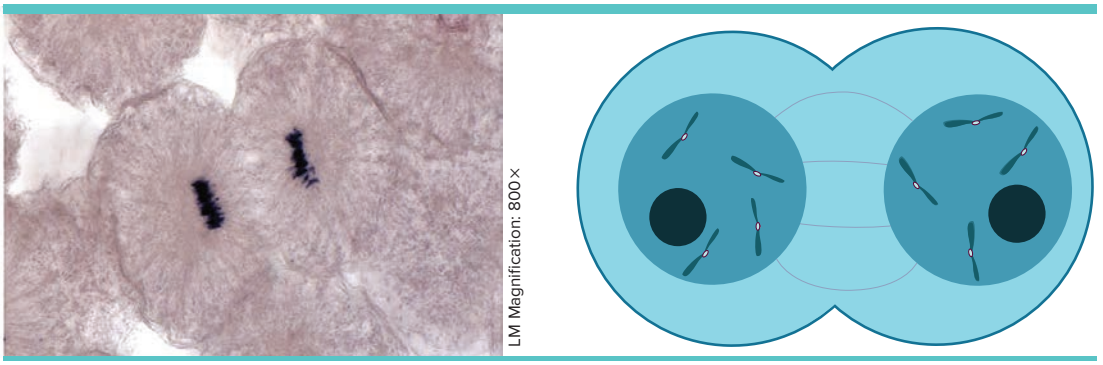


Figure 9 By the end of telophase, the cell has completed the work of duplicating the genetic material and dividing it into two "packages," but the cell has not completely divided.

Cytokinesis

Toward the end of mitosis, the cell begins **cytokinesis** (si toh kih NEE sis) by which a cell's cytoplasm divides. This results in two cells with identical nuclei. In animal cells, cytokinesis is accomplished by using microfilaments to constrict, or pinch, the cytoplasm, as shown in **Figure 10**. The area where constriction occurs is called the furrow.

Plant cells have a rigid cell wall. Instead of pinching in half, a new structure called a cell plate forms between the two daughter nuclei. Cell walls then form on either side of the cell plate. Once this new wall is complete, there are two genetically identical cells.

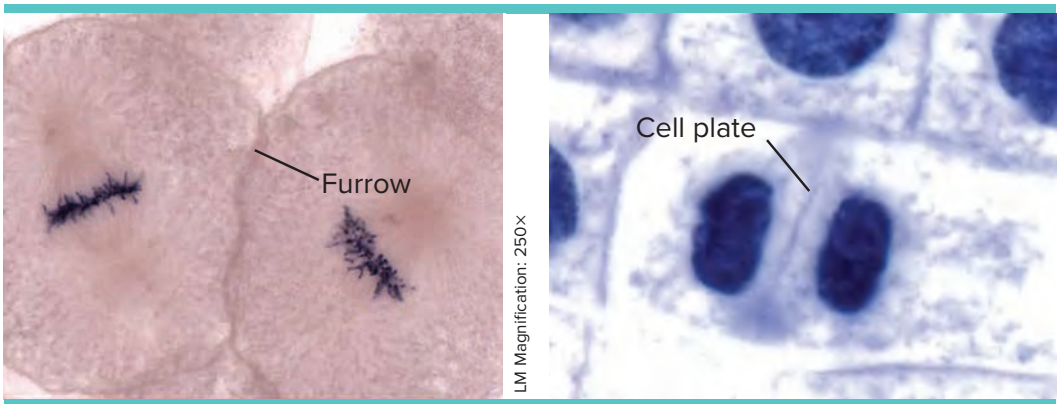


Figure 10 **Left:** In animal cells, cytokinesis begins with a furrow that pinches the cell and eventually splits the two cells apart. **Right:** Plant cells build a cell plate that divides the cell into the two daughter cells.

Cell Cycle Regulation

Cells have specific instructions for carrying out and completing the cell cycle. Although the cell cycle has a system of quality control checkpoints, it is a complex process that sometimes fails.

The role of cyclins In many cars, it takes a key turning in the ignition to signal the engine to start. Similarly, the cell cycle in eukaryotic cells is driven by a combination of two substances that signal the cellular reproduction processes. Proteins called **cyclins** bind to enzymes called **cyclin-dependent kinases** (CDKs) in the stages of interphase and mitosis to initiate the various activities that take place in the cell cycle. Different cyclin/CDK combinations control different activities at different stages in the cell cycle.

In the G_1 stage of interphase, the combination of cyclin with CDK signals the start of the cell cycle. Different cyclin/CDK combinations signal other activities, including DNA replication, protein synthesis, and nuclear division throughout the cell cycle. The same cyclin/CDK combination also signals the end of the cell cycle.

Get It?
Summarize the role of cyclins.

Quality control checkpoints The cell cycle has built-in checkpoints that monitor the cycle and can stop it if something goes wrong. For example, a checkpoint near the end of the G_1 stage monitors for DNA damage and can stop the cycle before it enters the S stage of interphase. There are other quality control checkpoints during the S stage and after DNA replication in the G_2 stage. Spindle checkpoints also have been identified in mitosis. If a failure of the spindle fibers is detected, the cycle can be stopped before cytokinesis. **Figure 11** shows the location of key checkpoints in the cell cycle.

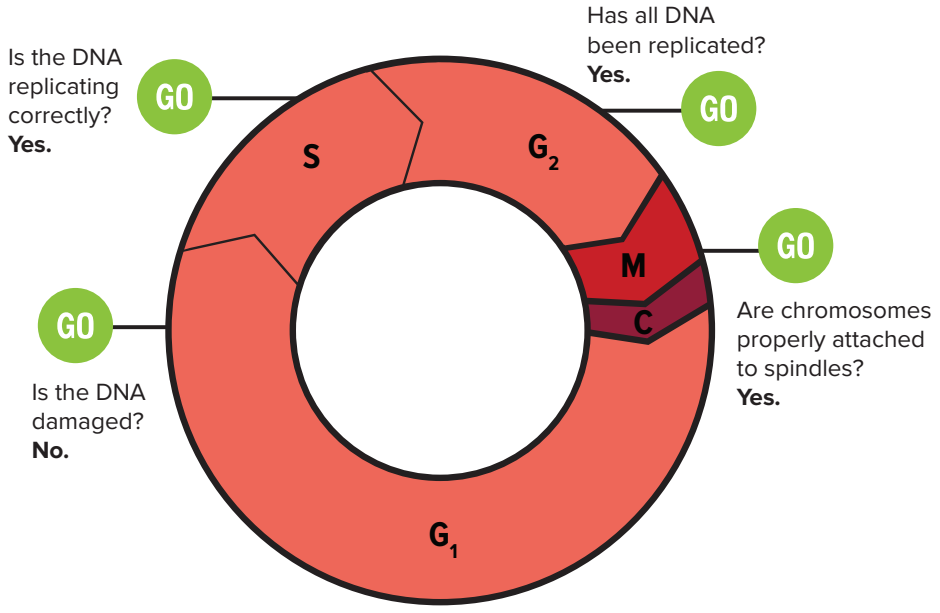


Figure 11 Signaling molecules made of a cyclin bound to a CDK kick off the cell cycle and drive it through mitosis. Checkpoints monitor the cell cycle for errors and can stop the cycle if an error occurs.

Apoptosis

Not every cell is destined to survive. Some cells go through a process called **apoptosis** (a pup TOH sus), or programmed cell death. Cells going through apoptosis actually shrink and shrivel in a controlled process. All animal cells appear to have a "death program" that can be activated. One example of apoptosis occurs during the development of the human hand and foot. When the hands and feet begin to develop, cells occupy the spaces between the fingers and toes. Normally, this tissue undergoes apoptosis, with the cells shriveling and dying at the appropriate time so that the webbing is not present in the mature organism.

An example of apoptosis in plants is the localized death of cells that results in leaves falling from trees during autumn. Apoptosis also occurs in cells that are damaged beyond repair, including cells with DNA damage that could lead to cancer. Apoptosis can help to protect organisms from developing cancerous growths.

Abnormal cell cycle: cancer

When cells do not respond to the normal cell cycle control mechanisms, a condition called cancer can result. **Cancer** is the uncontrolled growth and division of cells—a failure in the regulation of the cell cycle. When unchecked, cancer cells can kill an organism by crowding out normal cells, resulting in the loss of tissue function. Cancer cells spend less time in interphase than do normal cells, which means cancer cells grow and divide unrestrained as long as they are supplied with essential nutrients. **Figure 12** shows how cancer cells can intrude on normal cells.

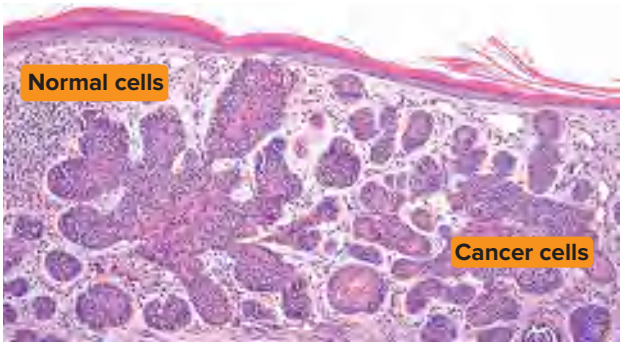


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Figure 12 Cancer cells often have an abnormal, irregular shape compared to normal cells. In this image some cancer cells are entering vessels, which might carry them to another part of the body. This is one way cancer can spread from one body part to another.

Causes of cancer Cancer does not just occur in a weak organism. In fact, cancer occurs in many healthy, active, and young organisms. The changes that occur in the regulation of cell growth and division of cancer cells are due to mutations or changes in the segments of DNA that control the production of proteins, including proteins that regulate the cell cycle. Often, the genetic change or damage that occurs is repaired. But if the repair systems fail, cancer can result. Various environmental factors can affect the occurrence of cancer cells. Substances and agents that are known to cause cancer are called **carcinogens** (kar SIHnuh junz).

CCC CROSSCUTTING CONCEPTS

Systems and Systems Models Develop a physical model to illustrate the cell cycle. Your model does not need to show each step in mitosis, but it should illustrate the role of the cell cycle in producing and maintaining complex organisms. What are the limitations of your model? How could you improve your model?

STEM CAREER Connection

Occupational Health and Safety Specialist

Do you always have your eyes out for safety hazards? Do you like the idea of being responsible for protecting people from harm? Occupational health and safety specialists work to ensure people are safe while they work. They inspect workplaces to ensure safety regulations are followed. Workplace radiation and chemical hazards can be carcinogenic.

Although not all cancers can be prevented, avoiding known carcinogens can help reduce the risk of cancer. A governmental agency called the Food and Drug Administration (FDA) works to make sure that food and drink are safe. The FDA requires labels and warnings for products that might be carcinogens. Laws help protect people from exposure to cancer-causing chemicals in the workplace. Avoiding tobacco of all kinds, even secondhand smoke and smokeless tobacco, can reduce the risk of cancer.

Some radiation, such as ultraviolet radiation from the Sun, is impossible to avoid completely. There is a connection between the amount of ultraviolet radiation to which a person is exposed and the risk of developing skin cancer. Sunscreen is recommended for everyone who is exposed to the Sun. Other forms of radiation, such as X-rays, are used for medical purposes, such as to view a broken bone or to check for cavities in teeth. To protect against exposure, you might have worn a heavy lead apron when an X-ray was taken.

Cancer genetics More than one change in DNA is required to change an abnormal cell into a cancer cell. Over time, there might be many changes in DNA. This might explain why the risk of cancer increases with age. An individual who inherits one or more changes from a parent is at a higher risk for developing cancer than someone who does not inherit these changes.

Check Your Progress

Summary

- The cell cycle is the process of cellular reproduction.
- The cell spends the majority of its lifetime in interphase.
- Mitosis is the process by which the duplicated DNA is divided.
- The stages of mitosis include prophase, metaphase, anaphase, and telophase.
- The cell cycle of eukaryotic cells is regulated by cyclins.
- Checkpoints occur during most of the stages of the cell cycle to ensure that the cell divides accurately.
- Apoptosis is a programmed cell death.
- Cancer is the uncontrolled growth and division of cells.

Demonstrate Understanding

1. **Relate** cell size to cell functions, and explain why cell size is limited.
2. **Summarize** the primary stages of the cell cycle.
3. **Explain** why mitosis alone does not produce daughter cells.
4. **Describe** the events of each stage of mitosis.
5. **Describe** how cyclins control the cell cycle.
6. **Explain** how the cancer cell cycle is different from a normal cell cycle.

Explain Your Thinking

7. **Hypothesize** what might happen if a drug that stopped microtubule movement but did not affect cytokinesis was applied to a cell.
8. **MATH Connection** If a plant cell completes the cell cycle in 24 hours, how many cells will be produced in a week?

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LESSON 2

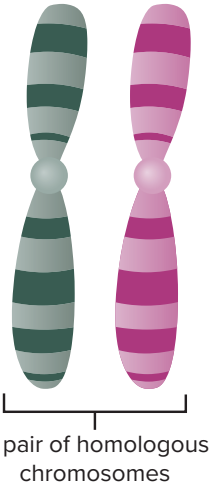
MEIOSIS AND SEXUAL REPRODUCTION

FOCUS QUESTION

What are the stages of meiosis, and how does meiosis provide genetic variation?

Chromosome Numbers

Each student in your class has characteristics passed on to them by their parents. Each characteristic, such as hair color, is called a trait. All cells contain genetic information in the form of DNA molecules. The instructions for each trait are located on chromosomes, which are found in the nucleus of cells. The DNA on chromosomes is arranged in regions called **genes** that code for the formation of proteins, which carry out most of the work of cells. Each chromosome consists of hundreds of genes, each gene playing a role in determining the characteristics and functions of the cell.



A pair of homologous chromosomes

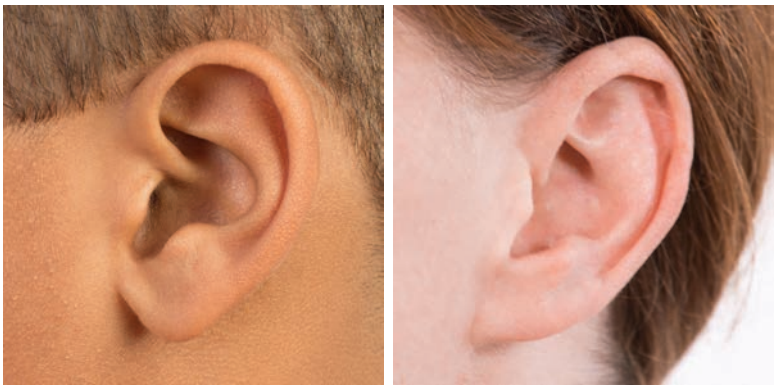


Figure 13 Homologous chromosomes carry genes for any given trait at the same location. The genes that code for earlobe type might not code for the exact same type of earlobe.

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-LS1-4. Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

Homologous chromosomes

Human body cells have 46 chromosomes. Each parent contributes 23 chromosomes, resulting in 23 pairs of chromosomes. The chromosomes that make up a pair, one chromosome from each parent, are called **homologous chromosomes.** As shown in **Figure 13** on the previous page, homologous chromosomes in body cells have the same length and the same centromere position, and they carry genes that control the same traits.

Haploid and diploid cells

In order to maintain the same chromosome number from generation to generation, an organism produces **gametes,** which are sex cells that have half the number of chromosomes. Although the number of chromosomes varies from one species to another, in humans each gamete contains 23 chromosomes. The symbol n can be used to represent the number of chromosomes in a gamete. A cell with n number of chromosomes is called a **haploid** cell. Haploid comes from the Greek word *haploos*, meaning *single*.

The process by which one haploid gamete combines with another haploid gamete is called **fertilization.** As a result of fertilization, the cell now will contain a total of $2n$ chromosomes—n chromosomes from the female parent plus n chromosomes from the male parent. A cell that contains $2n$ number of chromosomes is called a **diploid** cell.

Notice that n also describes the number of pairs of chromosomes in an organism. When two human gametes combine, 23 pairs of homologous chromosomes are formed.

Sex determination

Each cell in your body, except for gametes, contains 46 chromosomes, or 23 pairs of chromosomes. One pair of these chromosomes, the **sex chromosomes,** determines an individual's sex. There are two types of sex chromosomes—X and Y. Individuals with two X chromosomes are genetically classified as female, and individuals with an X and a Y chromosome are genetically classified as male. The other 22 pairs of chromosomes are called **autosomes.** The offspring's sex is determined by the combination of sex chromosomes in the egg and sperm cell, as shown in **Figure 14**.

Figure 14 **Left:** The individual on the left has an X chromosome and a Y chromosome. This individual is male. **Right:** The individual on the right has two X chromosomes. This individual is female.

Meiosis I

Gametes are formed during a process called **meiosis,** which is a type of cell division that reduces the number of chromosomes; therefore, it is referred to as a reduction division. Meiosis occurs in the reproductive structures of organisms that reproduce sexually, forming haploid gametes or spores.

While mitosis maintains the chromosome number during cellular reproduction and in organisms that reproduce asexually, meiosis reduces the chromosome number by half through the separation of homologous chromosomes. A cell with $2n$ number of chromosomes will have gametes with n number of chromosomes after meiosis, as illustrated in **Figure 15**. Meiosis involves two consecutive cell divisions called meiosis I and meiosis II.

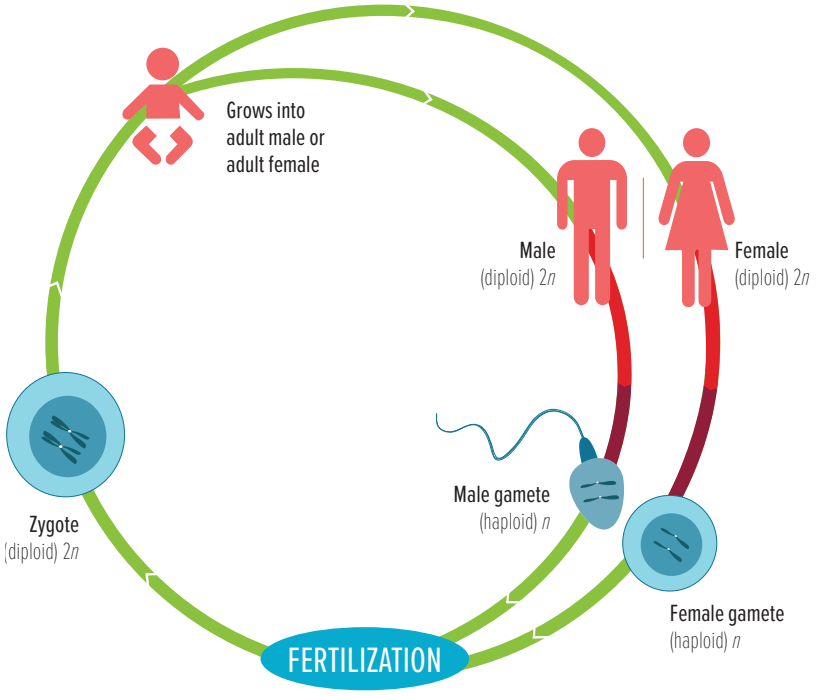


Figure 15 The sexual life cycle in animals involves meiosis, which produces gametes. When gametes combine in fertilization, the number of chromosomes is restored.

Describe *what happens to the number of chromosomes during meiosis.*

STEM CAREER Connection

Medical Scientist

Medical scientists study different tissues and systems in the human body. Their work helps to advance our knowledge and improve human health. Medical scientists who specialize in fertilization and the early stages of life are called embryologists.

Interphase

Recall that the cell cycle includes interphase prior to the four stages of mitosis. Cells that undergo meiosis rather than mitosis also go through interphase as part of the cell cycle. Cells in interphase carry out various metabolic processes, including the replication of DNA and the synthesis of proteins.

Prophase I

As a cell enters prophase I, the replicated chromosomes become visible. As in mitosis, the replicated chromosomes consist of two sister chromatids. As the homologous chromosomes condense, they begin to form pairs in a process called synapsis. The homologous chromosomes are held tightly together along their lengths, as illustrated in **Figure 16**.

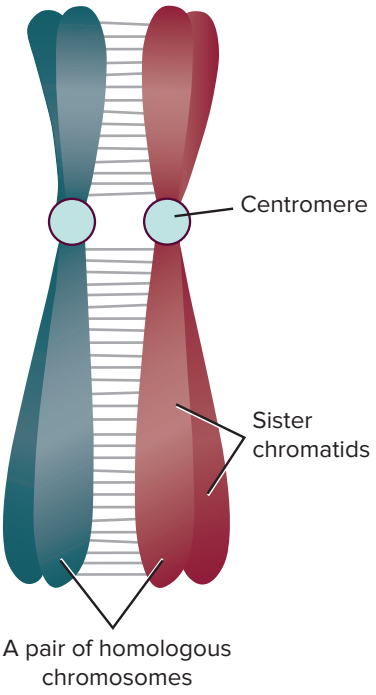


Figure 16 The homologous chromosomes are physically bound together during synapsis in prophase I.

Get It?

Distinguish between homologous chromosomes and sister chromatids.

Notice that in **Figure 17** the red and green chromosomes have exchanged segments. This exchange occurs during synapsis. **Crossing over** is a process during which chromosomal segments are exchanged between a pair of homologous chromosomes. Crossing over is a process that increases genetic variation.

As prophase I continues, centrioles move to the cell's opposite poles. Spindle fibers form and bind to the sister chromatids at the centromere.

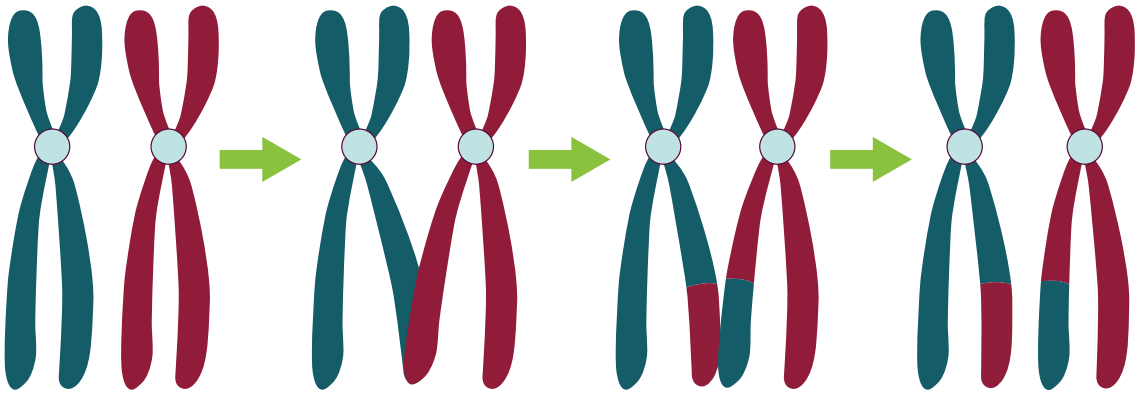


Figure 17 The results of crossing over are new combinations of genes.

Determine *which chromatids exchanged genetic material.*

Metaphase I

In the next phase of meiosis, the pairs of homologous chromosomes line up at the equator of the cell, as illustrated in **Figure 18** on the next page. In meiosis, the spindle fibers attach to the centromere of each homologous chromosome. Recall that during metaphase in mitosis, the individual chromosomes, which consist of two sister chromatids, line up at the cell's equator. During metaphase I of meiosis, the homologous chromosomes line up as pairs at the cell's equator. This is an important distinction between mitosis and meiosis.

Anaphase I

During anaphase I, the homologous chromosomes separate, as shown in **Figure 18**. Each member of the pair is guided by spindle fibers and moves toward opposite poles of the cell. The chromosome number is reduced from $2n$ to n when the homologous chromosomes separate. Recall that in mitosis, the sister chromatids split during anaphase. During meiosis anaphase I each homologous chromosome still consists of two sister chromatids.

Telophase I

The homologous chromosomes, consisting of two sister chromatids, reach the cell's opposite poles. Each pole contains only one member of the original pair of homologous chromosomes. Notice in **Figure 18** that each chromosome still consists of two sister chromatids joined at the centromere. The sister chromatids might not be identical because crossing over might have occurred during synapsis in prophase I.

During telophase I, cytokinesis usually occurs, forming a furrow by pinching in animal cells and by forming a cell plate in plant cells. Following cytokinesis, the cells may go into interphase again before the second set of divisions. However, the DNA is not replicated again during this interphase. In some species, the chromosomes uncoil, the nuclear membrane reappears, and nuclei re-form during telophase I.

Meiosis II

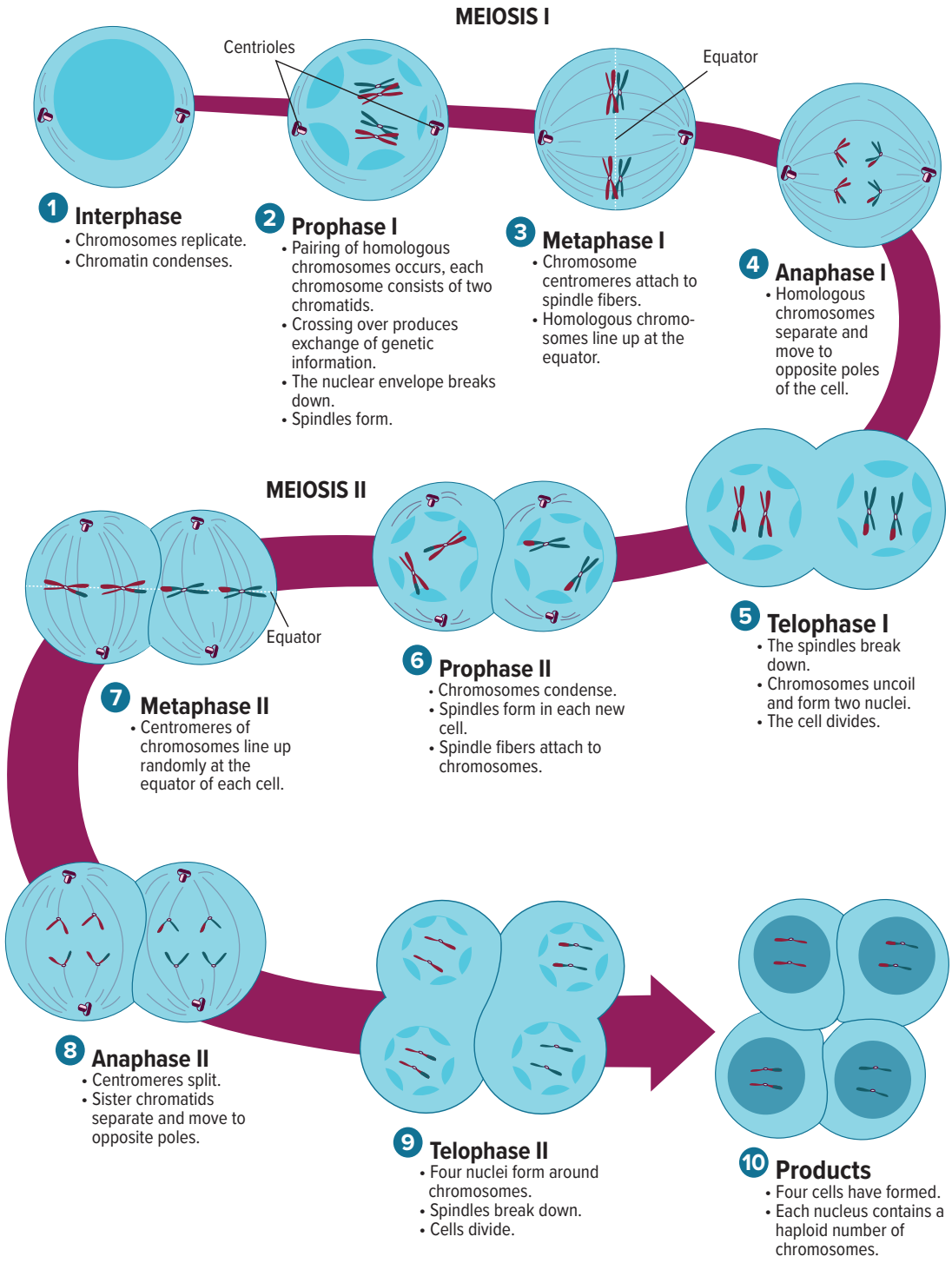
Meiosis is only halfway completed at the end of meiosis I. During prophase II, a second set of phases begins as the spindle apparatus forms and the chromosomes condense. During metaphase II, the chromosomes are positioned at the equator by the spindle fibers. During mitosis metaphase, a diploid number of chromosomes line up at the equator. During meiosis metaphase II, a haploid number of chromosomes line up at the equator. During anaphase II, the sister chromatids are pulled apart at the centromere by the spindle fibers. The sister chromatids move toward the opposite poles. The chromosomes reach the poles during telophase II, and the nuclear membrane and nuclei reform. At the end of meiosis II, cytokinesis occurs, resulting in four haploid cells, each with n number of chromosomes, as illustrated in **Figure 18**.

CCC CROSSCUTTING CONCEPTS

Cause and Effect Choose an inherited human trait. Think about the genetic variation in that trait. Write a summary paragraph to explain how crossing over results in increased genetic variation in the trait. Use evidence from the text in your summary.

Figure 18 Visualizing Meiosis

Follow along the stages of meiosis I and meiosis II, beginning with interphase at the left.

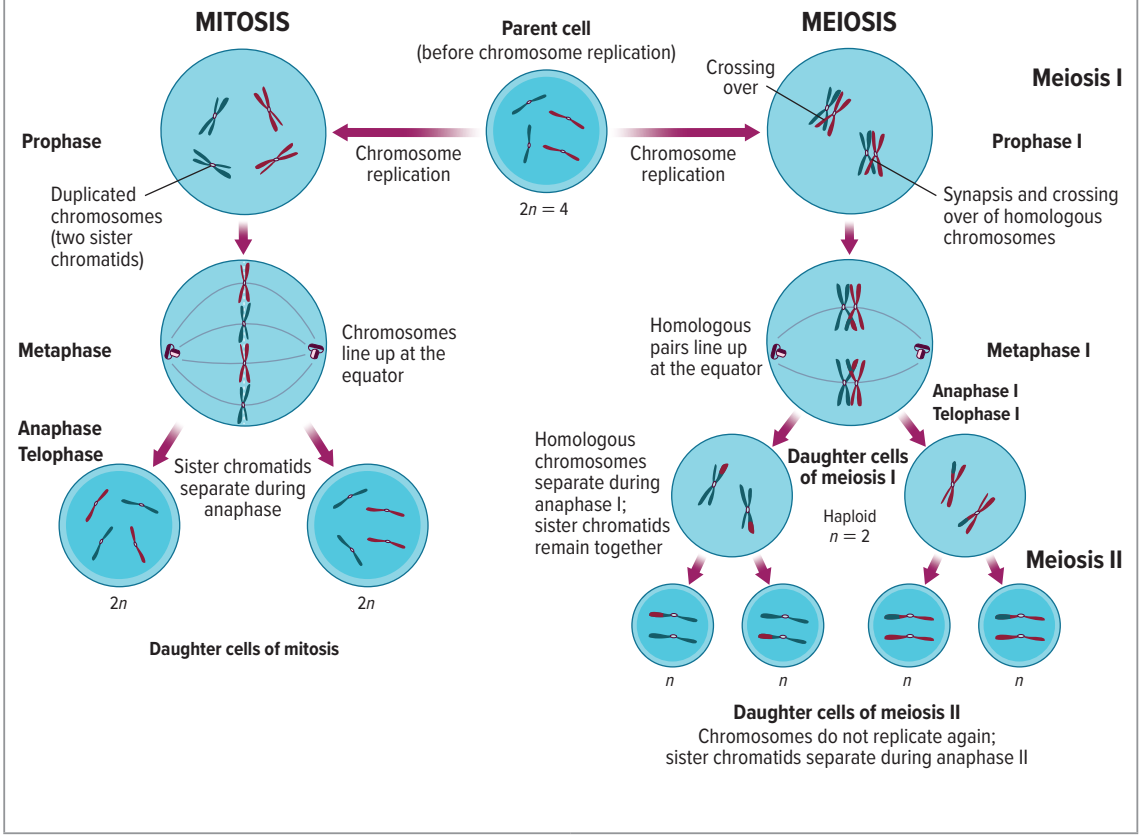


The Importance of Meiosis

Table 1 shows a comparison of mitosis and meiosis. Recall that mitosis consists of only one set of division phases and produces two identical diploid daughter cells. Meiosis, however, consists of two sets of divisions and produces four haploid daughter cells that are not identical. Meiosis is important because it results in genetic variation.

Table 1 Mitosis and Meiosis

Mitosis	Meiosis
One division occurs during mitosis.	Two sets of divisions occur during meiosis: meiosis I and meiosis II.
DNA replication occurs during interphase.	DNA replication occurs once before meiosis I.
Synapsis of homologous chromosomes does not occur.	Synapsis of homologous chromosomes occurs during prophase I.
Two identical cells are formed per cell cycle.	Four haploid cells (*n*) are formed per cell cycle.
The daughter cells are genetically identical.	The daughter cells are not genetically identical because of crossing over.
Mitosis occurs only in body cells.	Meiosis occurs only in reproductive cells.
Mitosis is involved in growth and repair.	Meiosis is involved in the production of gametes and providing genetic variation in organisms.



Meiosis provides variation

Pairs of homologous chromosomes line up at the equator during prophase I. How the chromosomes line up at the equator is a random process that results in gametes with different combinations of chromosomes, such as the ones in **Figure 19**. Depending on how the chromosomes line up at the equator, four gametes with four different combinations of chromosomes can result. This independent assortment of alleles that occurs during gamete formation is a source of genetic variation. Notice that the first possibility shows which chromosomes were on the same side of the equator and therefore traveled together. Different combinations of chromosomes were lined up on the same side of the equator to produce the gametes in the second possibility. Genetic variation is produced by crossing over and by the independent, random assortment of alleles during gamete formation.

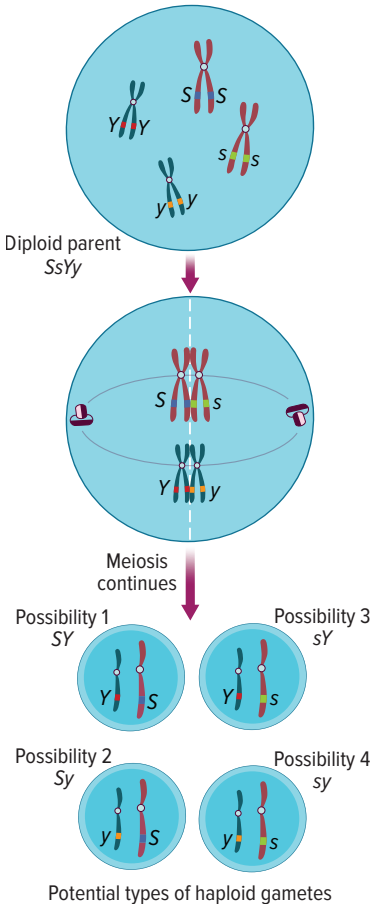


Figure 19 The order in which the homologous pairs line up explains how a variety of sex cells can be produced.

Sexual Reproduction v. Asexual Reproduction

Some organisms reproduce by asexual reproduction, some organisms reproduce by sexual reproduction, and still other organisms have life cycles that involve both asexual reproduction and sexual reproduction. During asexual reproduction, chromosome number is maintained by mitosis. The organism inherits all of its chromosomes from a single parent. The new individual is genetically identical to its parent. Bacteria reproduce asexually, whereas most protists reproduce both asexually and sexually, depending on environmental conditions. Most plants and many of the more simple animals can reproduce both asexually and sexually, compared to more advanced animals that can reproduce only sexually. During sexual reproduction, chromosome number is maintained by meiosis.

Why do some species reproduce sexually while others reproduce asexually? Recent studies with fruit flies have shown that the rate of accumulation of beneficial mutations is faster when species reproduce sexually than when they reproduce asexually. In other words, when reproduction occurs sexually, the beneficial genes multiply faster over time than they do when reproduction is asexual.

Get It?

Compare and contrast sexual and asexual reproduction.

Telomeres

Scientists have found that chromosomes end in protective caps called **telomeres.** Telomere caps consist of DNA associated with proteins. The cap serves a protective function for the structure of the chromosome. Scientists have discovered that telomeres also might be involved in both aging and cancer.

Karyotypes and Nondisjunction

Karyotypes

The study of genetic material does not involve the study of genes alone. Scientists also study whole chromosomes by using images of chromosomes stained during metaphase. The staining bands identify or mark identical places on homologous chromosomes. During metaphase of mitosis, each chromosome has condensed greatly and consists of two sister chromatids. The pairs of homologous chromosomes are arranged in decreasing size to produce a micrograph called a **karyotype** (KER ee uh tipe). Karyotypes of a human female and a human male, shown in **Figure 20**, each have 23 pairs of chromosomes: 22 autosomes and nonmatching sex chromosomes. Females will have two X chromosomes while males will have one X chromosome and one Y chromosome.

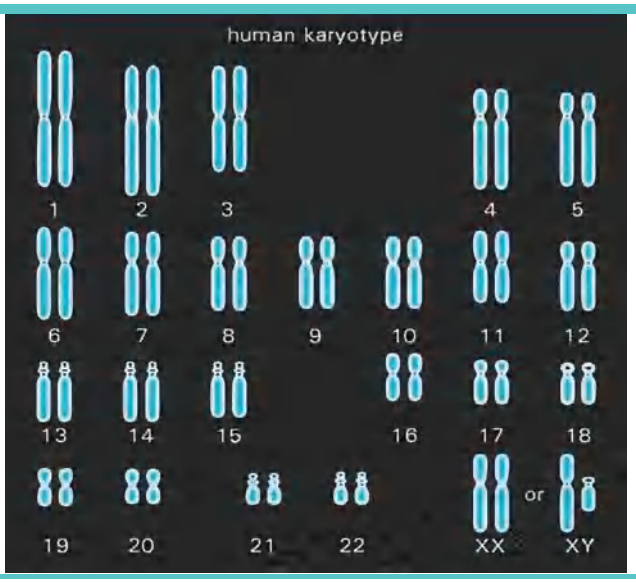


Figure 20 Karyotypes arrange the pairs of homologous chromosomes in order of decreasing size.
Distinguish *which two chromosomes are arranged separately from the other pairs.*

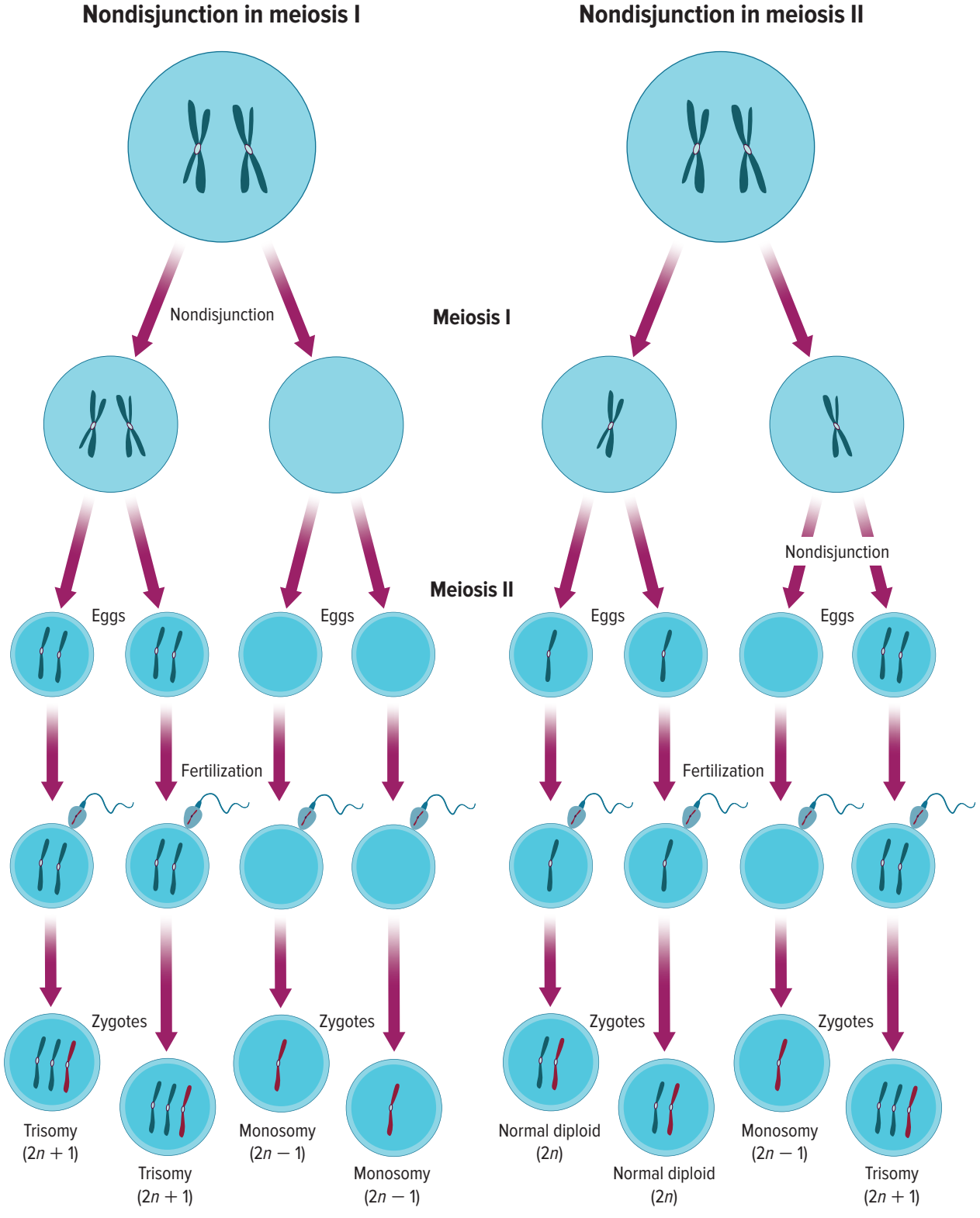
Nondisjunction

During cell division, the chromosomes separate, with one of each of the sister chromatids going to opposite poles of the cell. Therefore, each new cell has the correct number of chromosomes. Cell division during which sister chromatids fail to separate properly, which does happen occasionally, is called **nondisjunction.**

If nondisjunction occurs during meiosis I or meiosis II, the resulting gametes will not have the correct number of chromosomes, as shown in **Figure 21** on the next page. When one of these gametes fertilizes another gamete, the resulting offspring will not have the correct number of chromosomes. **Figure 21** shows that nondisjunction can result in extra copies of a certain chromosome or only one copy of a particular chromosome in the offspring. Having a set of three chromosomes of one kind is called trisomy (TRI so me). Having only one of a particular type of chromosome is called monosomy (MAH nuh some). Nondisjunction can occur in any organism in which gametes are produced through meiosis. In humans, alterations of chromosome numbers are associated with serious human disorders, which are often are fatal.

Figure 21 Visualizing Nondisjunction

Gametes with abnormal numbers of chromosomes can result from nondisjunction during meiosis. The orange chromosomes come from one parent, and the blue chromosomes come from the other parent.



Autosomes Autosomes are chromosomes that are not sex chromosomes. Humans have 22 pairs of autosomes. Down syndrome, Patau Syndrome, and Edward's syndrome are all examples of nondisjunction in autosomes.

One of the earliest known human chromosomal disorders is Down syndrome. It is the result of an extra chromosome 21, shown in **Figure 22**. Therefore, Down syndrome often is called trisomy 21. Many individuals with Down syndrome can live 60 or more years. The characteristics of Down syndrome include distinctive facial features, short stature, heart defects, and mental disability, as shown in **Figure 22**. The frequency of children born with Down syndrome in the United States is approximately one out of 800.

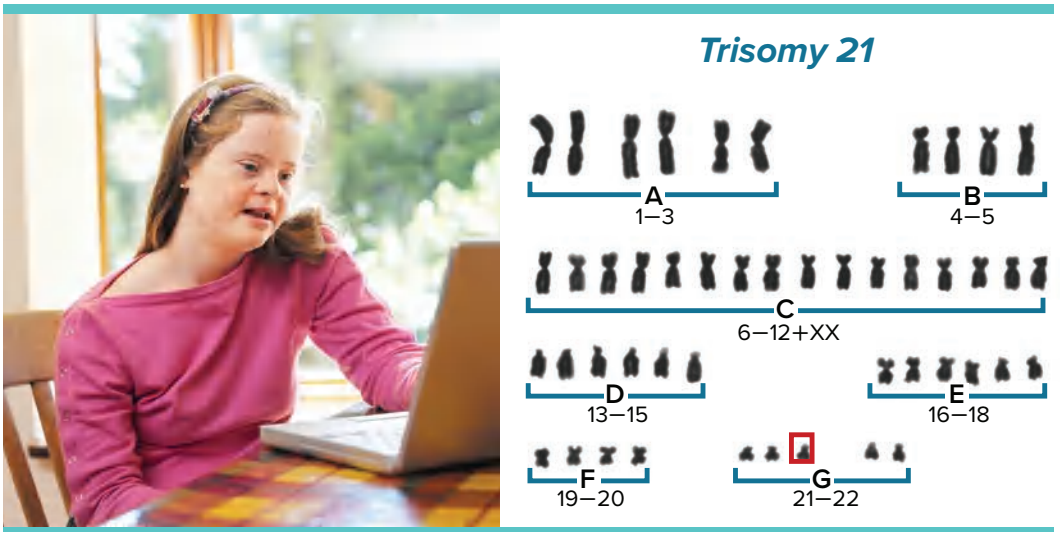
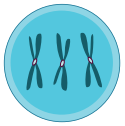
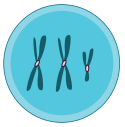


Figure 22 A person with Down syndrome has distinctive features and will have a karyotype that shows three copies of chromosome number 21.

Sex chromosomes Nondisjunction occurs in both autosomes and sex chromosomes. Some of the results of nondisjunction in human sex chromosomes are listed in **Table 2**. An individual with Turner's syndrome has only one sex chromosome. This condition results from fertilization with a gamete that had no sex chromosome. An individual with Klinefelter's syndrome has three sex chromosomes. This condition results from fertilization with a gamete that had two sex chromosomes.

Table 2 Nondisjunction in Sex Chromosomes

Genotype	XX	XO	XXX	XY	XXY	XYY	OY
Example							
Phenotype	Genetically classified as female	Female with Turner's syndrome	No phenotypic affect	Genetically classified as male	Male with Klinefelter's syndrome	No phenotypic affect	Results in death

Cellular Differentiation and Stem Cells

In multicellular organisms, individual cells grow and then divide via mitosis, thereby allowing the organism to grow. The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells. Cellular division and differentiation produce and maintain a complex organism, composed of tissue and organ systems that work together to meet the needs of the whole organism. **Cellular differentiation** is the process by which an unspecialized cell develops into a specialized cell with a defined structure and function.

The majority of cells in a multicellular organism are designed for a specialized function. For instance, during development some cells are signaled to become skin cells. Certain cells, called stem cells, have the ability to undergo cell differentiation. **Stem cells** are a type of cell that can be directed to become a specialized cell. There are two basic types of stem cells: embryonic stem cells and adult stem cells.

Embryonic stem cells

After a sperm fertilizes an egg, the resulting mass of cells divides repeatedly until there are about 100–150 cells. These cells have not become specialized and are called embryonic stem cells. During embryonic development, cell differentiation is vital as it results in the production of all of the different types of cells and subsequent tissues and organs in an animal's body.

As development continues, the DNA in specific embryonic stem cells receives signals to produce RNA which commits those cells to become specialized cells. As the embryo continues to divide, the cells specialize into various tissues, organs, and organ systems, as illustrated in **Figure 24,** on the next page. If separated, each embryonic stem cell has all of the DNA needed to develop into a wide variety of specialized cells. Scientists, such as the one shown below in **Figure 23,** are aware that embryonic stem cell research is controversial because of ethical concerns about the source of the cells.

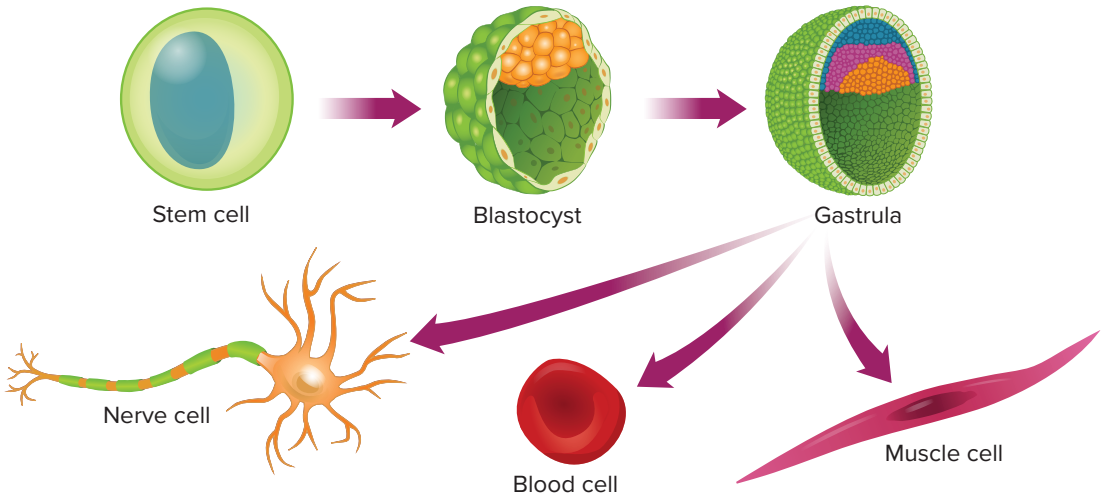
Figure 23 Scientists work with stem cells looking for new treatments for diseases such as cancer, Alzheimer's disease and Parkinson's disease.

Figure 24 Visualizing Stem Cells

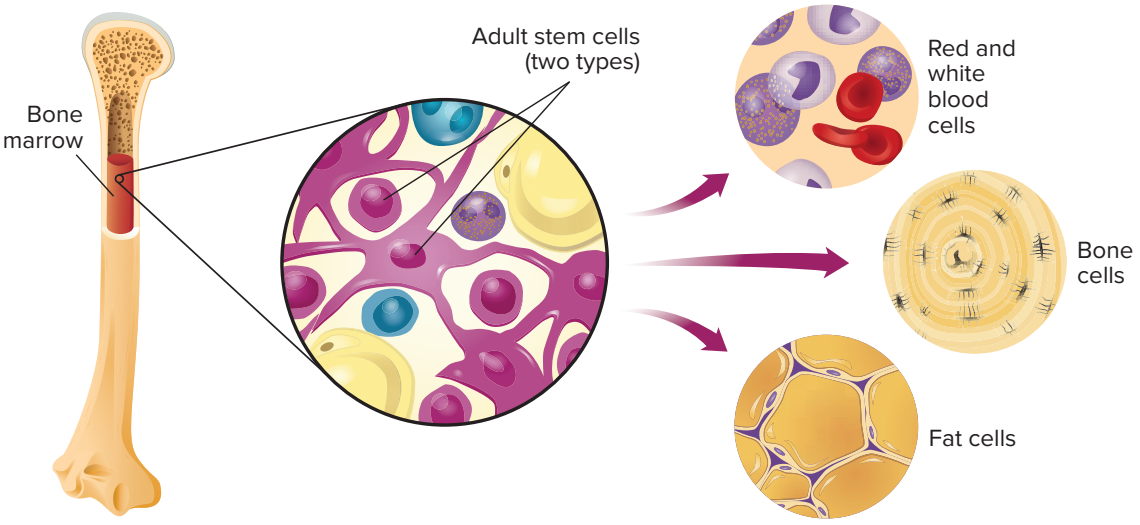
Because stem cells are not locked into becoming one particular type of cell, they might be the key to curing many medical conditions and genetic defects.

Explain *how stem cells could be used to cure nerve damage.*

Embryonic Stem Cells



Adult Stem Cells



Adult stem cells

The second type of stem cells are called adult stem cells shown in **Figure 24** on the previous page. As adults, animals have stem cells that can differentiate into the specific type of cells they are surrounded by. Stem cells are found in various tissues in the body and might be used to maintain and repair the same kind of tissue in which they are found. The term "adult stem cells" might be somewhat misleading because even a newborn has adult stem cells. Like embryonic stem cells, certain kinds of adult stem cells also might be able to develop into different kinds of cells, providing new treatments for many diseases and conditions. Research with adult stem cells is much less controversial because the adult stem cells can be obtained with the consent of their donors. Scientists are trying to find ways to grow stem cells in cell cultures and manipulate them to generate specific cell types. For example, stem cells might be used to repair cardiac tissue after a heart attack, to restore vision in diseased or injured eyes, to treat diseases such as diabetes, or to repair spinal cells to reverse paralysis caused by injury.

Get It?

Describe some ways that adult stem cells can be used to treat conditions that result from injury or illness.

Check Your Progress

Summary

- DNA replication takes place only once during meiosis, and it results in four haploid gametes.
- Meiosis consists of two sets of divisions.
- Meiosis produces genetic variation in gametes.
- Nondisjunction results in gametes with an abnormal number of chromosomes.
- Cellular differentiation is the process by which an unspecialized cell develops into a specialized cell with a defined structure and function.

Demonstrate Understanding

1. **Explain** how the structure of DNA determines the structure of proteins which carry out most of the work of cells.
2. **Assess** how meiosis contributes to genetic variation, while mitosis does not.
3. **Illustrate** how nondisjunction occurs during meiosis.
4. **Summarize** the role differentiation plays in the production and maintenance of a complex organism.
5. **Describe** a possible application for stem cells.

Explain Your Thinking

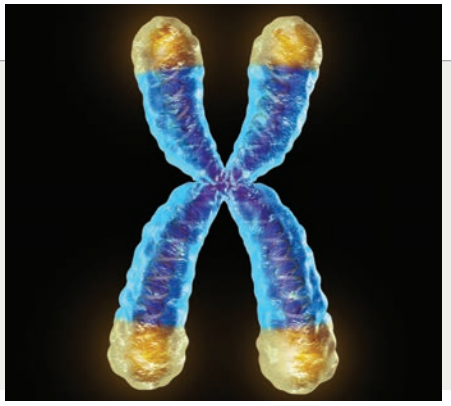
6. **Compare and contrast** mitosis and meiosis by creating a Venn diagram.
7. WRITING Connection **Conduct research** on the consequences of nondisjunction other than trisomy 21. Write a paragraph about your findings.

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

SCIENTIFIC BREAKTHROUGHS

Cancer and Aging Research Enters New TERRA-tory

Cell division is vital to a living organism's ability to grow and reproduce. Scientists have discovered that telomeres, the protective caps at the end of chromosomes, are essential for cell division during mitosis and meiosis. New evidence indicates that the RNA transcribed from telomeres might play a role in aging and cancer.



TERRA is transcribed from telomeres that are on the ends of chromosomes.

Telomeres and TERRA

Vital genetic information would be lost during cell division if it were not for telomeres, which shorten every time a cell divides. When telomeres become too short, the cell stops dividing and is often destroyed.

Cancer is essentially uncontrolled cell division. Many conditions associated with aging involve cells that stop dividing too soon. Scientists know telomeres play a role in cancer and aging, but they are still learning about the mechanisms involved.

Researchers are studying telomeric repeat-containing RNA molecules (TERRA), which are transcribed from telomeres. TERRA bind to the ends of very short telomeres, sending signals that these telomeres should be repaired so that cell division can continue.

Telomeres are repaired by the enzyme telomerase. TERRA regulate telomerase activity, causing the cell to make more or less of the enzyme. Less enzyme means less telomere repair, which means the cell will eventually stop dividing. Drugs that regulate TERRA in some cancer cells can be used to stop their division.

Aging-related conditions are caused by too little cell division. Evidence suggests TERRA can have an effect opposite of the way they act on cancer cells by preventing telomeres from shortening too soon, and instead promoting cell division.

Scientists think that a greater understanding of TERRA will lead to positive developments in the treatment of cancer and aging-related conditions.

DEVELOP A MODEL TO ILLUSTRATE

Research how TERRA is transcribed from telomeres. Develop a model to illustrate this process.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 CELLULAR REPRODUCTION

- The cell cycle is the process of cellular reproduction.
- The cell spends the majority of its lifetime in interphase.
- Mitosis is the process by which the duplicated DNA is divided.
- The stages of mitosis include prophase, metaphase, anaphase, and telophase.
- The cell cycle of eukaryotic cells is regulated by cyclins.
- Checkpoints occur during most of the stages of the cell cycle to ensure that the cell divides accurately.
- Apoptosis is a programmed cell death.
- Cancer is the uncontrolled growth and division of cells.

- chromatin
- chromosome
- nucleosome
- cell cycle
- interphase
- mitosis
- prophase
- sister chromatid
- centromere
- spindle apparatus
- metaphase
- anaphase
- telophase
- cytokinesis
- cyclin
- cyclin-dependent kinase
- apoptosis
- cancer
- carcinogen

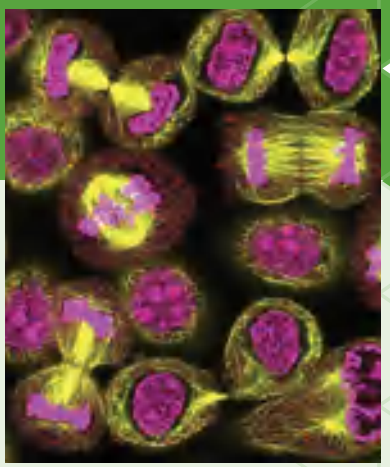
Lesson 2 MEIOSIS AND SEXUAL REPRODUCTION

- DNA replication takes place only once during meiosis, and it results in four haploid gametes.
- Meiosis consists of two sets of divisions.
- Meiosis produces genetic variation in gametes.
- Nondisjunction results in gametes with an abnormal number of chromosomes.
- Cellular differentiation is the process by which an unspecialized cell develops into a specialized cell with a defined structure and function.
- Stem cells are unspecialized cells that can develop into specialized cells with the proper signals.

- gene
- homologous chromosome
- gamete
- haploid
- fertilization
- diploid
- sex chromosome
- autosome
- meiosis
- crossing over
- telomere
- karyotype
- nondisjunction
- cellular differentiation
- stem cell

THREE-DIMENSIONAL THINKING

Module Wrap-Up



REVISIT THE PHENOMENON

Why do some of these cells look so different from each other?

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

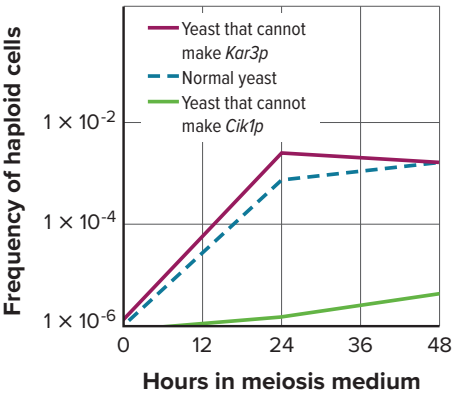
SEP Data Analysis Lab

How do motor proteins affect cell division?

Many scientists think that motor proteins play an important role in the movement of chromosomes in both mitosis and meiosis.

To test this hypothesis, researchers have produced yeast that cannot make the motor protein called Kar3p. They have also produced yeast that cannot make the motor protein called Cik1p, which many think moderates the function of Kar3p. The results of their experiment are shown in the graph to the right.

Motor Protein Effect on Cell Division



*Data obtained from: Shanks, et al. 2001. The Kar3-Interacting protein Cik1p plays a critical role in passage through meiosis I in *Saccharomyces cerevisiae*. *Genetics* 159: 939-951.

CER Analyze and Interpret Data

1. **Claim, Evidence** Determine whether Cik1p or Kar3p seems to be important for yeast meiosis. Explain.
2. **Reasoning** Conclude whether all motor proteins seem to play a vital role in meiosis. Explain.

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.

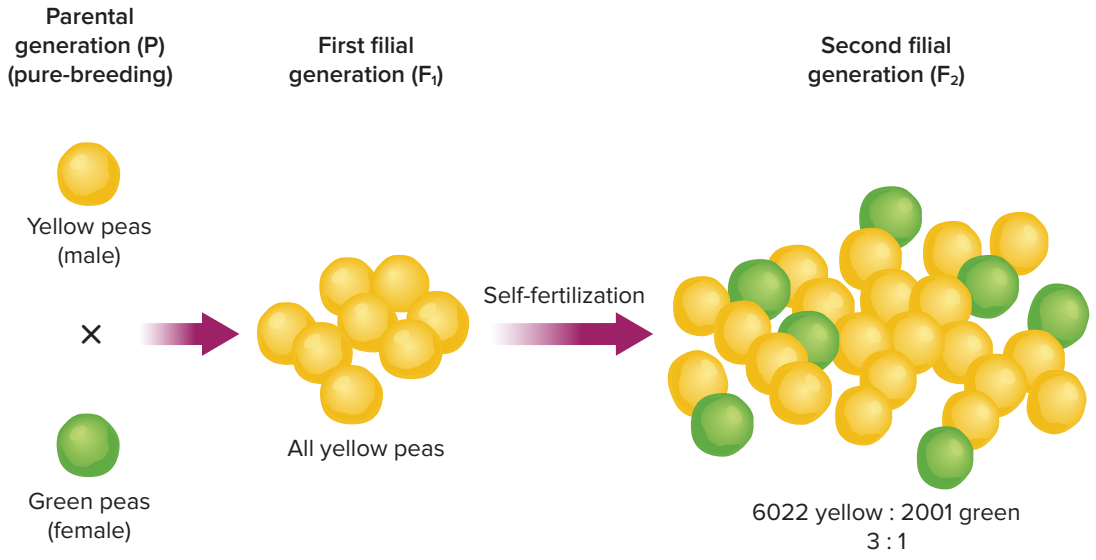


Figure 2 The results of Mendel's cross involving true-breeding pea plants with yellow seeds and green seeds are shown here.

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.

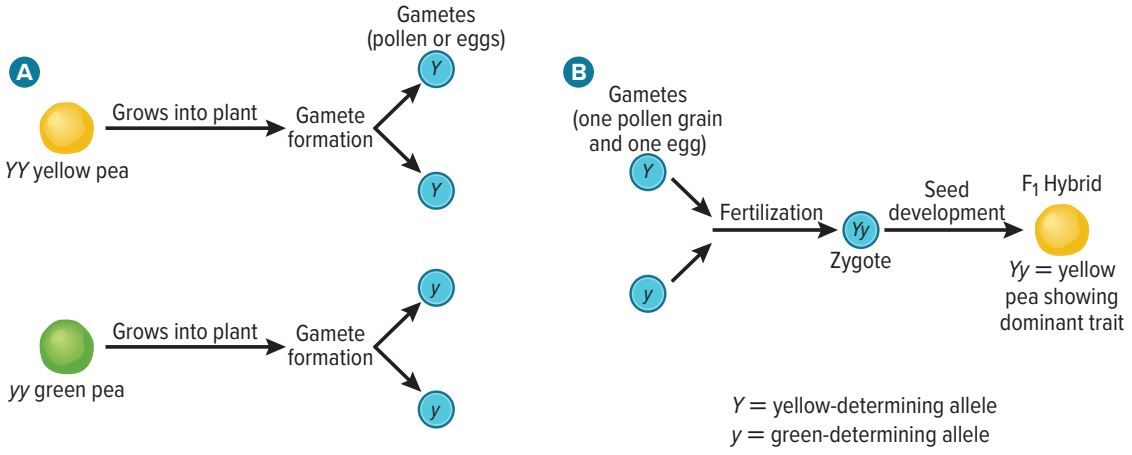


Figure 3 During gamete formation in the *YY* or *yy* plant, the two alleles separate, resulting in *Y* or *y* in the gametes. Gametes from each parent unite during fertilization.

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?

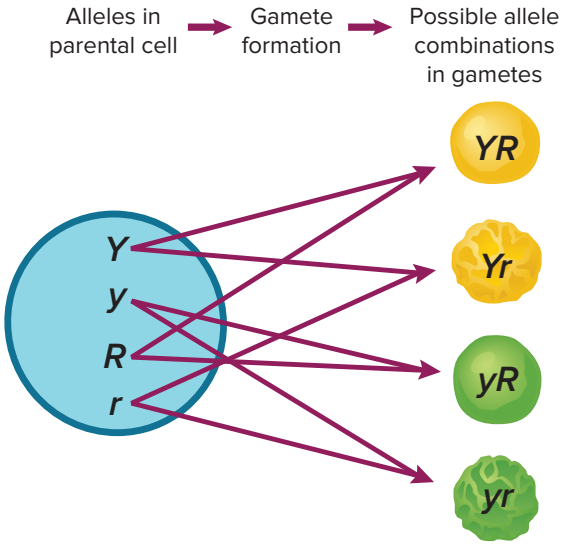


Figure 4 The law of independent assortment is demonstrated by the equal chance that each pair of alleles (*Yy* and *Rr*) can randomly combine with each other.

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.

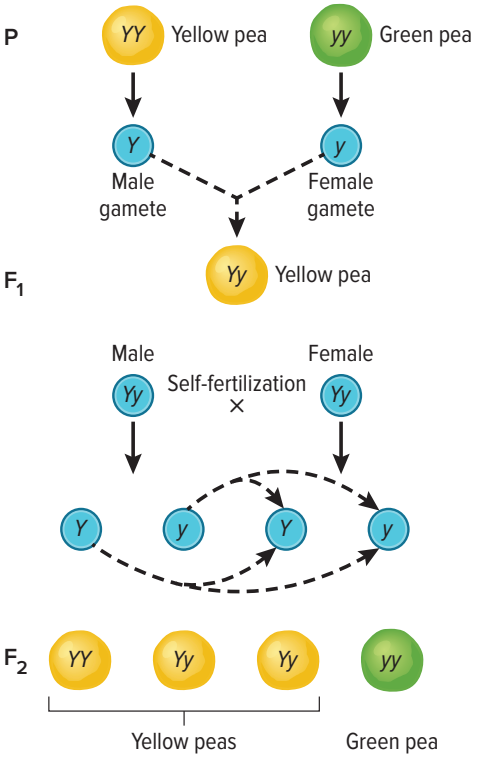


Figure 5 During the F_1 generation self-fertilization, the male gametes randomly fertilize the female gametes.

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.

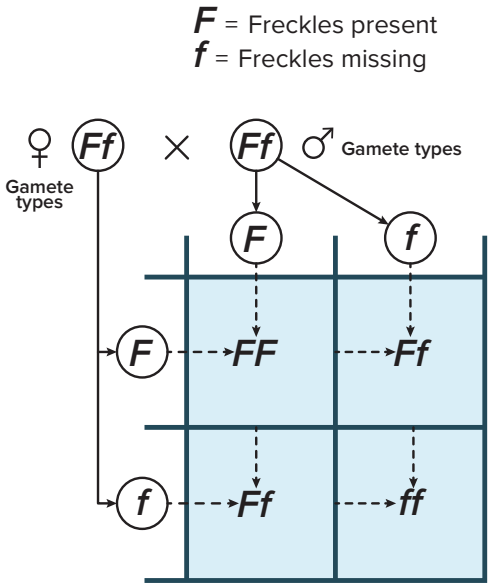
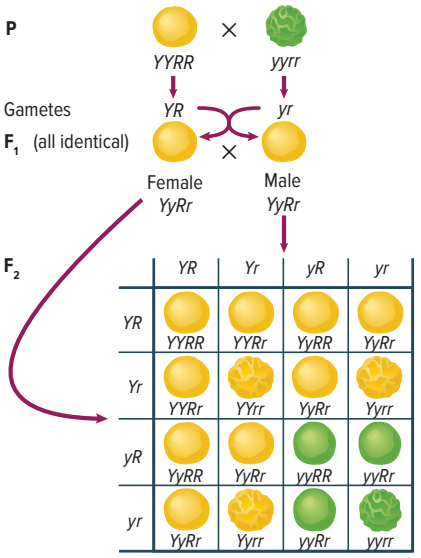


Figure 7 Freckles are a dominant trait. The Punnett square is a visual summary of the possible combinations of the alleles for the trait of freckles.

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 × 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**.

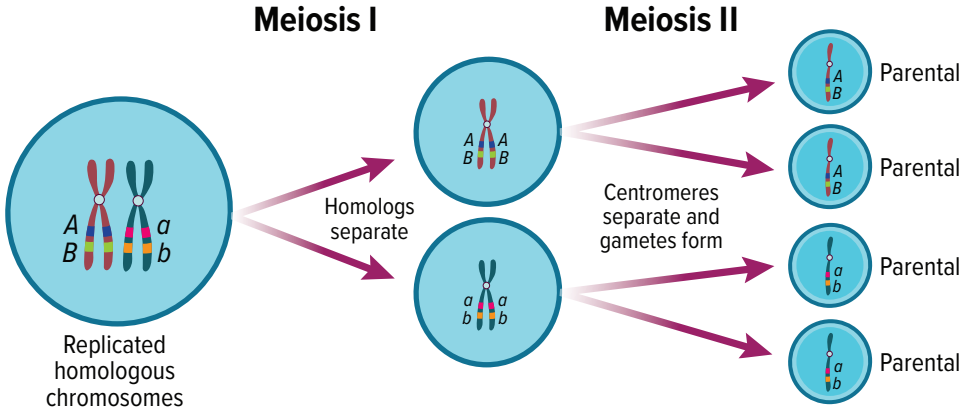

Figure 10 Genes that are linked together on the same chromosome usually travel together in the gamete.

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.

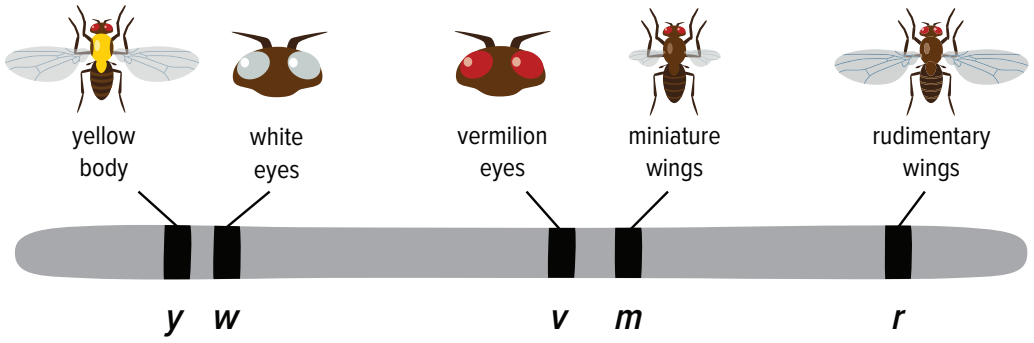

Figure 11 This chromosome map of the X chromosome of the fruit fly *Drosophila melanogaster* was created in 1913.

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

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.

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

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.

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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.

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.

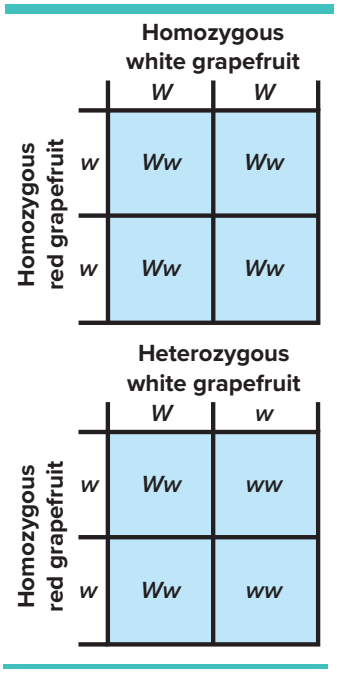

Figure 14 The genotype of a white grapefruit tree can be determined by a test cross.

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.

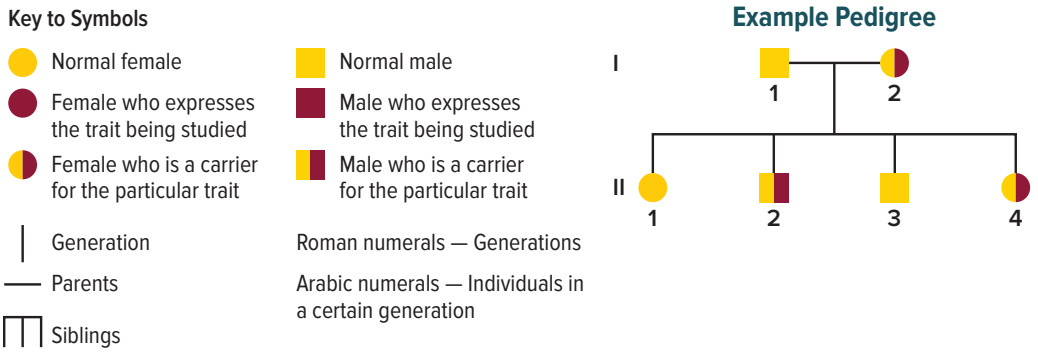

Figure 15 A pedigree uses standard symbols to indicate what is known about the trait being studied.
Summarize *the genotypes and phenotypes of the individuals in generation II for the trait being studied.*

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.

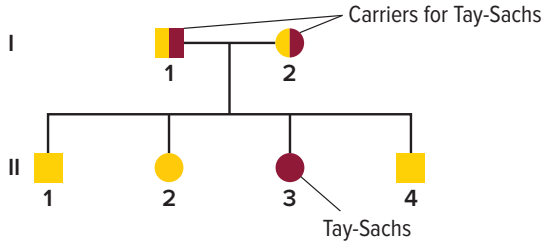

Figure 16 This pedigree illustrates the inheritance of the recessive disorder Tay-Sachs disease. Note that two unaffected parents (I1 and I2) can have an affected child (II3).

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?

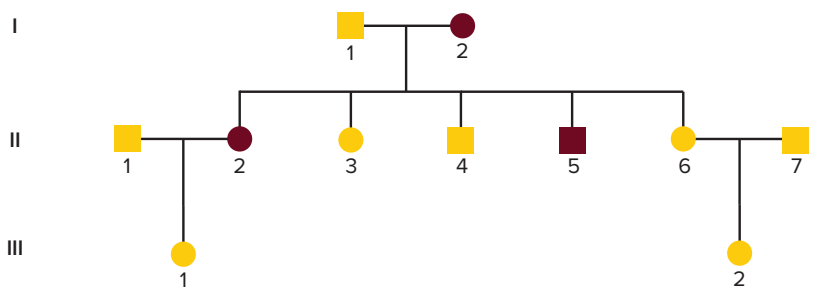

Figure 17 This pedigree illustrates the inheritance of a dominant disorder. Note that affected parents can pass on their genes (II2, II5), but unaffected parents cannot have an affected child (III2).

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 environmental 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/galactose 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.

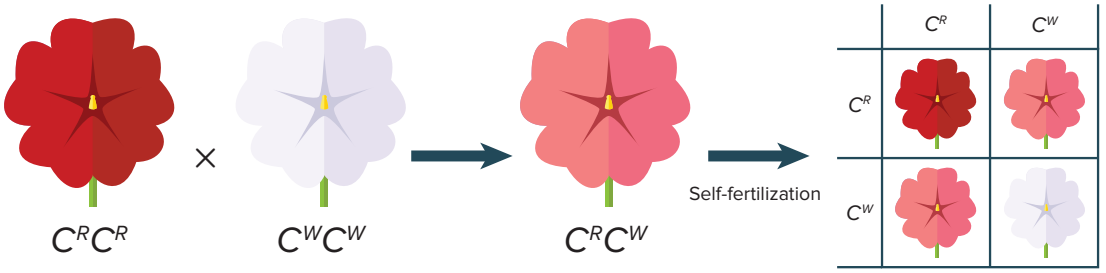

Figure 18 The color of snapdragon flowers is a result of incomplete dominance. When a plant with white flowers is crossed with a plant with red flowers, the offspring have pink flowers. Red, pink, and white offspring will result from self-fertilization of a plant with pink flowers.

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.

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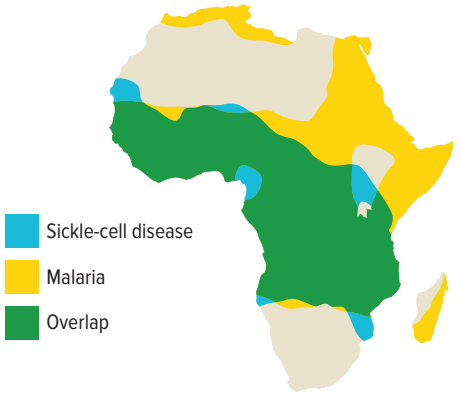


Figure 19

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.

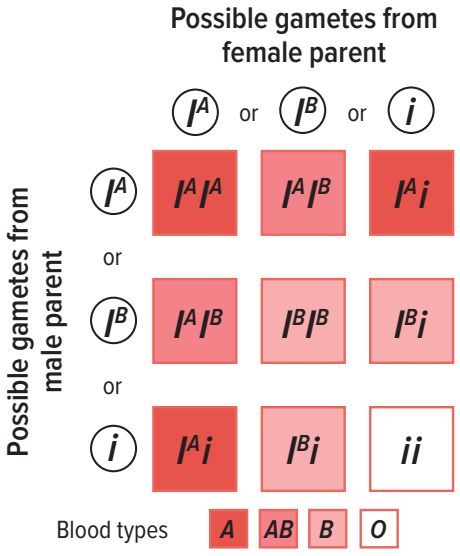


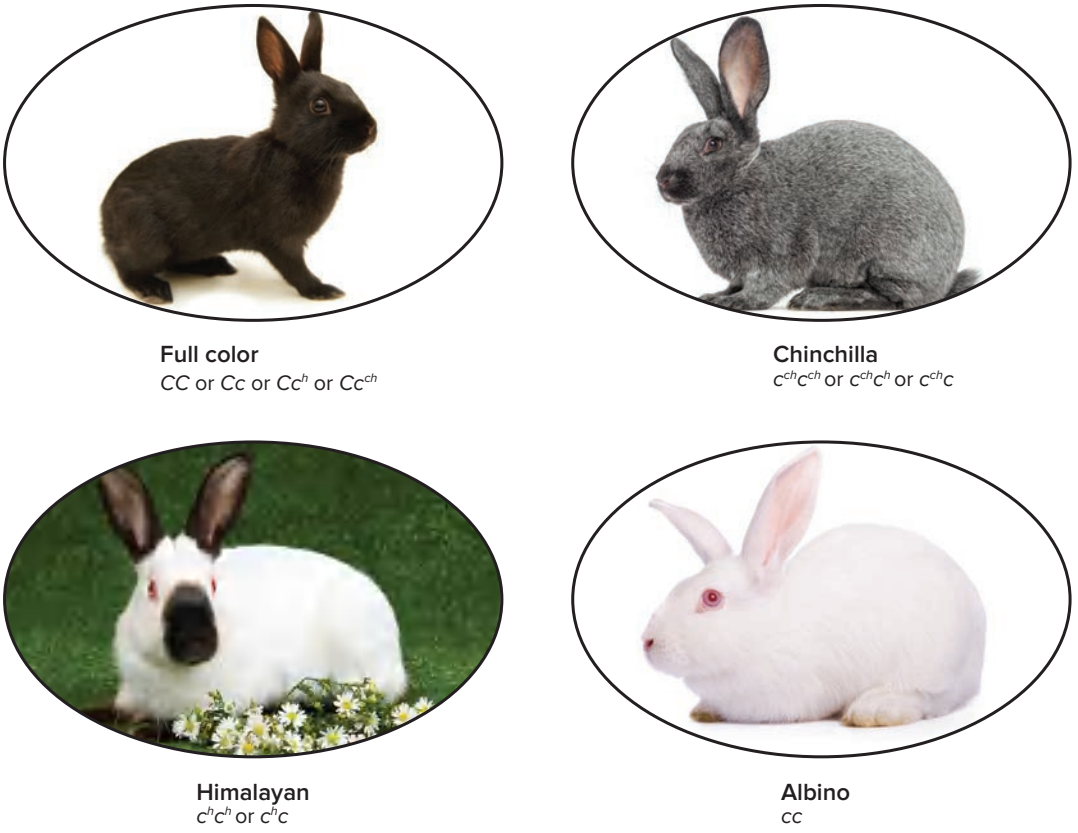
Figure 20 There are three forms of alleles in the ABO blood group—I^A, I^B, and *i*. *I^A and I^B are codominant. i* is recessive to both *I^A and I^B*.

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.



Full color
CC or Cc or Cc^{h} or Cc^{ch}

Chinchilla
$c^{ch}c^{ch}$ or $c^{ch}c^{h}$ or $c^{ch}c$

Himalayan
$c^{h}c^{h}$ or $c^{h}c$

Albino
cc

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.

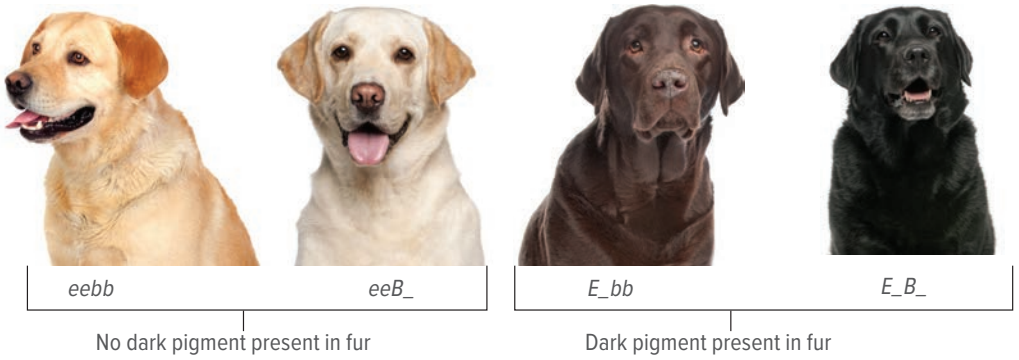


Figure 22 The results of epistasis in coat color in Labrador retrievers show an interaction of two genes, each with two alleles.

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.

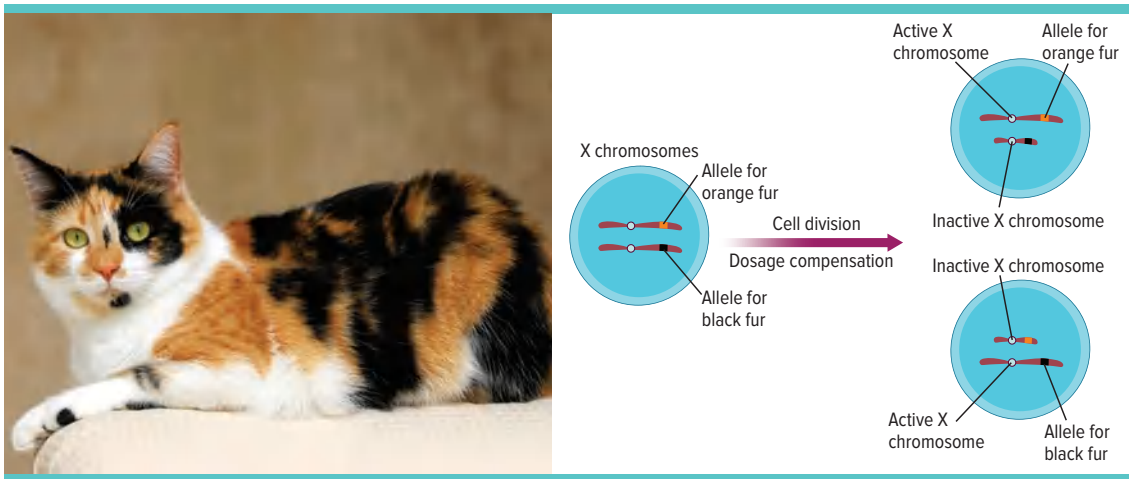
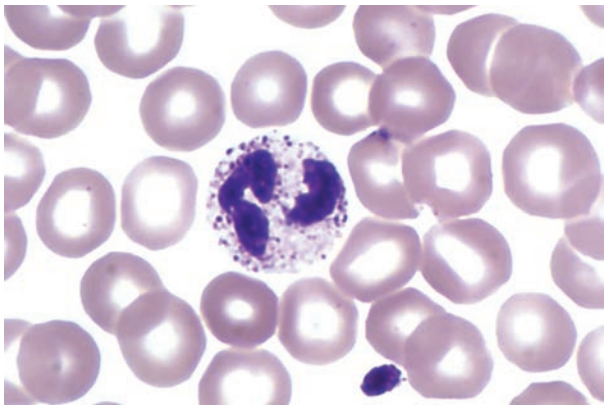


Figure 23 The calico coat of this cat results from the random inactivation of the X chromosomes in body cells. One X chromosome codes for orange fur, and one X chromosome codes for black fur, as illustrated on the right.

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.



LM Magnification: 1600×

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.

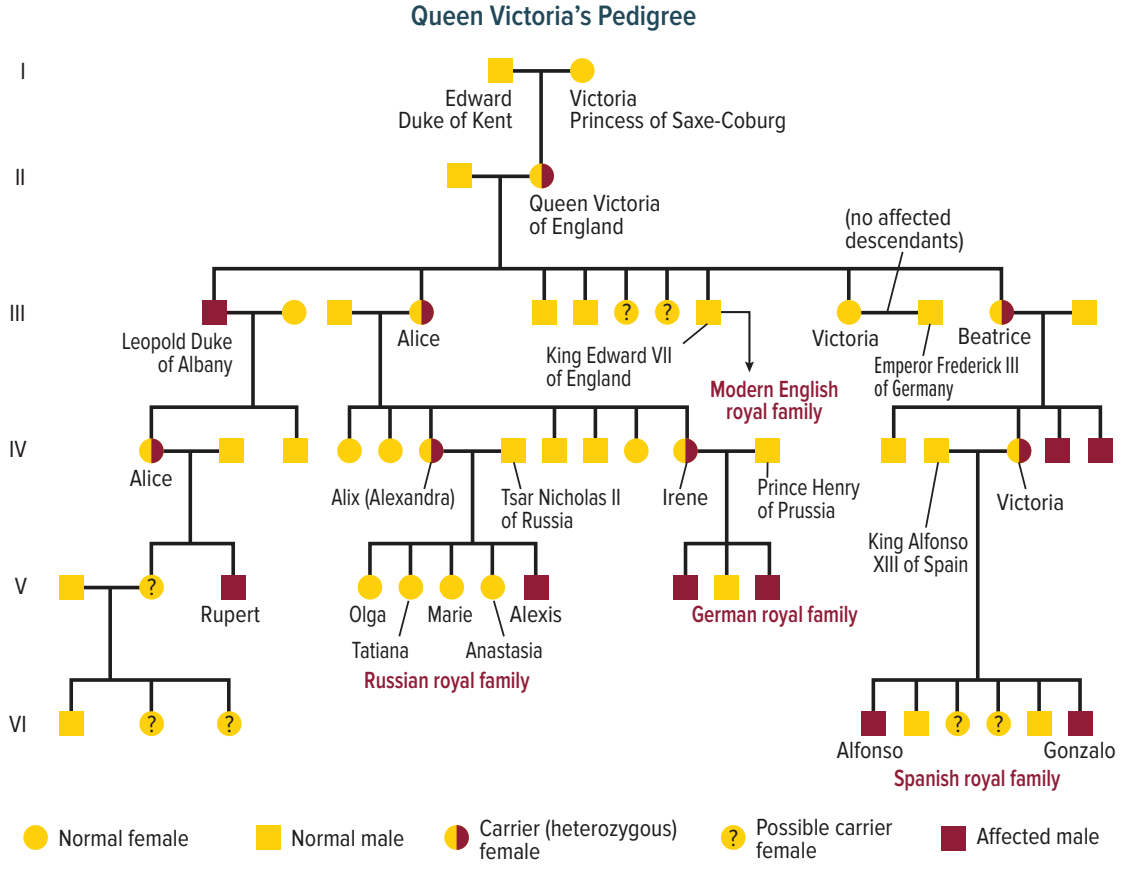


Figure 26 The pedigree above shows the inheritance of hemophilia in the royal families of England, Germany, Spain, and Russia, starting with the children of Queen Victoria.

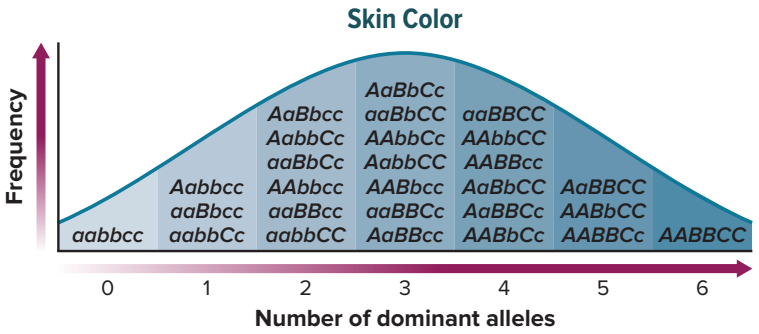


Figure 27 This graph shows possible shades of skin color from three sets of alleles, although the trait is thought to involve more than three sets of alleles.

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.

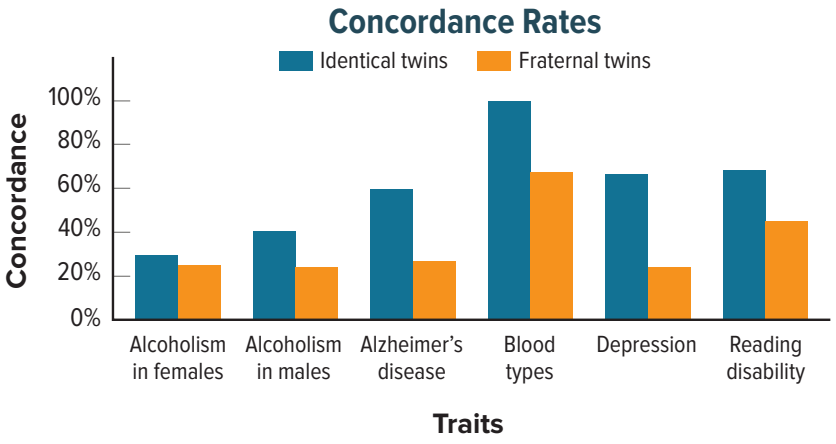


Figure 29 When a trait is found more often in both members of identical twins than in fraternal twins, the trait is presumed to have a significant inherited component.

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

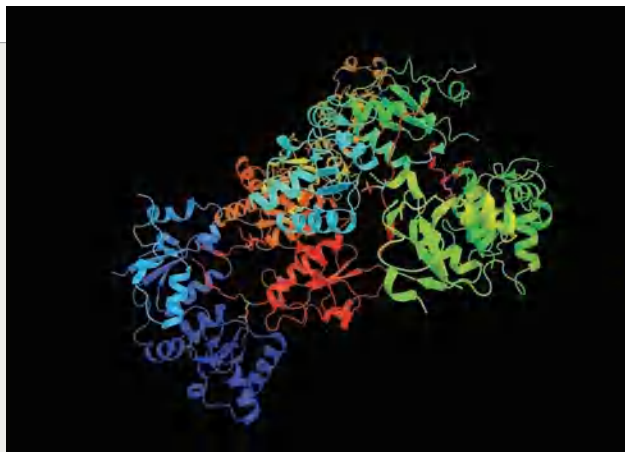
5. **Evaluate** the influence of environmental factors on why the trait for sickle cell disease might be an advantage in central Africa.
6. **MATH Connection** What is the chance of producing a son with normal vision if the father is colorblind and the mother is homozygous normal? Explain.

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

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

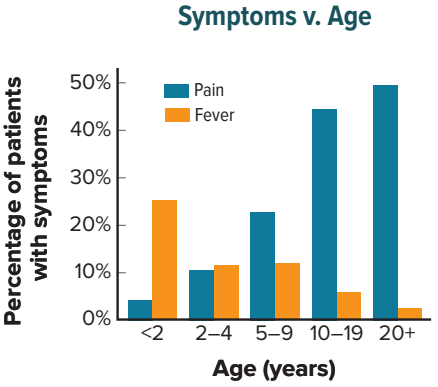
SEP Data Analysis Lab

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.

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.



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

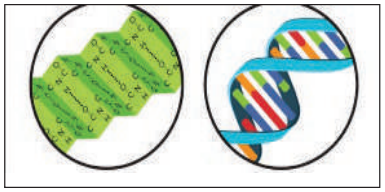
CER Claim, Evidence, Reasoning

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

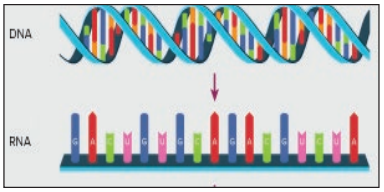
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

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.**

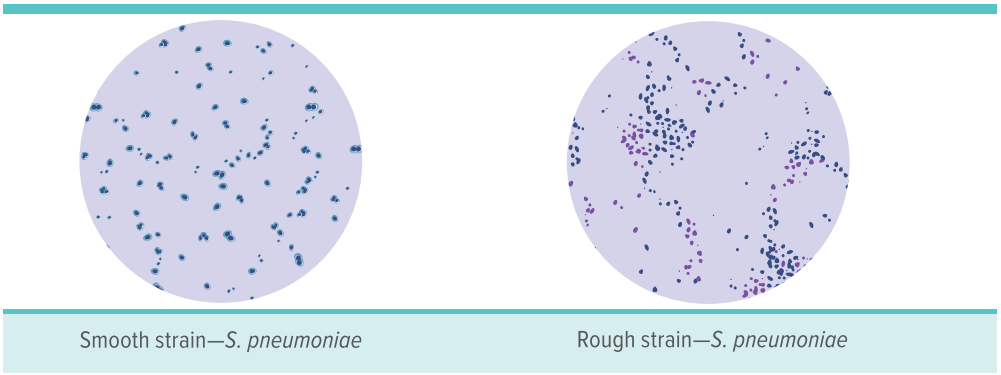


Figure 1 The smooth (S) strain of *S. pneumoniae* can cause pneumonia, though the rough (R) strain is not disease-causing. The strains can be identified by the appearance of the colonies.

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.

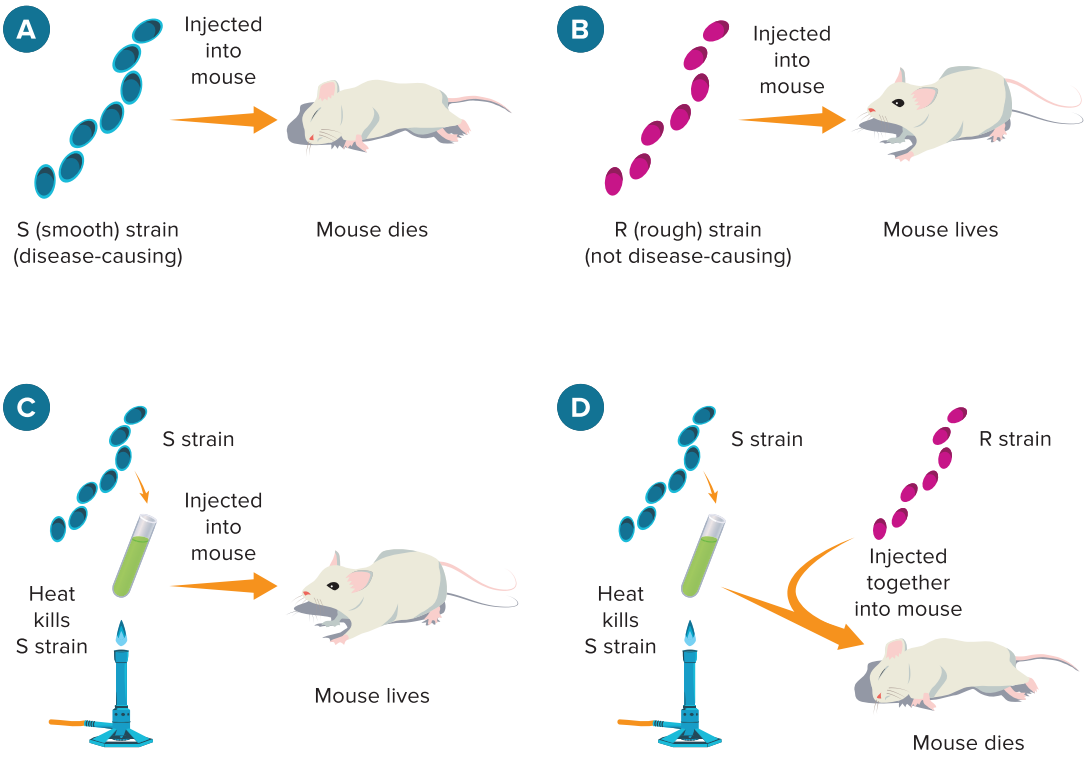


Figure 2 Griffith's transformation experiment demonstrates the change of rough bacteria into smooth bacteria.

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.

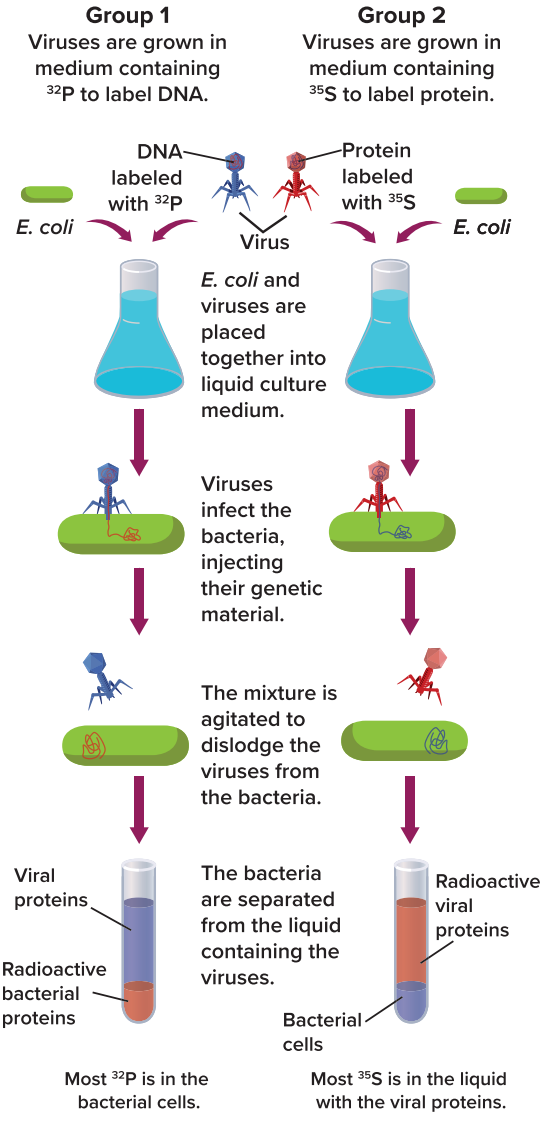


Figure 3 Hershey and Chase used radioactive labeling techniques to demonstrate that DNA is the genetic material in viruses.

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.

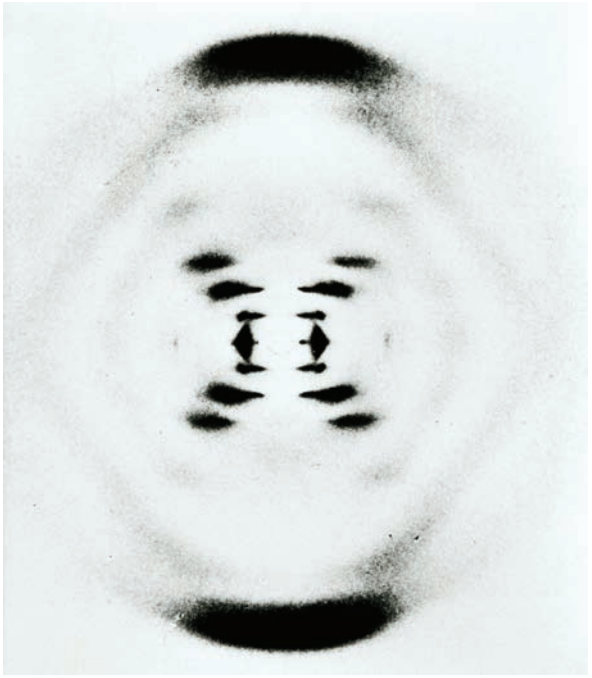


Figure 5 Rosalind Franklin's Photo 51 and X-ray diffraction data helped Watson and Crick solve the structure of DNA. When analyzed and measured carefully, the pattern shows the characteristics of a helical structure.

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.

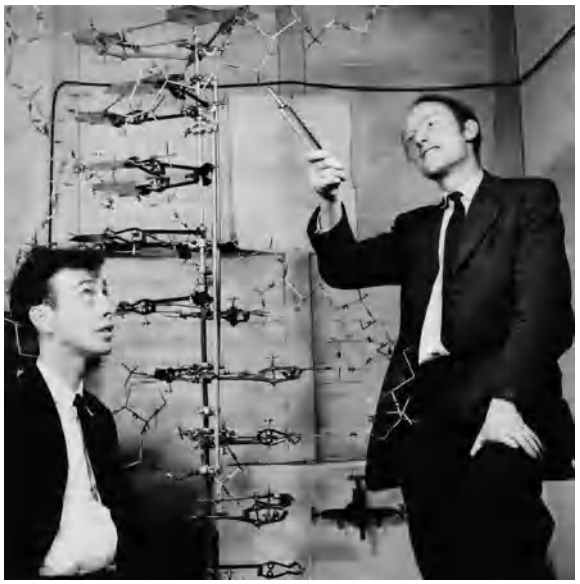


Figure 6 Using Chargaff's and Franklin's data, Watson and Crick, shown here, solved the puzzle of the structure of DNA.

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.

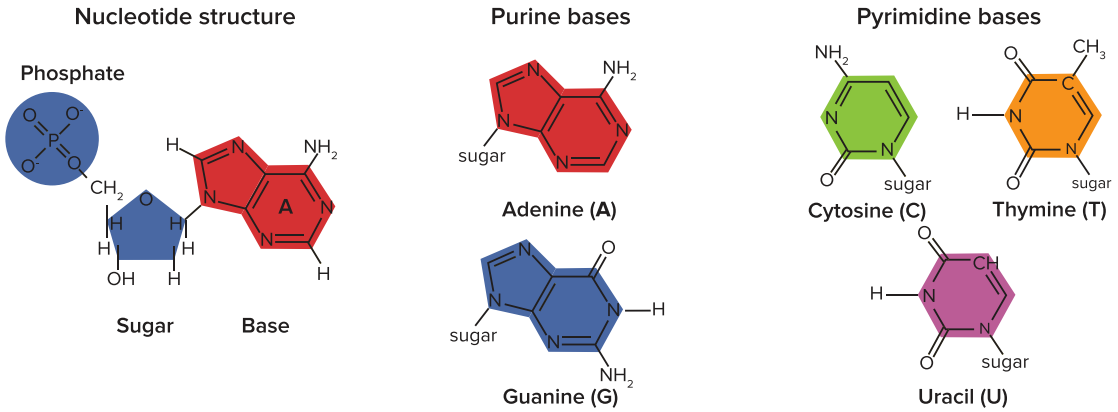


Figure 7 Nucleotides are made of a phosphate, sugar, and a base. There are five different bases found in nucleotide subunits that make up DNA and RNA.

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.

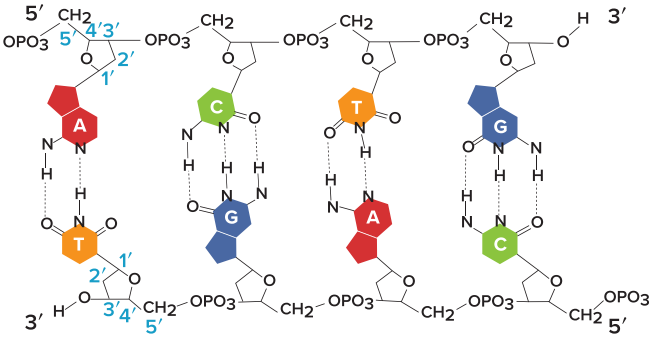


Figure 8 Two strands of DNA running antiparallel make up the DNA helix.

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.

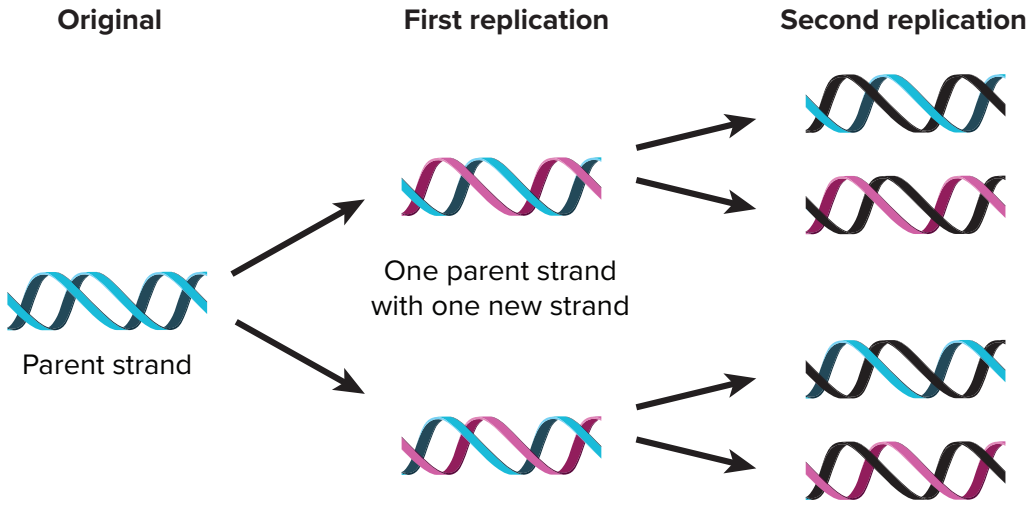

Figure 9 In semiconservative replication, the parental DNA strands separate and serves as templates to produce two daughter DNA molecules, which then can separate to produce four DNA molecules.

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

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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.

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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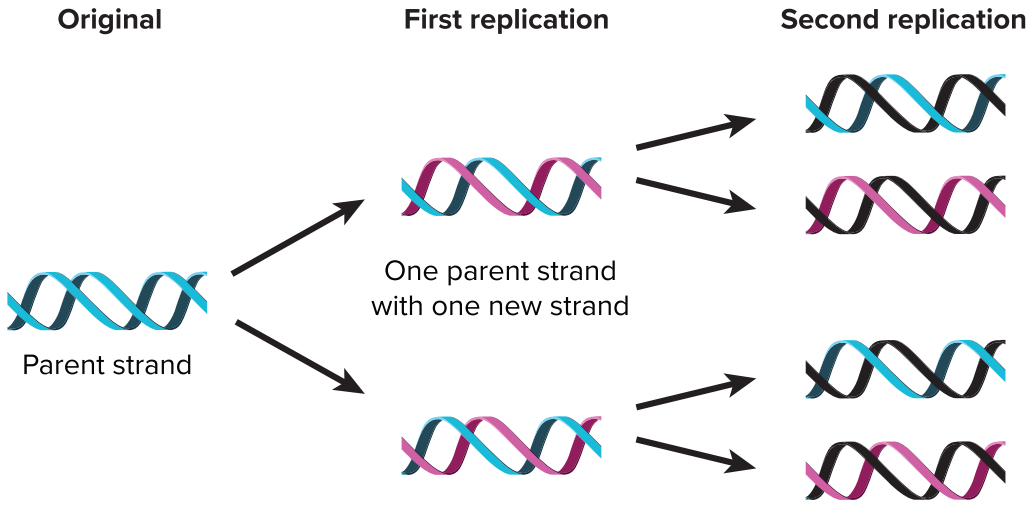

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Quick Investigation: Model DNA Replication
Use a model to determine the cause and effect of DNA replication.

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.

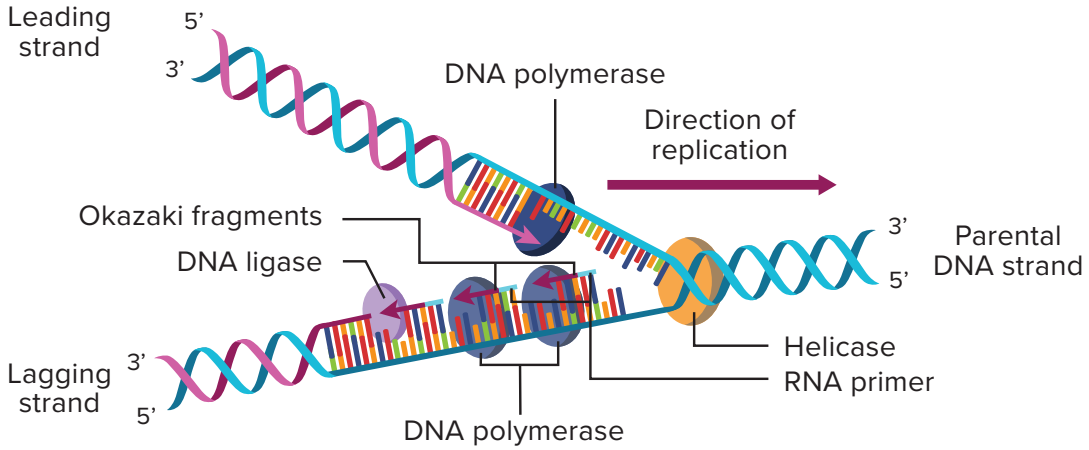

Figure 10 The DNA strands are separated during replication as each parent strand serves as a template for new strands.

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.

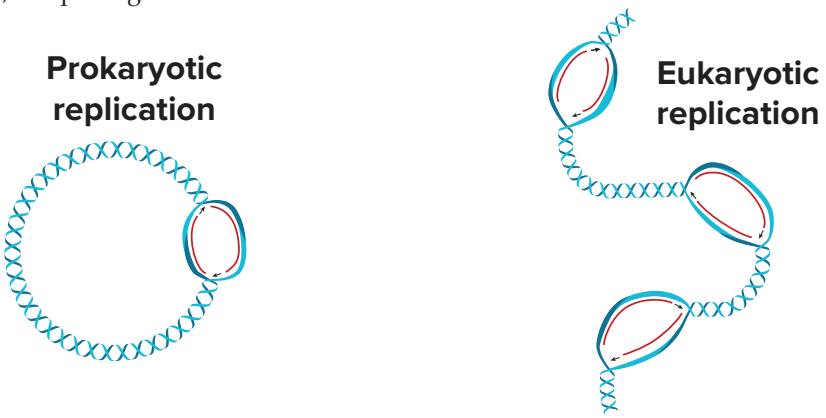

Figure 11 Eukaryotes have many origins of replication. Bacteria have one origin of replication, with the DNA replicating in both directions when it unzips.

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			

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COLLECT EVIDENCE

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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.

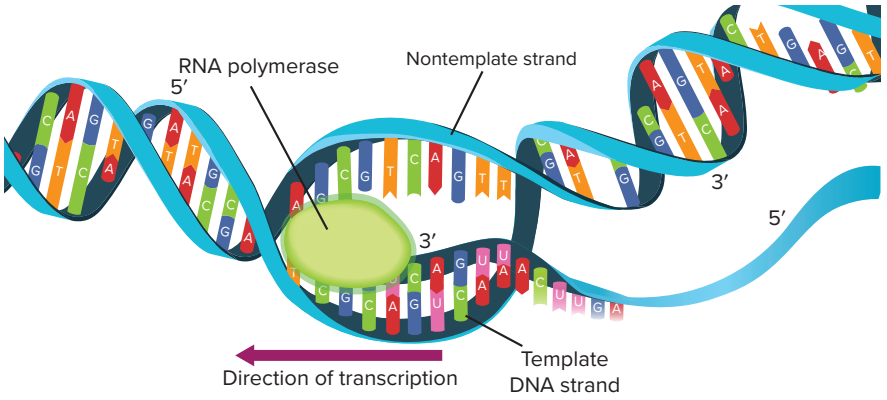


Figure 12 RNA is grown in the 5′ to 3′ direction.

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.

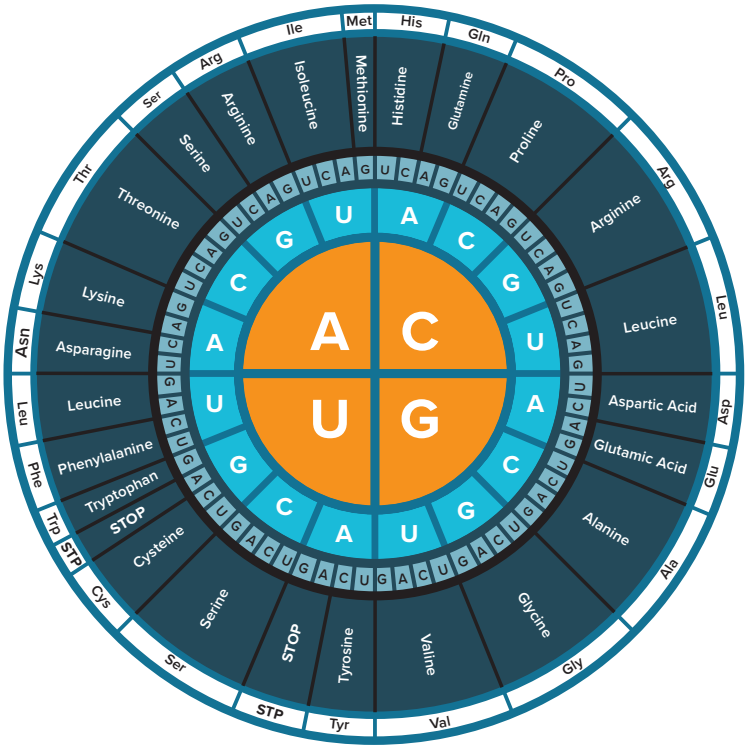


Figure 13 This "dictionary" of the genetic code is helpful for knowing which codons code for which amino acids.

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.

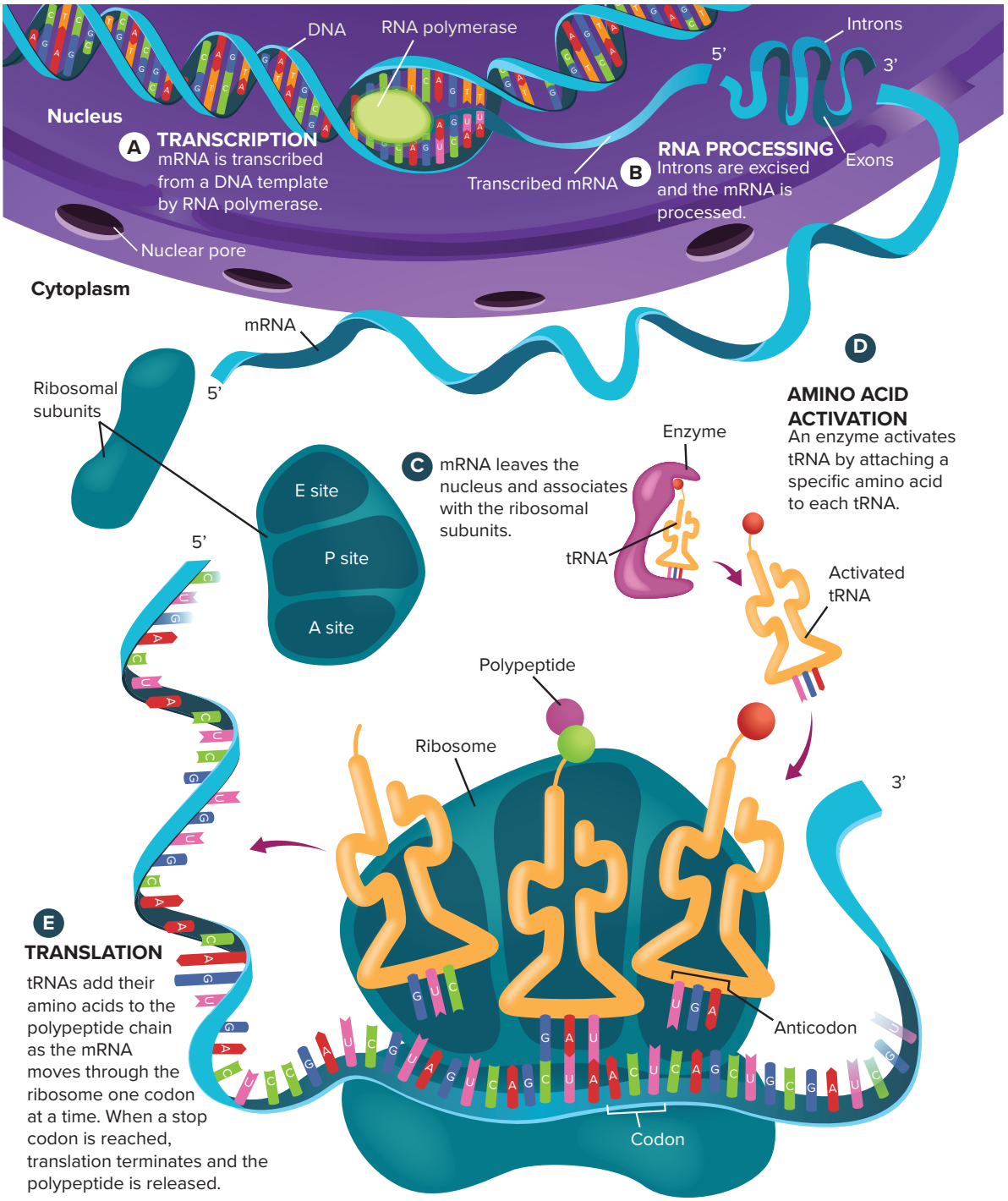
In translation, tRNA molecules act as the interpreters of the mRNA codon sequence. The tRNA is folded into a cloverleaf shape and is activated by an enzyme that attaches a specific amino acid to the 3′ end. At the middle of the folded strand, there is a three-base coding sequence called the **anticodon.**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

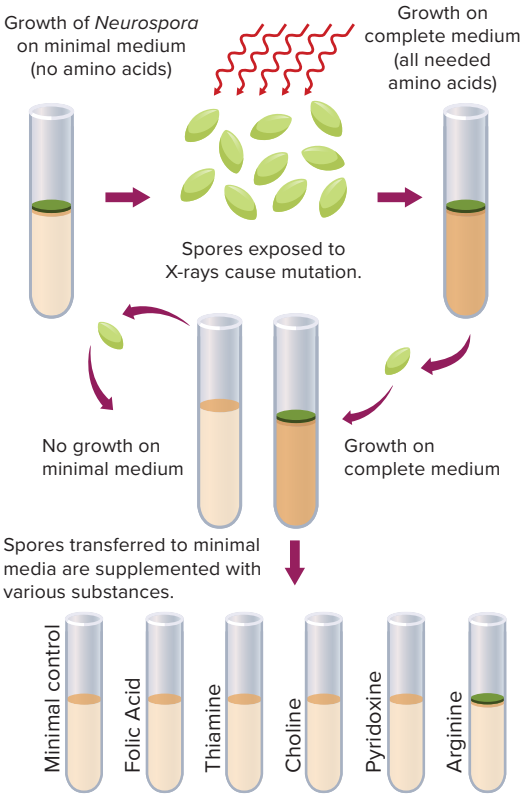


Figure 15 The Beadle and Tatum experiment showed that a gene codes for an enzyme. We now know that a gene codes for a polypeptide.

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.

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COLLECT EVIDENCE

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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 occurring during replication, and/or (3) mutations caused by environmental factors.

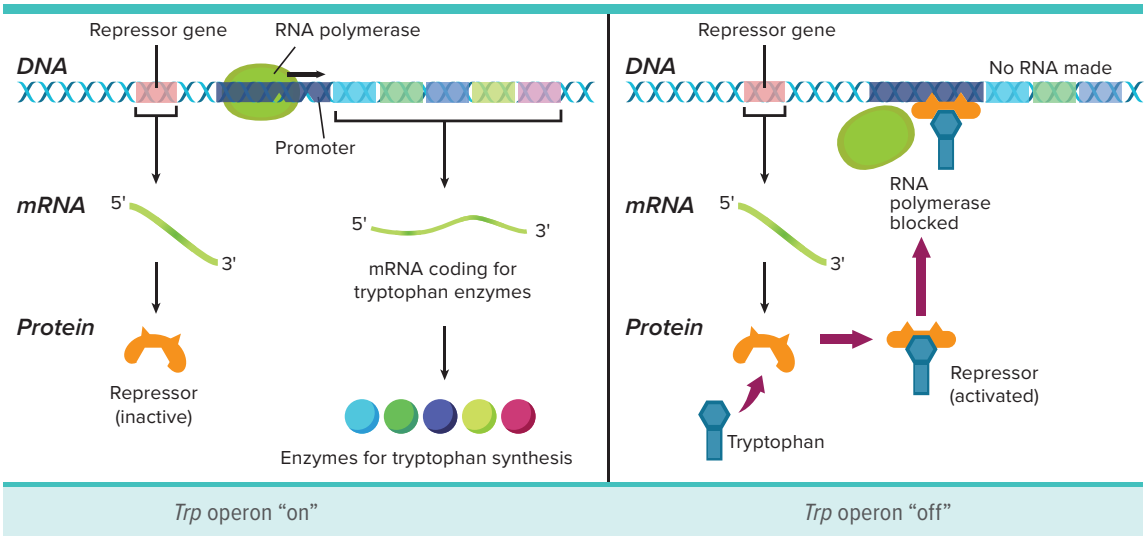

Figure 16 The *trp* operon is an example of the gene expression of repressible enzymes.

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.

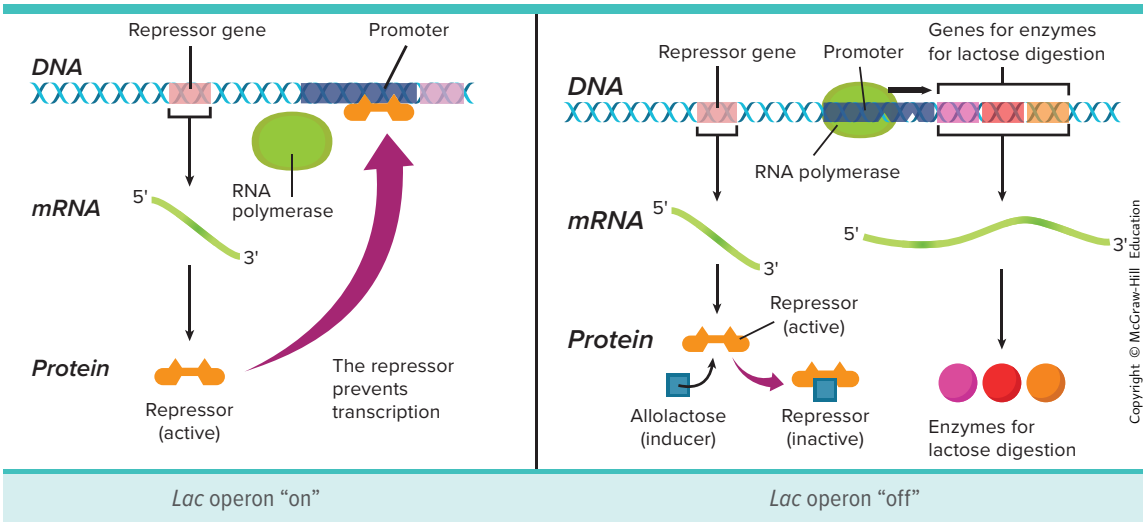

Figure 17 The *lac* operon is an example of the gene expression of inducible enzymes.

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.

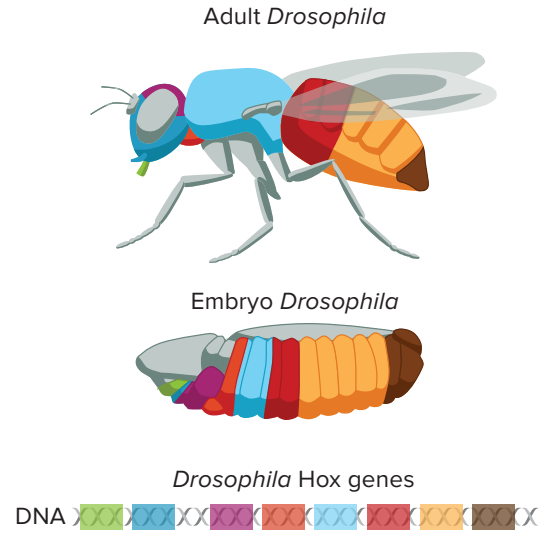

Figure 18 Hox genes are responsible for the general body pattern of most animals. Notice that the order of the genes is the same as the order of the body sections the genes control.

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.

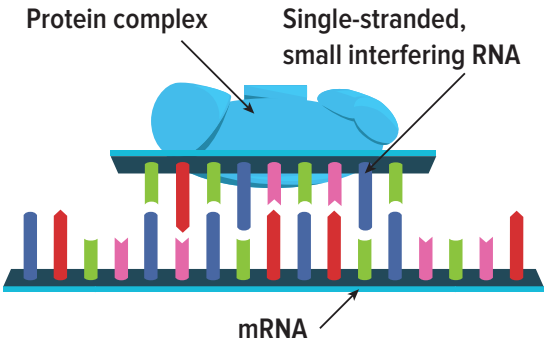

Figure 19 RNA interference can stop the mRNA from translating its message.

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 frame-shift 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.

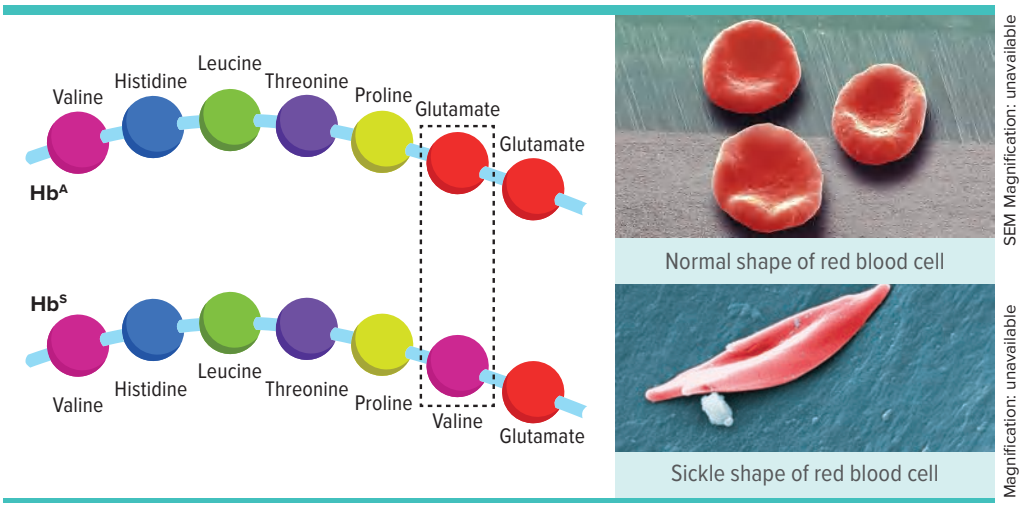

Figure 21 A single amino acid substitution can cause the genetic disorder sickle-cell disease.

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.

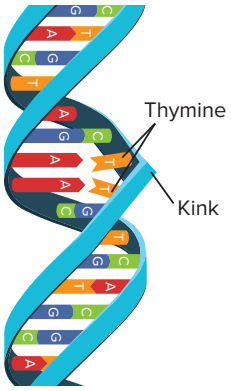

Figure 22 Ultraviolet radiation can cause adjacent thymines to bind to each other instead of to their complementary bases, making the DNA "kink" and preventing replication.

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?

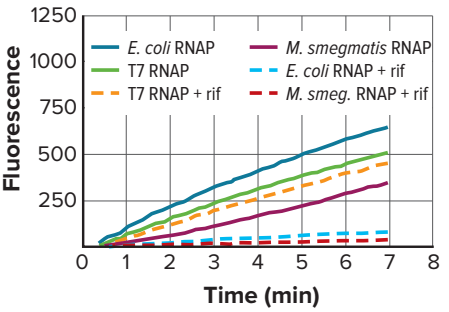
To study RNA synthesis, a group of scientists used a fluorescent molecular beacon to trace molecules. This beacon becomes fluorescent when it binds to newly synthesized RNA. The fluorescence increases as the RNA chain lengthens. Thus, the beacon can be used to follow RNA synthesis.

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.

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.

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.

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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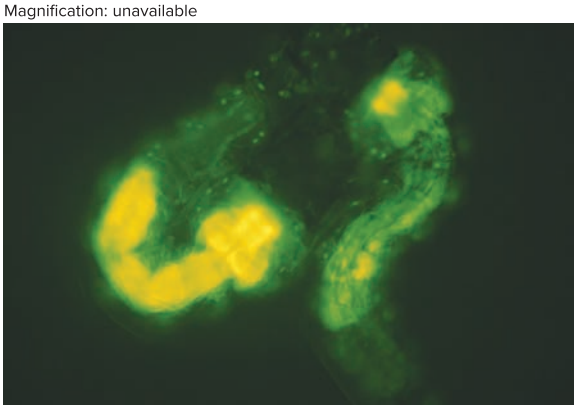

Figure 1 The gene for green fluorescent protein (GFP) was introduced into mosquito larvae so that researchers could verify that exogenous DNA was inserted.

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.

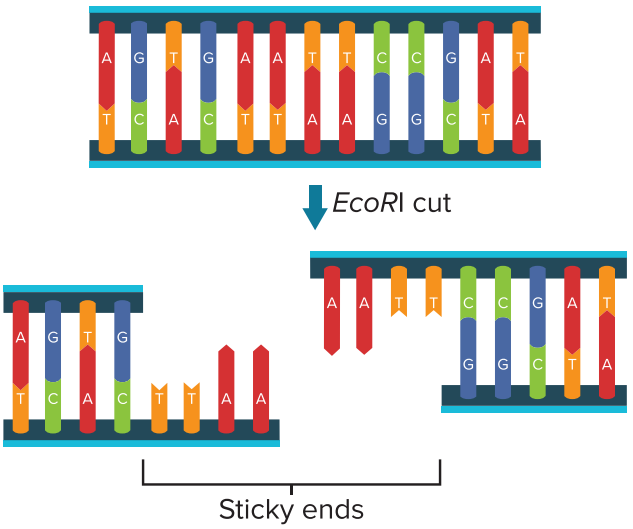

Figure 2 DNA containing the sequence GAATTC can be cut by the restriction enzyme *Eco*RI to produce sticky ends.

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.

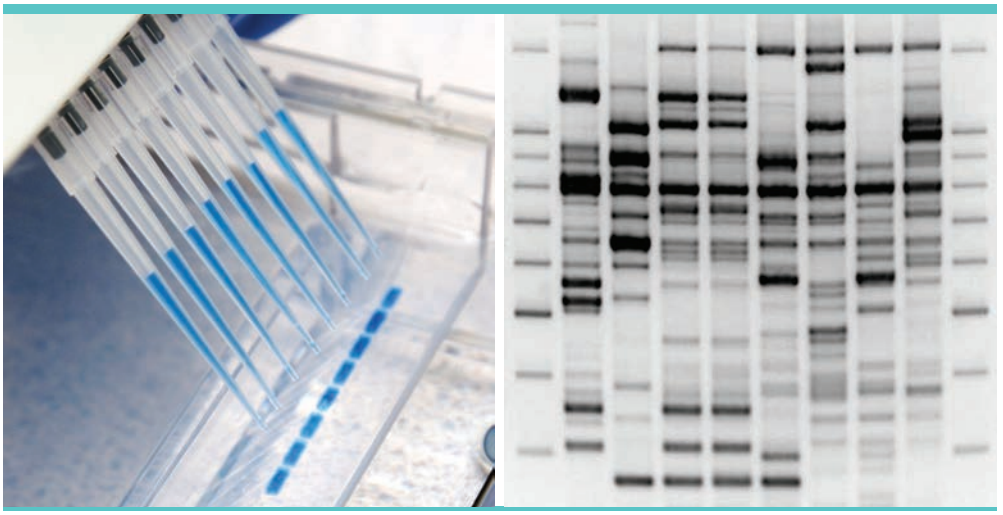

Figure 3 When the loaded gel is placed in an electrophoresis tank and the electric current is turned on, the DNA fragments separate.

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.

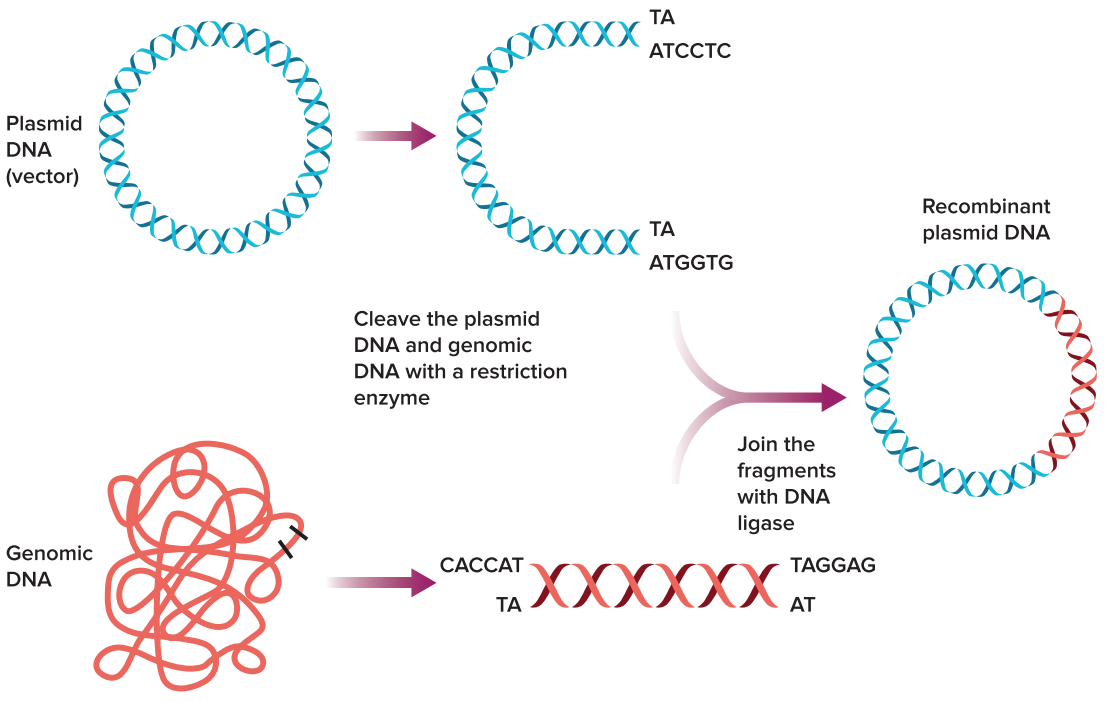

Figure 4 Recombinant DNA is created by joining together DNA from two different sources.

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.**

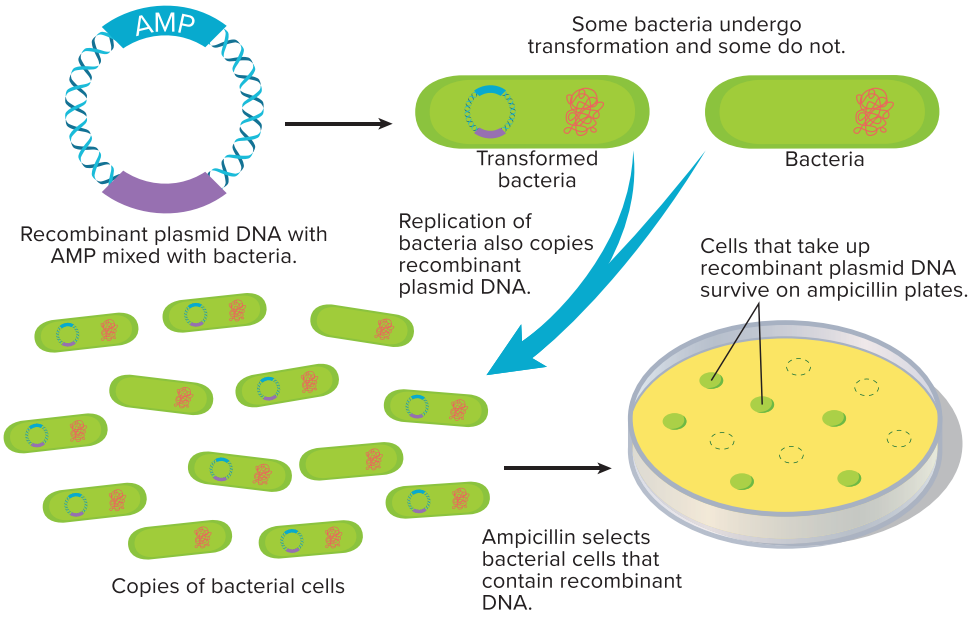

Figure 5 Clones containing copies of the recombinant DNA can be identified and used for further study when the bacterial cells that do not contain recombinant DNA die.

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.

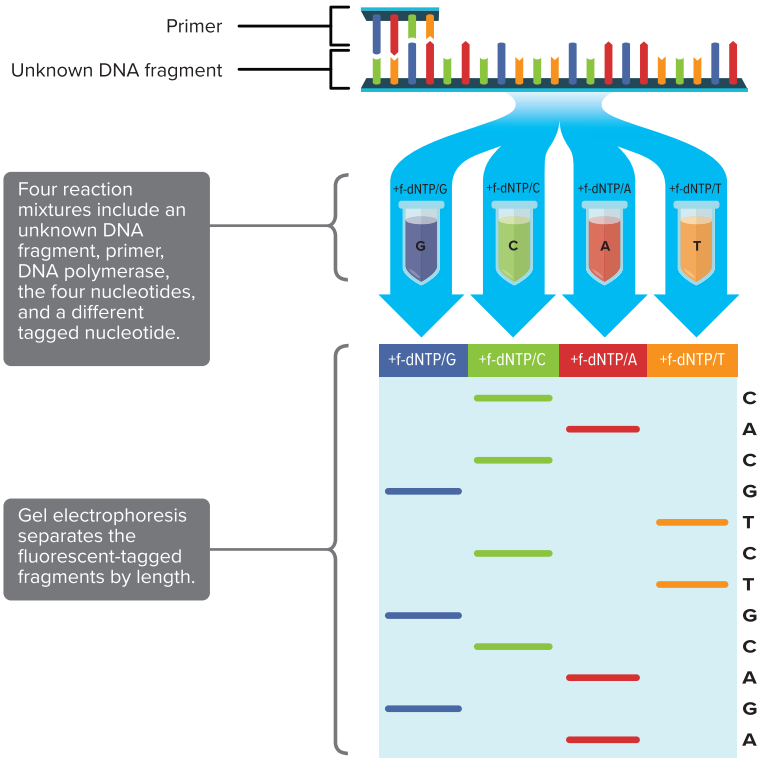

Figure 6 DNA can be sequenced using fluorescent-tagged nucleotides.

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.

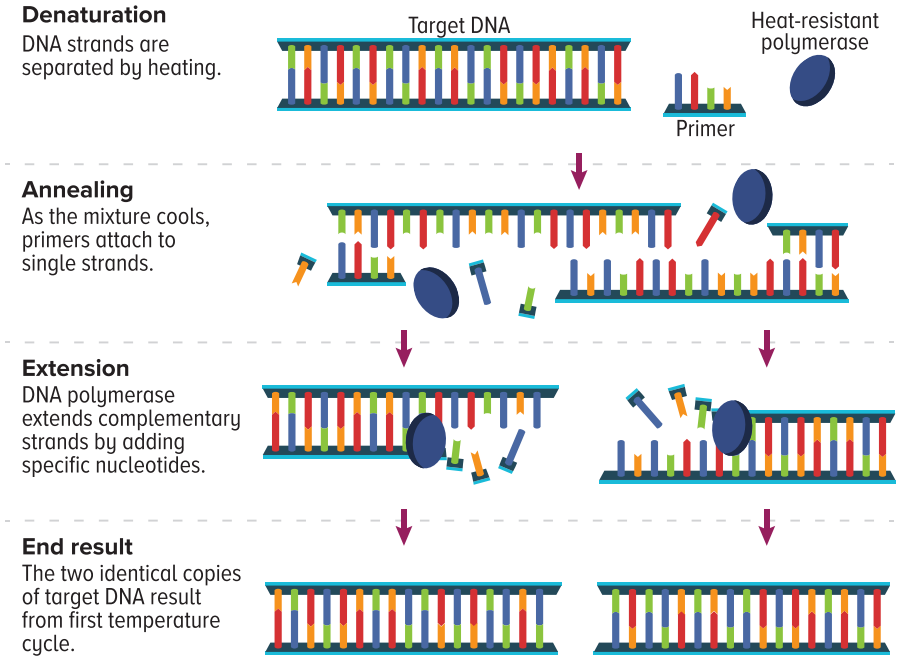

Figure 7 PCR is a biological version of a copy machine. During each PCR cycle, the reaction mixture is heated to separate the DNA strands and then cooled to allow primers to bind to complementary sequences. The DNA polymerase then adds nucleotides to form new DNA molecules.

Table 1 Genetic Engineering

Tool/Process	Function	Applications
Restriction enzymes Example: *Eco*RI	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

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.

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

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.

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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.

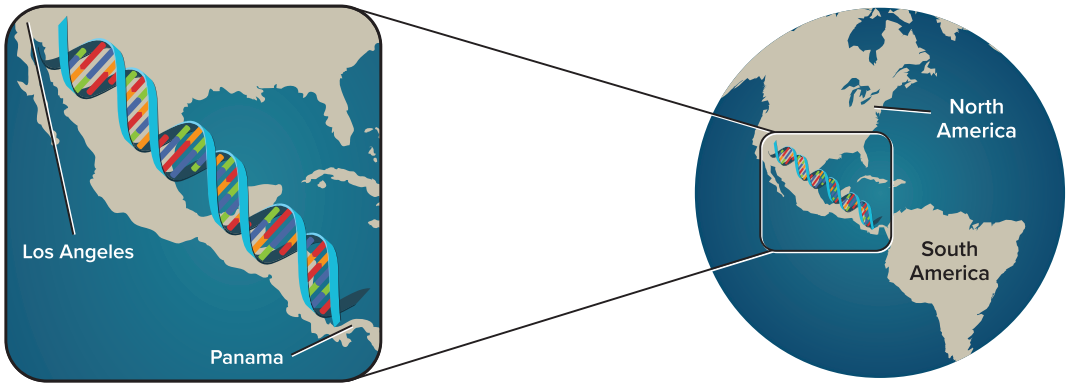


Figure 9 This image shows how far the nucleotides in the human genome would stretch if each of the approximately three billion nucleotides in human DNA were the size of the type on this page, and if all of the DNA in the human genome were fused together in one continuous line.

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.

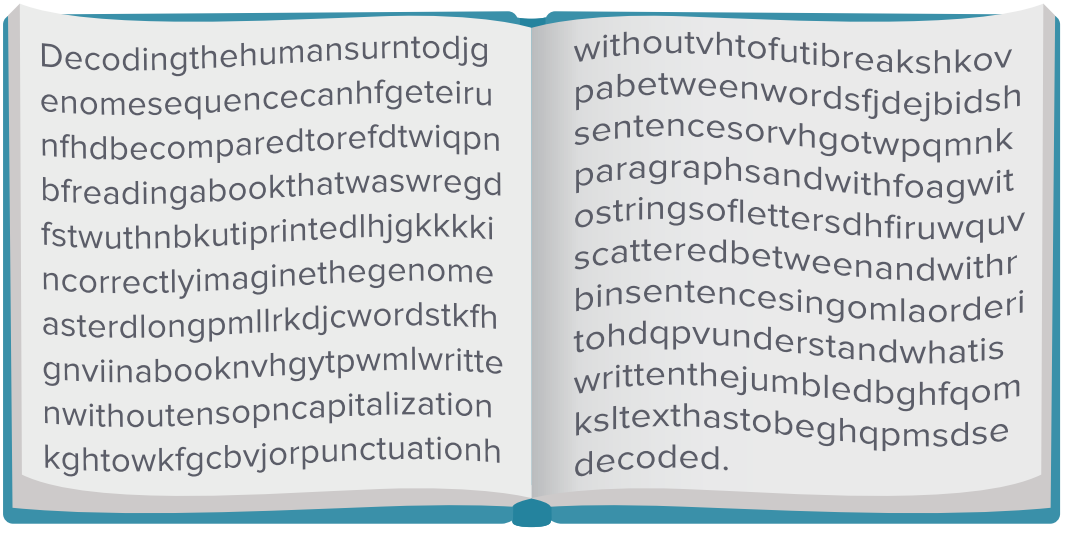


Figure 10 The genetic information contained within the human genome has to be decoded in order to uncover important sequences.

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.

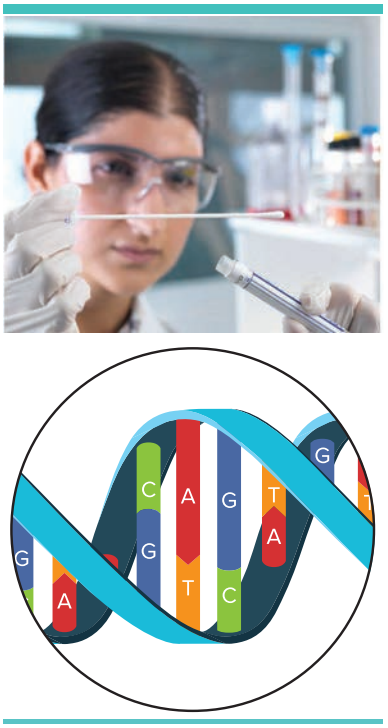


Figure 11 People can be identified using the genetic information contained in blood, hair, semen, or skin.

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

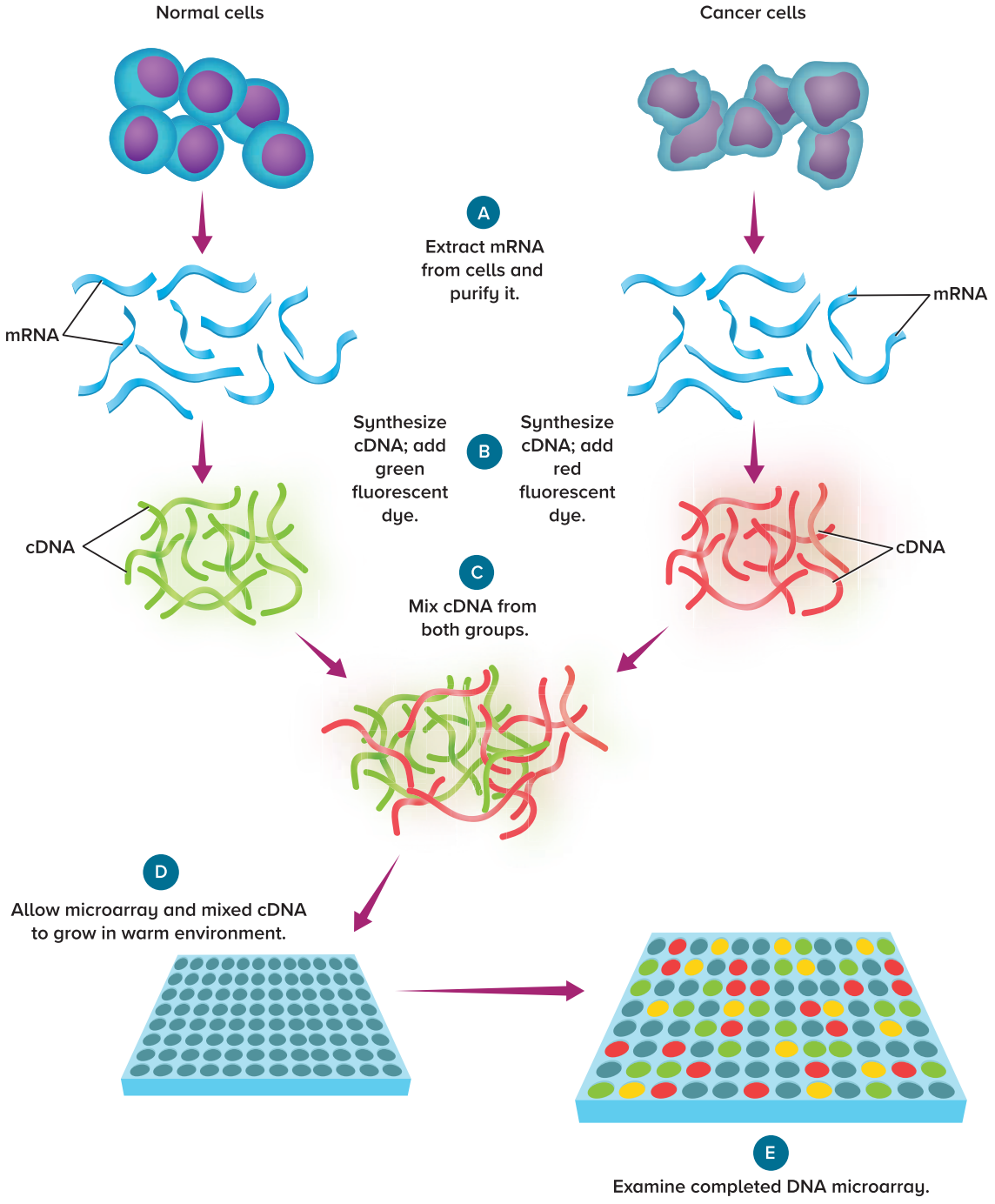
analysis

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.

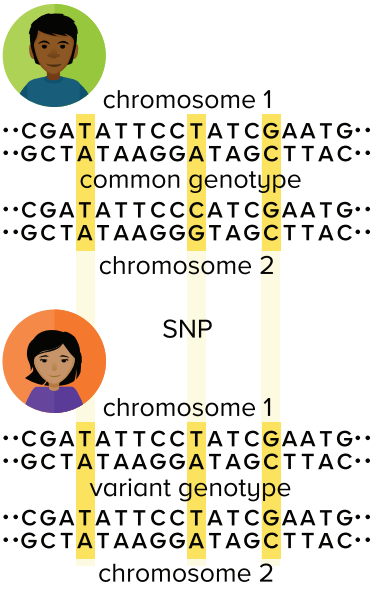


Figure 14 The HapMap project involves grouping all adjacent SNPs that are inherited together into haplotypes.

Get It?

Summarize how the HapMap project could impact human health.

Pharmacogenomics

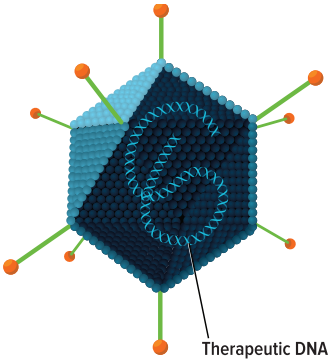
Sequencing the human genome combines the knowledge of genes, proteins, and SNPs with other areas of science. The patterns of genetic variation found while analyzing the human genome have been applied to medicine. The study of how genetic inheritance affects the body's response to drugs is called **pharmacogenomics**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

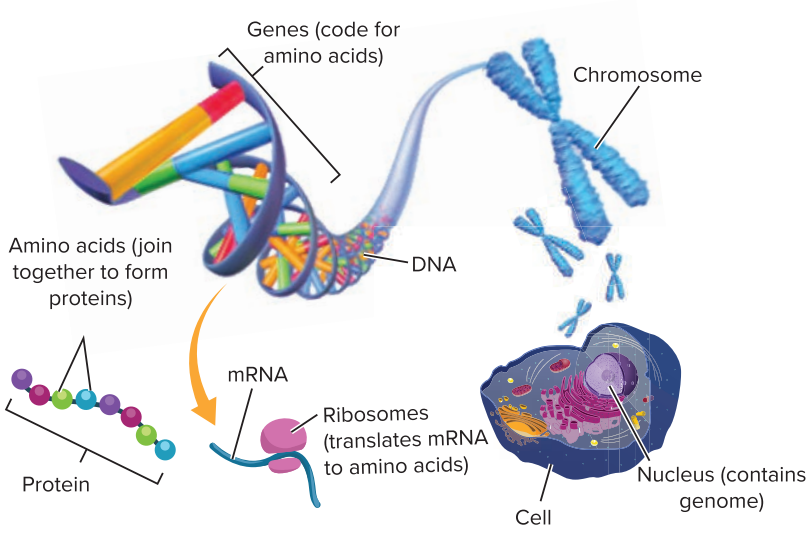


Figure 16 The central dogma is that the information in genes flows from DNA to RNA and RNA to proteins.

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.

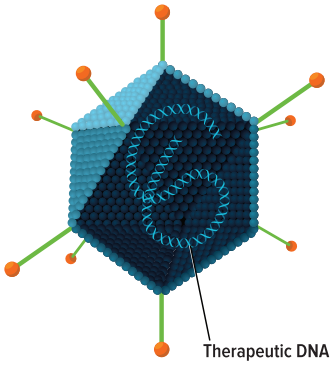
Lesson 1 DNA TECHNOLOGY

- 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.

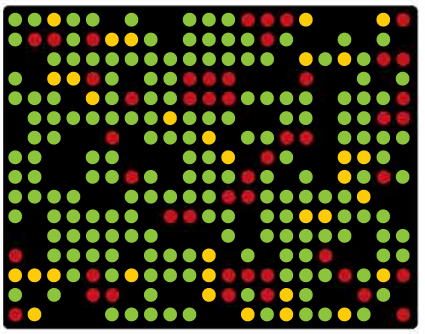
GO FURTHER

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

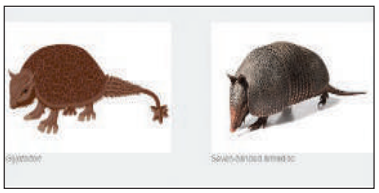
Make Your Claim Use your CER chart to make a claim about why an animal would try to look like a plant. Explain your reasoning.

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.

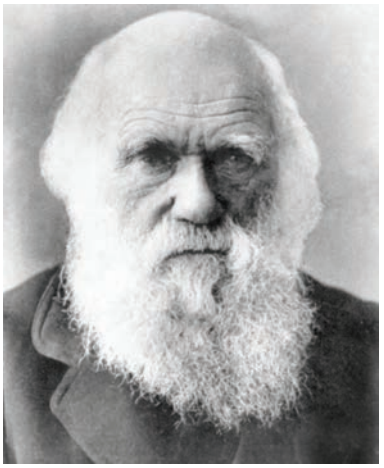


Figure 1 Charles Darwin (1809–1882)

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.

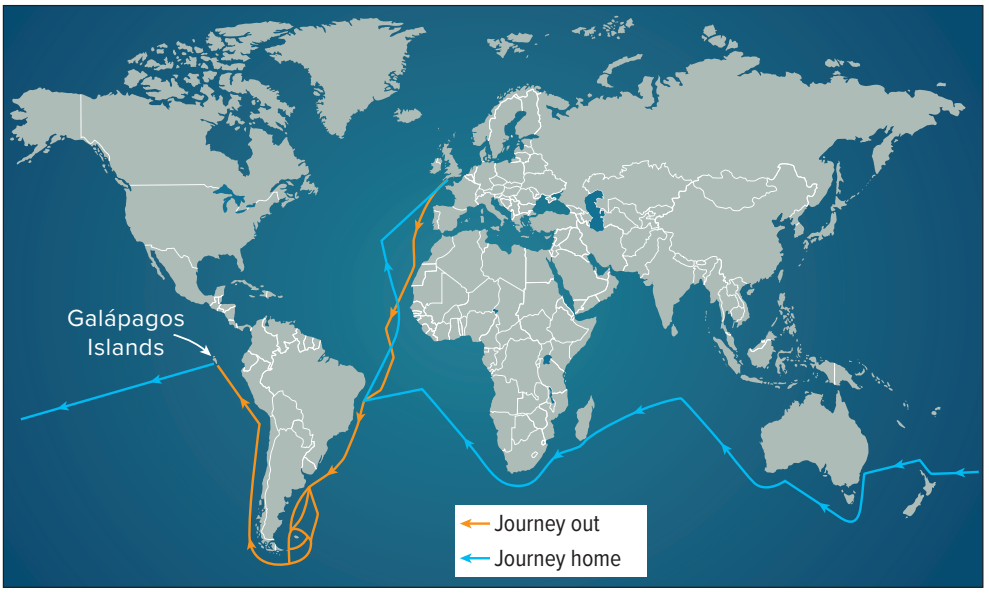


Figure 2 The map shows the route of the Beagle's voyage.

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.

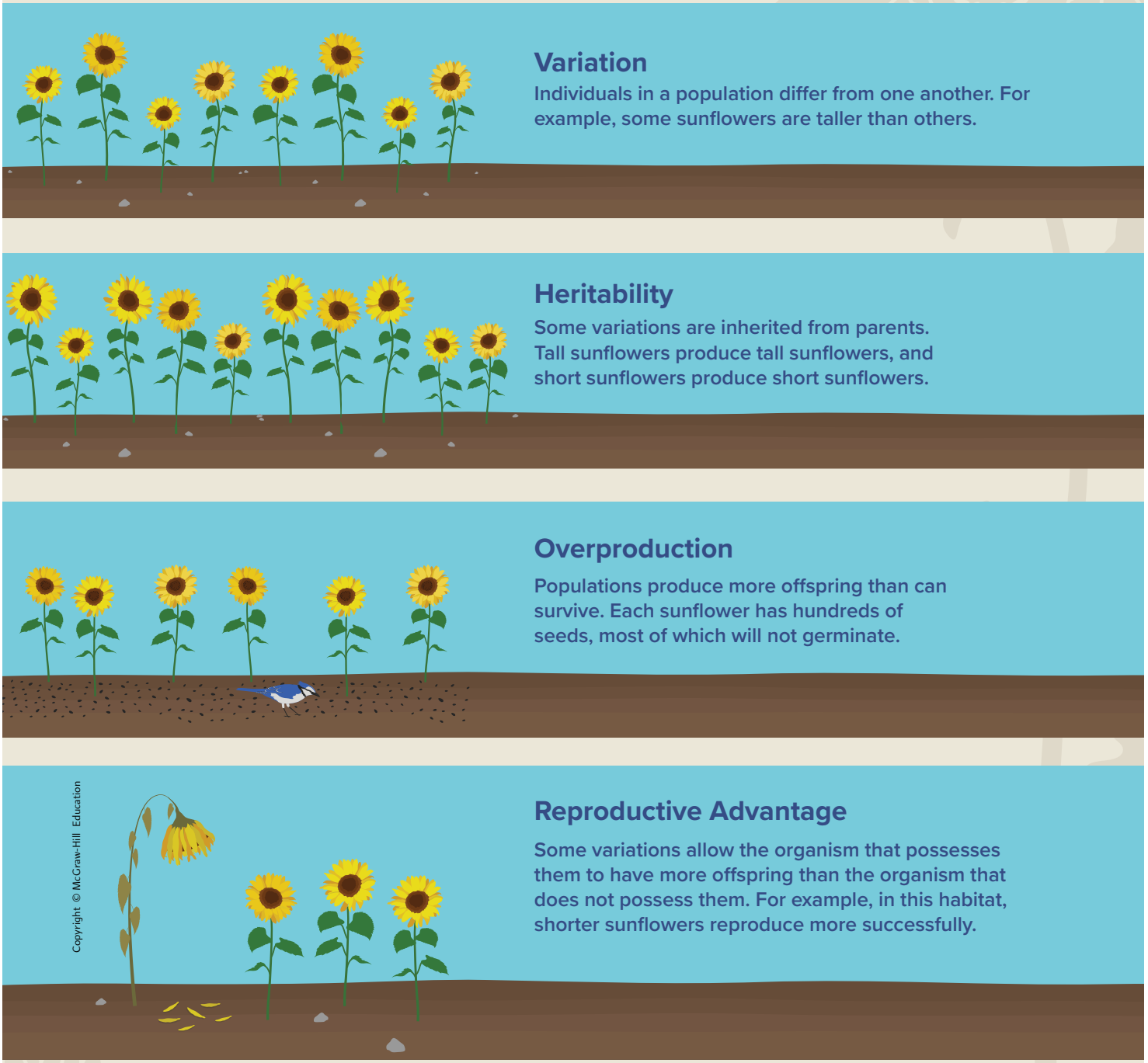
The Origin of Species

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.

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

LESSON 2

EVIDENCE OF EVOLUTION

FOCUS QUESTION

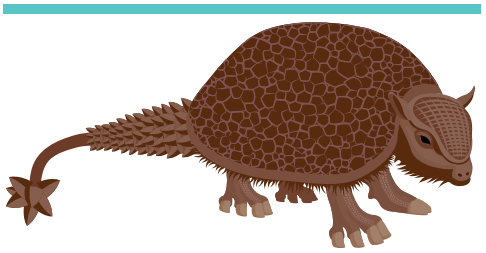
How does the fossil record, morphology, biochemistry, and adaptation provide evidence of evolution?

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?*

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: 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.

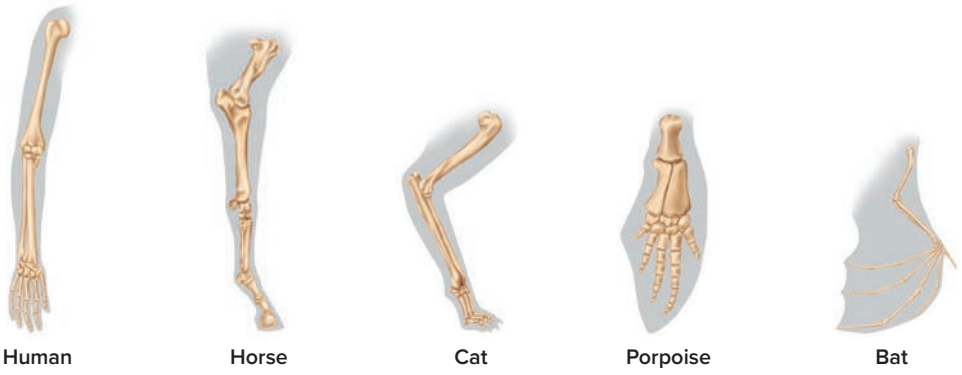


Figure 6 The forelimbs of vertebrates illustrate homologous structures. Each limb is adapted for different uses, but they all have similar bones.

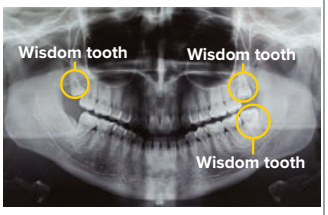
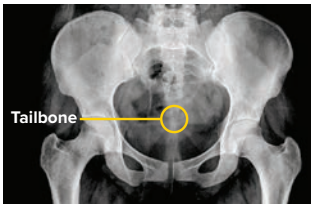
Infer *how the structures of a mouse forelimb would compare to the limbs shown.*

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.

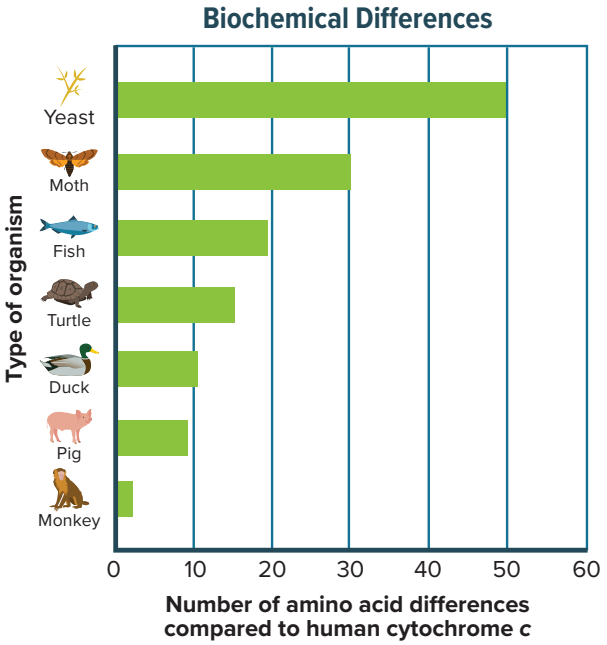


Figure 9 This illustration compares amino acid sequences of cytochrome *c* in humans and other organisms.

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.

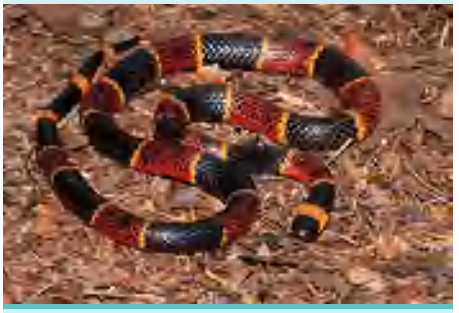
Natural selection results in populations that are dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. Organisms in a population that have a trait that gives them an advantage will survive and reproduce more successfully 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.

Kingsnake



Coral snake

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.

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.

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.

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**.

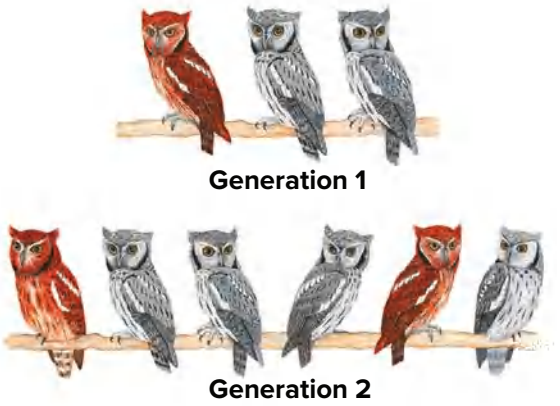

Figure 14 According to the Hardy-Weinberg principle, if the number of owls in a population doubles, the ratio of gray to red owls will remain the same.

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: 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.

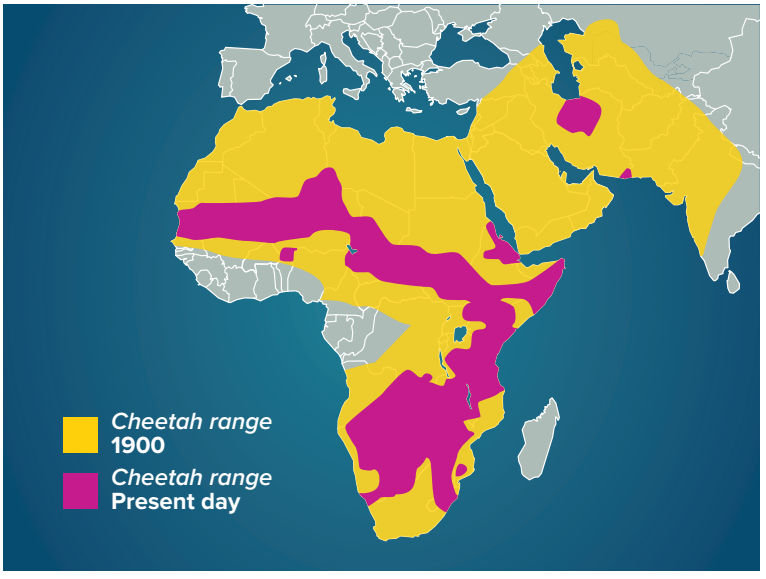

Figure 15 The map shows the present range of cheetahs in Africa. It is believed that cheetahs had a much larger population until a bottleneck occurred.

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.

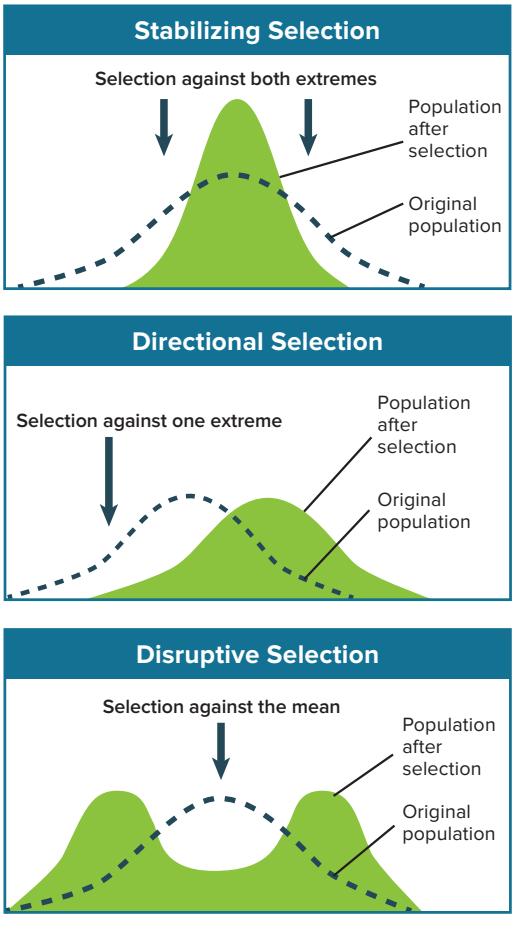

Figure 16 Natural selection can alter allele frequencies of a population in three ways. The bell-shaped curve shown as a dotted line in each graph indicates the trait's original variation in a population. The solid line indicates the outcome of each type of selection pressure.

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.

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.

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.*

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.

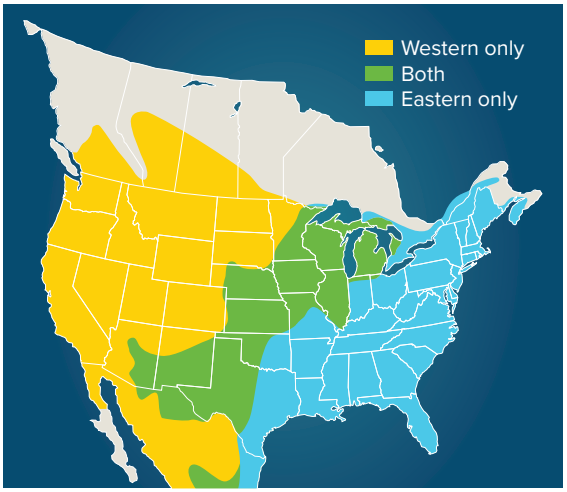

Figure 20 The map shows the overlapping ranges of the Eastern meadowlark, and the left, and Western meadowlark, on the right. While the two are similar in appearance, their songs separate them behaviorally.

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.

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.

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

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.

Abert squirrel

Kaibab squirrel

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.

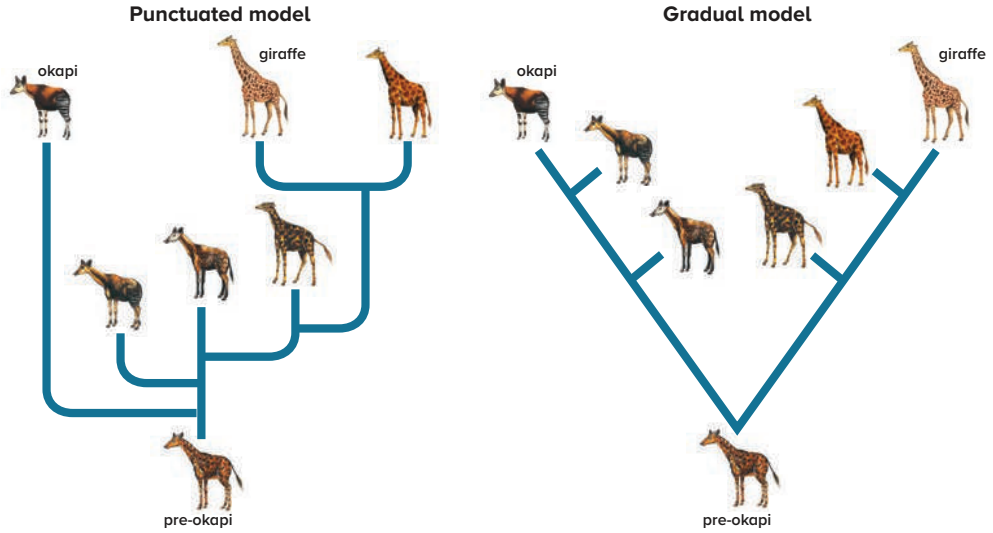

Figure 24 Gradualism and punctuated equilibrium are two competing models describing the tempo of evolution.

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?

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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

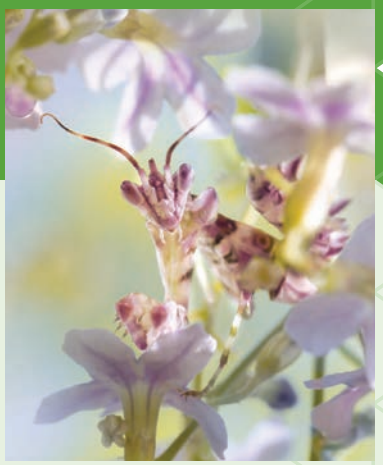
Lesson 3 SHAPING EVOLUTIONARY THEORY

- 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.

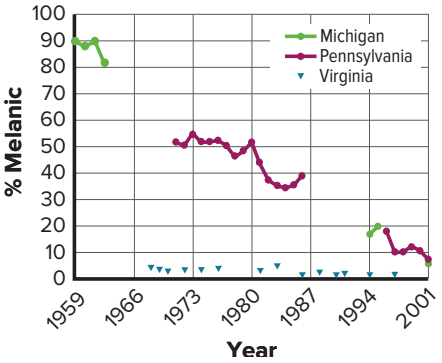
GO FURTHER

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.

ORGANIZING LIFE'S DIVERSITY

ORGANIZING LIFE'S DIVERSITY

ENCOUNTER THE PHENOMENON

Why are these butterflies similar in structure but different in color?

SEP Ask Questions

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

CER Claim, Evidence, Reasoning

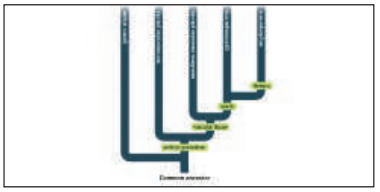
Make Your Claim Use your CER chart to make a claim about why butterflies can be similar in structure but different in color. Explain your reasoning.

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: Taxonomic Categories



LESSON 2: Explore & Explain: Phylogenetic Reconstruction: Character Types and Cladograms

LESSON 1

THE HISTORY OF CLASSIFICATION

FOCUS QUESTION

How and why do we classify animals?

Early Systems of Classification

Has anyone ever told you to get organized? You are probably expected to keep your room in order. Your teachers might have asked you to organize your notes. Keeping items or information in order makes them easier to find and understand. Biologists find it easier to communicate and retain information about organisms when the organisms are organized into groups. This is called biological classification. **Classification** is the grouping of objects or organisms based on a set of criteria. **Table 1** shows how Aristotle, a Greek philosopher, may have classified different plants and animals into groups.

Get It?

Explain why classification is a useful tool.

Table 1 Aristotle's Classification Sysytem

Plants		
Herbs	**Shrubs**	**Trees**
Violets	Blackberry bush	Apple
Rosemary	Honeysuckle	Oak
Onions	Flannelbush	Maple
Animals with red blood		
Land	**Water**	**Air**
Wolf	Dolphin	Owl
Cat	Eel	Bat
Bear	Sea bass	Crow

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 a taxonomic key?

Plan and carry out an investigation using models to create a taxonomic key.

Quick Investigation: Develop a Dichotomous Key

Analyze and interpret data to determine patterns among organisms to create a dichotomous key.

Aristotle's system

More than two thousand years ago, Aristotle (384–322 B.C.) developed the first widely accepted system of biological classification. Aristotle classified organisms as either animals or plants. Animals were classified according to the presence or absence of "red blood." Aristotle's "bloodless" and "red-blooded" animals nearly match the modern distinction of invertebrates and vertebrates. Animals were further grouped according to their habitats and morphology. Plants were classified by average size and structure as trees, shrubs, or herbs.

Aristotle's system was useful for organizing, but it had many limitations. Aristotle's system was based on his view that species are distinct, separate, and unchanging. This view was fairly common until Darwin presented his theory of evolution. Because of his understanding of species, Aristotle's classification did not account for evolutionary relationships. Additionally, many organisms do not fit easily into Aristotle's system, such as birds that do not fly or frogs that live both on land and in water. Nevertheless, many centuries passed before Aristotle's system was replaced by a new system that was better suited to the increased knowledge of the natural world.

Linnaeus's system

In the eighteenth century, Swedish naturalist Carolus Linnaeus (1707–1778) broadened Aristotle's classification method and formalized it into a scientific system. Like Aristotle, he based his system on observational studies of the morphology and the behavior of organisms. For example, he organized birds into three major groups based on their behavior and habitat. The birds in **Figure 1** illustrate these categories. The eagle is classified as a bird of prey, the heron as a wading bird, and the bluejay is grouped with the perching birds.

Linnaeus's system of classification was the first formal system of taxonomic organization. **Taxonomy** (tak SAH nuh mee) is a discipline of biology primarily concerned with identifying, naming, and classifying species based on natural relationships. Taxonomy is part of the larger branch of biology called systematics. Systematics is the study of biological diversity with an emphasis on evolutionary history.

Bird of prey | Wading bird | Perching bird

Figure 1 Linnaeus would have classified these birds based on their morphological and behavioral differences.

Infer *in which group Linnaeus might have placed a robin.*

Modern classification systems

The study of evolution in the 1800s added a new dimension to Linnaeus's classification system. Many scientists at that time, including Charles Darwin, Jean-Baptiste Lamarck, and Ernst Haeckel, began to classify organisms using things other than morphological and behavioral characteristics. They also included inferred evolutionary relationships in their classification systems. Today, modern classification systems have been modified to reflect new knowledge about evolutionary ancestry.

Taxonomic Categories

Think about your favorite book store. How are the books arranged on the shelves? They might be arranged according to genre according to genre, and then by author and title. Each of Earth's living things is placed in a taxon. A **taxon** (plural, taxa) is a named group of organisms. Taxonomists also subdivide groups of organisms based on more specific criteria. The categories used by scientists are part of a nested-hierarchical system. Each category is contained within another, and they are arranged from broadest to most specific.

Higher Taxa

A **domain** is the broadest of all the taxa and contains one or more kingdoms. The taxon composed of related phyla or divisions is a **kingdom.** A **phylum** (FI lum) (plural, phyla) or division contains related classes. The term *division* is used instead of *phylum* for the classification of bacteria and plants. The bears in **Figure 2** are classified in Domain Eukarya, Kingdom Animalia, and phylum Chordata. The basic characteristics of the three domains and six kingdoms are described later in this module. A **class** contains related orders. An **order** contains related families. Bears belong to the order Carnivora and class Mammalia.

Ursus americanus | *Ursus arctos horribilis* | *Melursus ursinus*

Figure 2 All species in the genus *Ursus* have large body size and massive skulls. **Right:** Sloth bears are classified in the genus *Melursus*

WORD ORIGINS

binomial nomenclature

comes from Latin words *bi*, meaning *two, nomen,* meaning *name*, and *calatus*, meaning *list*.

Family

All bears, both living and extinct species, belong to the same family, Ursidae. A **family** is the next taxon, consisting of similar, related genera. In addition to the three species shown in **Figure 2** on the last page, the Ursidae family contains six other species: brown bears, polar bears, giant pandas, sun bears, and Andean bears. All members of the bear family share certain characteristics. For example, they all walk flatfooted and have forearms that can rotate to grasp prey closely.

Genus and species

A **genus** (plural, genera) is defined as a group of species that are closely related and share a common ancestor. Note the similarities and differences among the three species of bears in **Figure 2**. The scientific names of the American black bear (*Ursus americanus*) and the Grizzly bear (*Ursus arctos*) indicate that they belong to the same genus, *Ursus*. All species in the genus *Ursus* have massive skulls and similar tooth structures. Sloth bears (*Melursus ursinus*), despite their similarity to members of the genus *Ursus*, usually are classified in a different genus, *Melursus*, because they are smaller, have a different skull shape and size, and have two fewer incisor teeth than bears of the genus *Ursus*.

Figure 3 shows how the taxa are organized into a hierarchical system. Taxa range from having broad diagnostic characteristics to having specific characteristics. The broader the characteristics, the more species the taxon contains.

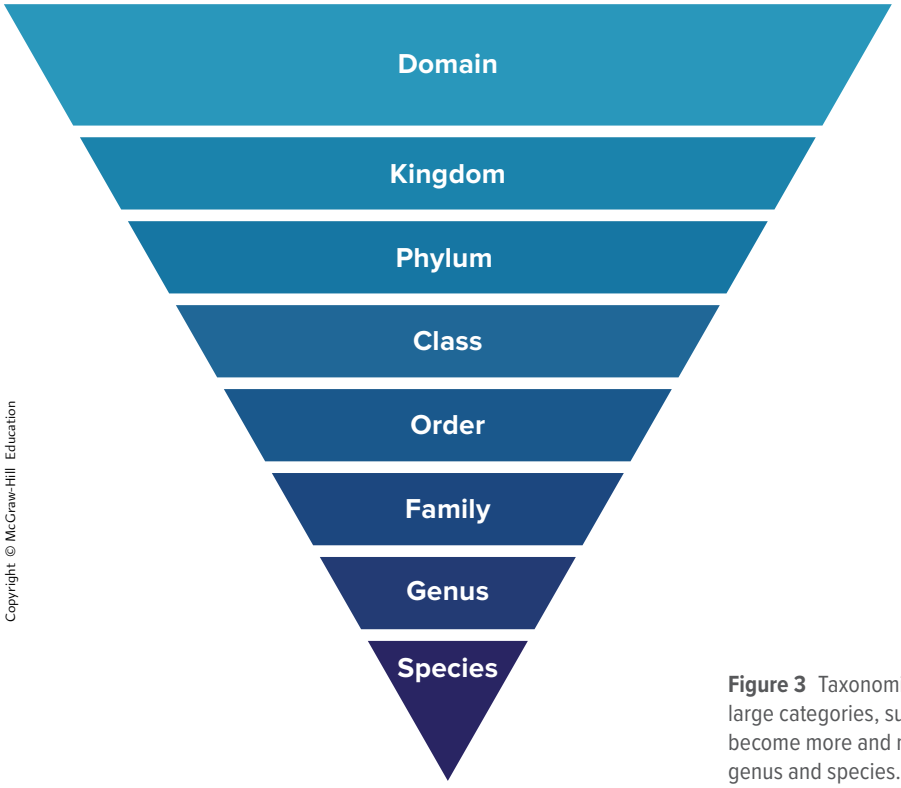


Figure 3 Taxonomic categories begin with large categories, such as domains, and then become more and more specific, down to genus and species.

Binomial Nomenclature

Linnaeus's method of naming organisms, called binomial nomenclature, set his system apart from Aristotle's system, and remains valid today. **Binomial nomenclature** (bi NOH mee ul NOH mun klay chur) gives each species a scientific name that has two parts. The first part is the genus (JEE nus) name, and the second part is the specific epithet (EP uh thet), or specific name, that identifies the species. Latin is the basis for binomial nomenclature because Latin is an unchanging language, and, historically, it has been the language of science and education.

Biologists use scientific names for species because common names vary in useage. Many times the bird shown in **Figure 4** is called a redbird. Sometimes, however, it is called a cardinal, and other times it is called a Northern cardinal. In 1758, Linnaeus gave this bird its scientific name, *Cardinalis cardinalis*. The use of scientific names avoids the confusion that can be created with common names. Binomial nomenclature also is useful because common names can be misleading. If you were doing a scientific study on fish, you would not include starfish in your studies. Starfish are not fish. In the same way, great horned owls do not have horns and sea cucumbers are not plants.

When writing a scientific name, scientists follow these rules.

- The first letter of the genus name is always capitalized, but the rest of the genus name and all letters of the specific epithet are lowercase.
- If a scientific name is written in a printed book or magazine, it should be italicized.
- When a scientific name is written by hand, both parts of the name should be underlined.
- After the scientific name has been written once completely, the genus name often will be abbreviated to the first letter in later appearances. For example, the scientific name of *Cardinalis cardinalis* can be written *C. cardinalis*.

Get It?

Explain why Latin is the basis for many scientific names.

Figure 4 *Cardinalis cardinalis* is a bird with many common names and is seen throughout much of the United States. It is the state bird of Illinois, Indiana, Kentucky, North Carolina, and Ohio.

Identify *some other animals that have multiple common names.*

Systematics Applications

Scientists who study classification provide detailed guides that help people identify organisms. Many times a field guide will contain a dichotomous (di KAHT uh mus) key, which is a key based on a series of choices between alternate characteristics. You can find out whether a plant or animal is poisonous by using a dichotomous key to identify it.

Figure 5 This systematist is searching for new species of insects as a part of his research.

Systematists, like the one shown in **Figure 5,** also work to identify new species and relationships among known species. They incorporate information from taxonomy, paleontology, molecular biology, and comparative anatomy in their studies. While the discovery of new species is exciting and important, learning a new connection between species also impacts science and society. For example, if a biologist knows that a certain plant such as the Madagascar periwinkle, *Catharanthus roseus*, produces a chemical that can be used to treat cancer, he or she knows that it is possible related plants also might produce the same or similar chemicals.

Check Your Progress

Summary

- Aristotle developed the first widely accepted biological classification system.
- Linnaeus used morphology and behavior to classify plants and animals.
- Binomial nomenclature uses the Latin genus and species to give an organism a scientific name.
- Organisms are classified according to a nested hierarchical system.

Demonstrate Understanding

1. **Describe** how and why organisms are hierarchically classified.
2. **Summarize** the rules for using binomial nomenclature.
3. **Compare and contrast** how modern classification systems differ from those used by Aristotle and Linnaeus.
4. **Classify** a giant panda, *Ailuropoda melanoleuca*, completely from domain to species level.

Explain Your Thinking

5. **Write** a short story describing an application of biological classification.
6. **Consider** where you would expect to see more biodiversity: among members of a phyla or among members of a class. Why?
7. **Differentiate** between taxonomy and systematics.

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LESSON 2

MODERN CLASSIFICATION

FOCUS QUESTION

How is the evolutionary history of an organism determined?

Determining Species

It is not always easy to define a species. Organisms that are different species by one definition might be the same species by a different definition. As knowledge increases, definitions change. The concept of a species today is much different than it was 100 years ago.

Typological species concept

Aristotle and Linnaeus thought of each species as a distinctly different group of organisms based on physical similarities. This definition of species is called the typological species concept. It is based on the idea that species are unchanging, distinct, and of natural types, as defined earlier by Aristotle. The type specimen was an individual of the species that best displayed the characteristics of that species. When another specimen was found that varied significantly from the type specimen, it was classified as a different species. For example, in **Figure 6** the color patterns on the butterflies' wings are all slightly different. At one time, they might have been classified as three different species because of these differences, but now they are classified as the same species.

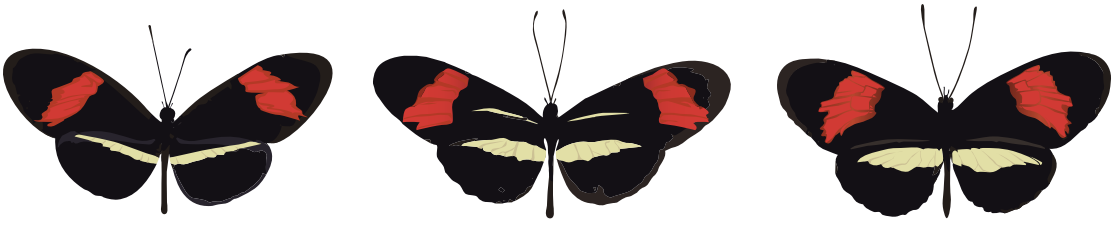


Figure 6 Although these tropical butterflies vary in their color patterns, they are classified as different varieties of the same species, *Heliconius erato*.

Describe *why early taxonomists might have classified these as separate species.*

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: Common Ancestry, Adaptations, and Biological Evolution

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

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

Biological species concept

Theodosius Dobzhansky and Ernst Mayr, two evolutionary biologists, redefined the term species in the 1930s and 1940s. They defined a species as a group of organisms that is able to interbreed and produce fertile offspring in a natural setting. This is called the biological species concept, and it is the definition for species used throughout this textbook. Though the butterflies in **Figure 6** on the last page have variable color patterns, they can interbreed to produce fertile offspring and therefore are classified as the same species.

There are limitations to the biological species concept. For example, wolves and dogs, as well as many plant species, are known to interbreed and produce fertile offspring even though they are classified as different species. The biological species concept also does not account for extinct species or species that reproduce asexually. However, because the biological species concept works in most everyday experiences of classification, it is used often.

Phylogenetic species concept

In the 1940s, the evolutionary species concept was proposed as a companion to the biological species concept. The evolutionary species concept defines species in terms of populations and ancestry. According to this concept, two or more groups that evolve independently from an ancestral population are classified as different species. More recently, this concept has developed into the phylogenetic species concept. **Phylogeny** (fi LAH juh nee) is the evolutionary history of a species. The phylogenetic species concept defines a species as a cluster of organisms that is distinct from other clusters and shows evidence of a pattern of ancestry and descent. When a phylogenetic species branches, it becomes two different phylogenetic species. For example, recall that when organisms become isolated, geographically or otherwise, they often evolve different adaptations. Eventually, they might become different enough to be classified as a new species.

This definition of a species solves some of the problems of earlier concepts because it applies to extinct species and species that reproduce asexually. It also incorporates molecular data. **Table 2** summarizes the three main species concepts.

Table 2 Species Concepts

Species Concept	Description	Limitation	Benefit
Typological species concept	Classification is determined by the comparison of physical characteristics with a type specimen.	Alleles produce a wide variety of features within a species.	Descriptions of type specimens provide detailed records of the physical characteristics of many organisms.
Biological species concept	Classification is determined by similar characteristics and the ability to interbreed and produce fertile offspring.	Some organisms that interbreed occasionally, are of different species; does not account for extinct species	The concept applies in most cases, so it is still used frequently.
Phylogenetic species concept	Classification is determined by evolutionary history.	Evolutionary histories are not known for all species.	Accounts for extinct species and considers molecular data.

Characters

To classify a species, scientists often construct patterns of descent by using **characters**—inherited features that vary among species. Characters can be morphological (for example, anatomical or embryological) or biochemical. Shared morphological characters suggest that species are related closely and evolved from a recent common ancestor. For example, because hawks and eagles share many morphological characters that they do not share with other bird species, such as keen eyesight and taloned feet, they should share a more recent common ancestor with each other than with other birds.

Morphological characters

When comparing morphological characters, it is important to remember that analogous characters do not indicate a close evolutionary relationship. Remember that analogous structures are those that have the same function but different underlying construction. Homologous characters, however, might perform different functions but show an anatomical similarity inherited from a common ancestor.

Birds and dinosaurs The fossil record provides evidence of evolution. Consider the oviraptor and the sparrow shown in **Figure 7**. You might think that dinosaurs and birds do not have much in common and do not share a close evolutionary relationship. A closer look at dinosaur fossils shows that they share many features with birds. Some fossil dinosaur bones, like those of the large, carnivorous theropod dinosaurs, show that their bones had large hollow spaces. Birds have bones with hollow spaces. In this respect, they are more like birds than most living reptiles, such as alligators, lizards, and turtles, which have dense bones. Also, theropods have hip, leg, wrist, and shoulder structures that are more similar to birds than to other reptiles. Scientists have discovered fossil dinosaur bones that suggest some theropods had feathers. The evidence provided by these morphological characters indicates that theropod dinosaurs are related more closely to modern birds than they are to other reptiles.

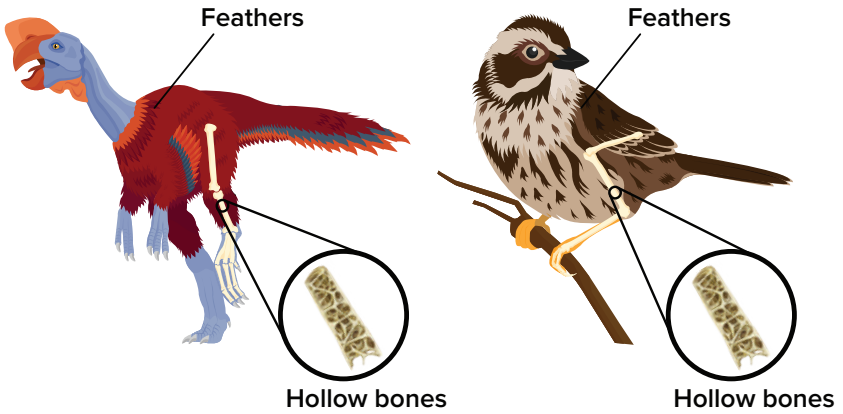
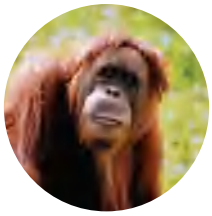


Figure 7 This artist's conception of *Oviraptor philoceratops* might not appear to be related to the sparrow *Zonotrichia leucophrys*, but these animals share many characteristics that indicate a shared evolutionary history.

Deduce *which similarities might prompt you to think that these species are more closely related than was commonly thought.*

Chimpanzee
Pan troglodytes

Gorilla
Gorilla gorilla



Orangutan
Pongo pygmaeus

Figure 8 The representation of chromosome-banding patterns for these homologous chromosomes illustrates the evidence of a close evolutionary relationship among the chimpanzee, gorilla, and orangutan.

Biochemical characters

Genetic information provides evidence of evolution. Scientists use biochemical characters, such as amino acids and nucleotides, to help them determine evolutionary relationships among species. Chromosome structure and number is also a powerful clue for determining species similarities. For example, members of the mustard family (Cruciferae)—including broccoli, cauliflower, and kale—all look different, but these plants have almost identical chromosome structures. This is strong evidence that they share a recent common ancestor. Likewise, the similar appearance of chromosomes among chimpanzees, gorillas, and orangutans suggests a shared ancestry. **Figure 8** shows the similar appearance of a chromosome-banding pattern in these three primates.

DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. The greater the number of shared DNA sequences between species, the greater the number of shared genes—and the greater the evidence that the species share a recent common ancestor.

Scientists use a variety of techniques to compare DNA sequences. They can sequence and compare whole genomes of different organisms. They can compare genome maps made by using restriction enzymes. They also use a technique called DNA-DNA hybridization, during which single strands of DNA from different species are melted together. The success of the hybridization depends on the similarity of the sequences—complementary sequences will bind to each other, while dissimilar sequences will not bind. Comparing DNA sequences is an objective, quantitative way to measure evolutionary relationships.

African elephant (savanna) | African elephant (forest) | Asiatic elephant

Figure 9 The two populations of African elephants had been classified as the same species; however, DNA analysis shows that they might be separate species. The Asiatic elephant belongs to a separate genus.

A species example The classification of elephants is one example of how molecular data has changed traditional taxonomic organization. **Figure 9** shows pictures of elephants that live in the world today. Taxonomists have classified the Asiatic elephant (*Elephas maximus*) as one species and the African elephant (*Loxodonta africana*) as another for over 100 years.

However, the two types of African elephant have been classified as the same species, even though the two populations look different. The forest-dwelling elephants are much smaller and have longer tusks and smaller ears than the savanna-dwelling elephants. Even so, scientists thought that the elephants interbred freely at the margins of their ranges. DNA studies show that the African elephants diverged from a common ancestor about 2.5 million years ago. Scientists have proposed renaming the forest-dwelling elephant *Loxodonta cyclotis*.

Molecular clocks You know that mutations occur randomly in DNA. As time passes, mutations accumulate, or build up, in the chromosomes. Some of these mutations do not affect the way cells function, and they are passed down from parent to offspring. Systematists can use these mutations to help them determine the degree of relationship among species.

A **molecular clock** is a model that is used to compare DNA sequences from two different species to estimate how long the species have been evolving since they diverged from a common ancestor. **Figure 10** illustrates how a molecular clock works.

Scientists use molecular clocks to compare the DNA sequences or amino acid sequences of genes that are shared by different species. The differences between the genes indicate the presence of mutations. The more mutations that have accumulated, the more time that has passed since divergence.

When the molecular clock technique was first introduced in the 1960s, scientists thought the rate of mutation within specific genes was constant. Hence, they used the clock as an analogy. However, scientists now know that the speed by which mutations occur is not always the same in a single gene or amino acid sequence.

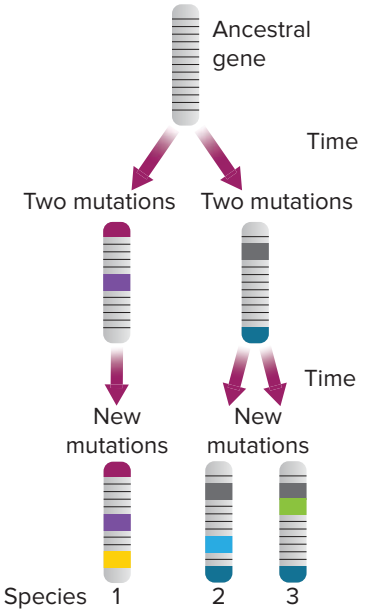


Figure 10 This molecular clock diagram shows how mutations might accumulate over time.

Infer *why a clock is not a good analogy for this process.*

The rate of mutation is affected by many factors, including the type of mutation, where it is in the genome, the type of protein that the mutation affects, and the population in which the mutation occurs. In a single organism, different genes might mutate, or "tick," at different speeds. This inconsistency makes molecular clocks difficult to read. Researchers try to compare genes that accumulate mutations at a relatively constant rate in a wide range of organisms. One such gene is the gene for cytochrome *c* oxidase, which is found in the mitochondrial DNA of most organisms.

Despite their limitations, molecular clocks can be valuable tools for determining a relative time of divergence of a species. They are especially useful when used in conjunction with other data, such as the fossil record.

Get It?

Explain what the molecular clock model uses to compare DNA.

Phylogenetic Reconstruction

The most common systems of classification today are based on a method of analysis called cladistics. **Cladistics** (kla DIHS tiks) is a method that classifies organisms according to the order that they diverged from a common ancestor.

Character types

Scientists consider two main types of characters when doing cladistic analyses. An ancestral character is found within the entire line of descent of a group of organisms. Derived characters are present in members of one group of the line but not in the common ancestor. For example, when considering the relationship between birds and mammals, a backbone is an ancestral character because both birds and mammals have a backbone and so did their shared ancestor. However, birds have feathers and mammals have hair. Therefore, having hair is a derived character for mammals because only mammals have an ancestor with hair. Having feathers is a derived character for birds.

Cladograms

Systematists use shared derived characters to make a cladogram. A **cladogram** (KLAD uh gram) is a branching diagram that represents the proposed phylogeny or evolutionary history of a species or group. A cladogram is a model similar to a pedigree. Just as a pedigree's branches show direct ancestry, a cladogram's branches indicate phylogeny. The groups used in cladograms are called clades. A clade is one branch of the cladogram.

CCC CROSSCUTTING CONCEPTS

Patterns Using the genetic information illustrated in **Figure 8** and your knowledge of the morphological characters of chimpanzees and gorillas, write a short report to explain the evidence for common ancestry and biological evolution.

STEM CAREER Connection

Museum Curator

Have you ever thought about what it might be like to work at a museum? Museum curators are in charge of the acquisition, storage and exhibition of collections. Some curators are involved in research and educational outreach. Natural history museums may have curators who specialize in evolutionary biology or in specific classes or orders of organisms.

Constructing a cladogram **Figure 11** is a simplified cladogram for some major plant groups. This cladogram was constructed in the following way. First, two species were identified, conifers and ferns, to compare with the lily species. Then, another species was identified that is ancestral to conifers and ferns. This species is called the outgroup. The outgroup is the species or group of species on a cladogram that has more ancestral characters with respect to the other organisms being compared. In the diagram below, the outgroup is moss. Mosses are distantly related to ferns, conifers, and lilies.

The cladogram is constructed by sequencing the order in which derived characters evolved with respect to the outgroup. The closeness of clades in the cladogram indicate the number of characters shared. The group that is closest to the lily shares the most derived characters with lilies and thus shares a more recent common ancestor with lilies than with the groups farther away. The nodes where the branches originate represent a common ancestor. This common ancestor generally is not a known organism, species, or fossil. Scientists hypothesize its characters based on the traits of its descendants.

The primary assumption that systematists make when constructing cladograms is that the greater the number of derived characters shared by groups, the more recently the groups share a common ancestor. Thus, as shown in **Figure 11**, lilies and conifers have three derived characters in common and are presumed to share a more recent common ancestor than lilies and ferns, which share only two characters.

A cladogram also is called a phylogenetic tree. Detailed phylogenetic trees show relationships among many species and groups of organisms. **Figure 12** on the next page illustrates a phylogenetic tree that shows the relationships among the domains and kingdoms of the most commonly used classification system today.

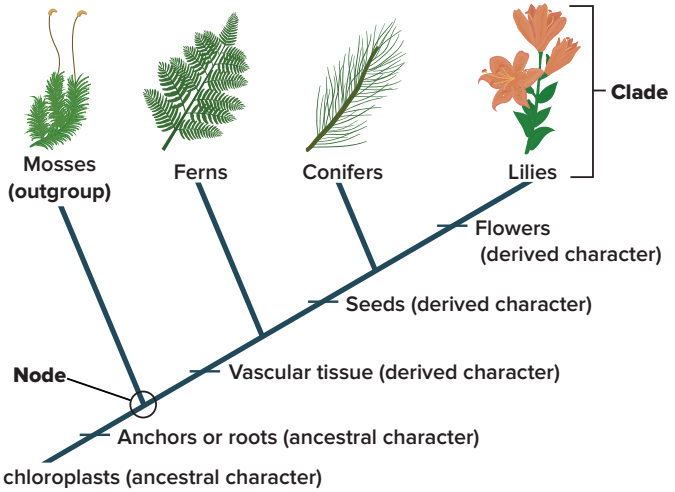


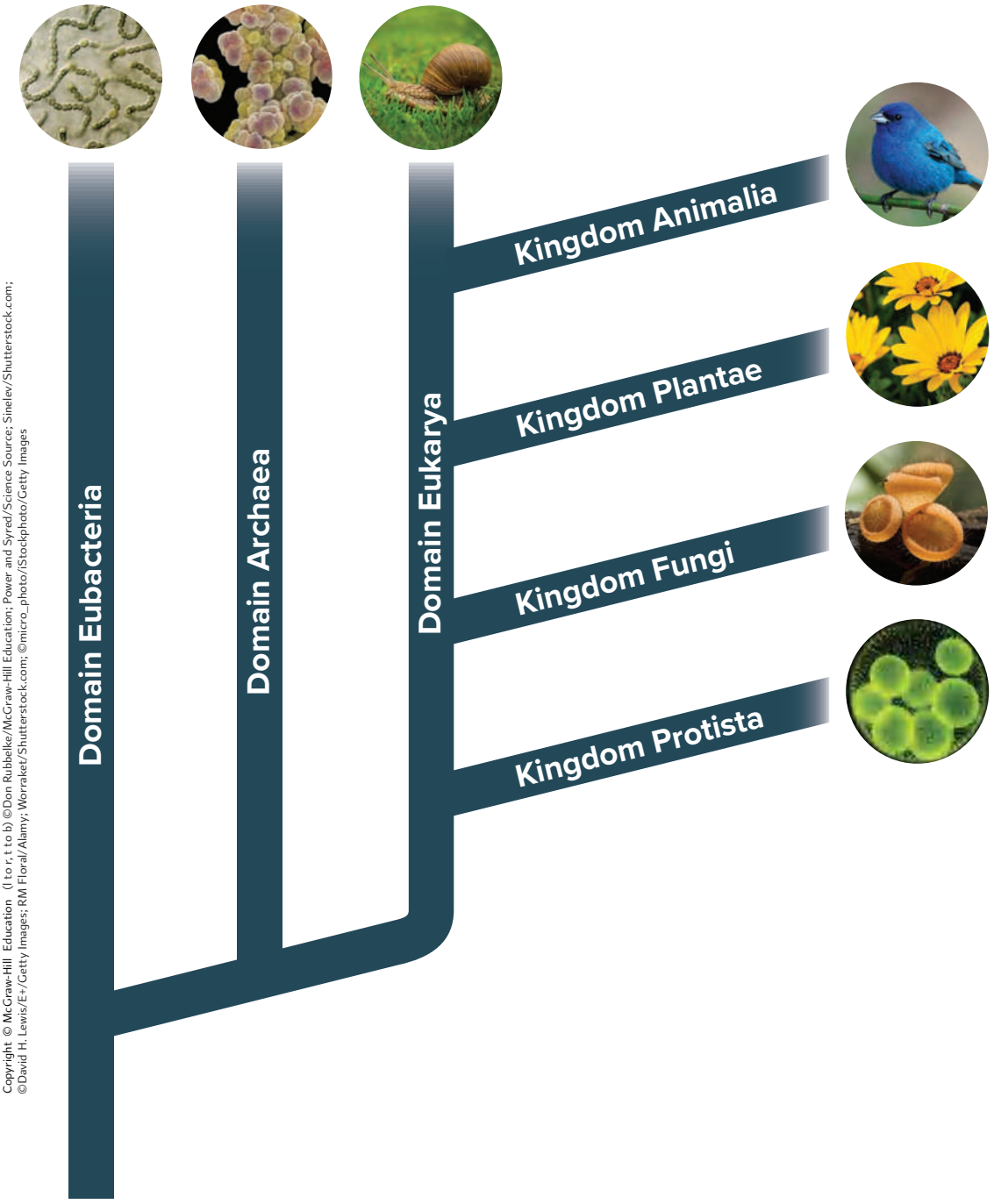
Figure 11 This cladogram uses the derived characters of plant taxa to model its phylogeny. Groups that are closer to the lily on the cladogram share a more recent common ancestor.

Identify *which clades have chloroplasts but do not produce seeds.*

Figure 12:

Visualizing the Tree of Life

This phylogenetic tree shows the main branches in the "tree of life." Notice the three domains and the four kingdoms of Domain Eukarya. All of the branches are connected at the trunk, which is labeled "Common ancestor."



The tree of life

In his book *On the Origin of Species*, Charles Darwin used the analogy of a tree to suggest that all of the species developed from one or a few species. He imagined the tree's trunk to represent ancestral groups and each of the branches to have similar species. From each branch, smaller and smaller branches grew. Finally, at the tips of the twigs of these branches were the leaves, consisting of individual living species. This concept was developed further, and the term tree of life was coined by German biologist Ernst Haeckel (1834–1919). **Figure 13** shows Haeckel's Tree of Humanity.

The tree of life diagram in **Figure 13** shows a small part of the diversity of living organisms. A tree of life that incorporates all known organisms is almost unimaginably large. Assembling a comprehensive tree of life requires a convergence of data from phylogenetic and molecular analysis. It also requires collaboration among many scientists representing many disciplines, from molecular biology to Earth science to computer science. Many scientists think that the construction of a comprehensive tree of life is an important goal. Knowing how all organisms are related would benefit industry, agriculture, medicine, and conservation.

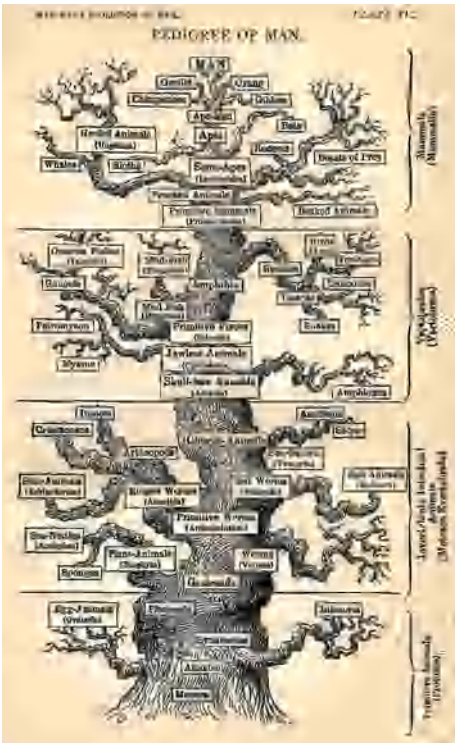


Figure 13 This illustration, made by Haeckel in the nineteenth century, was one of the first depictions of evolutionary relationships.

Check Your Progress

Summary

- The definition of species has changed over time.
- Phylogeny is the inferred evolutionary history of a species, evidence for which comes from a variety of studies.
- A molecular clock uses comparisons of DNA sequences to estimate phylogeny and rate of evolutionary change.
- Cladistic analysis models evolutionary relationships based on sequencing derived characters.

Demonstrate Understanding

1. **Describe** how the changing species concept has affected classification systems.
2. **Summarize** the different concepts of a species.
3. **Describe** some methods used to determine phylogeny.
4. **Organize** the following derived characters on a cladogram in order of ascending complexity: multicellular, hair, backbone, unicellular, and four appendages.

Explain Your Thinking

5. **Describe** the mathematical challenges of counting the "ticks" of a molecular clock.
6. **Indicate** the hypothetical evolutionary relationship between two species if their DNA sequences share a 98 percent similarity.

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LESSON 3

DOMAINS AND KINGDOMS

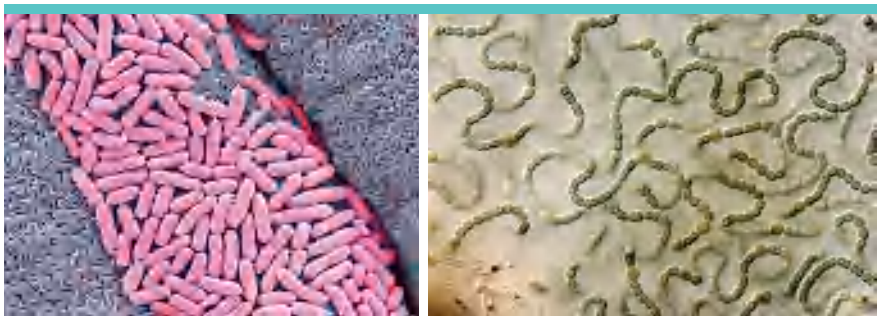
FOCUS QUESTION

What are the major characteristics of the three domains?

Grouping Species

The broadest category in the classification system used by most biologists is the domain. There are three domains: Bacteria, Archaea, and Eukarya. Within these domains are six kingdoms: Bacteria, Archaea, Protists, Fungi, Plantae, and Animalia. Organisms are classified into domains according to cell type and structure, and into kingdoms according to cell type, structure, and nutrition.

This three-domain, six-kingdom classification system has been in use for less than three decades. It was modified from a system that did not have domains but had five kingdoms after scientists discovered an entirely new kind of organism in the 1970s. These new organisms are unicellular prokaryotes that scientists named archaea (ar KEE uh). Subsequent biochemical studies found that archaea are significantly different from the only other prokaryotes then known—the bacteria—and, in 1990, they were renamed and a new classification scheme was proposed to accommodate them. Archaea are now members of their own domain.



Color-Enhanced SEM Magnification: 8000×

LM Magnification: 400×

Escherichia coli

Anabaena

Figure 14 Bacteria vary in their habitats and their methods of obtaining nourishment. The bacteria *Mycobacterium tuberculosis* that cause tuberculosis are heterotrophs. Cyanobacteria, such as *Anabaena*, are autotrophs.

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 Bacteria

Draw a pictorial model of the structure of bacteria.

Virtual Investigation: Classifying Using Biotechnology

Use a model to discover patterns among organisms to identify bacteria.

Domain Bacteria

CHEMISTRY Connection Bacteria, members of Domain and Kingdom Bacteria, are prokaryotes whose cell walls contain peptidoglycan (pep tih doh GLY kan). Peptidoglycan is a polymer that contains two kinds of sugars that alternate in the chain. The amino acids of one sugar are linked to the amino acids in other chains, creating a netlike structure that is simple and porous, yet strong. Two examples of bacteria are shown in **Figure 14** on the last page.

Bacteria are a diverse group that can survive in many different environments. Some are aerobic organisms that need oxygen to survive, while others are anaerobic organisms that die in the presence of oxygen. Some bacteria are autotrophic and produce their own food, but most are heterotrophic and get their nutrition from other organisms. Bacteria are more abundant than any other organism. There are probably more bacteria in your body than there are people in the world.

Get It?

Describe what heterotrophic aerobic bacteria need to survive.

Domain Archaea

Archaea (ar KEE uh), the species classified in Domain Archaea, are thought to be more ancient than bacteria and yet more closely related to eukaryotic ancestors. Their cell walls do not contain peptidoglycan, and they have some of the same proteins that eukaryotes do. They are diverse in shape and nutrition requirements. Some are autotrophic, but most are heterotrophic.

Archaea are called extremophiles because they can live in extreme environments. They have been found in boiling hot springs, salty lakes, thermal vents on the oceans' floors, and in the mud of marshes where there is no oxygen. The archaea *Staphylothermus marinus*, shown in **Figure 15**, is found in deep ocean thermal vents and can live in water temperatures up to 98°C.

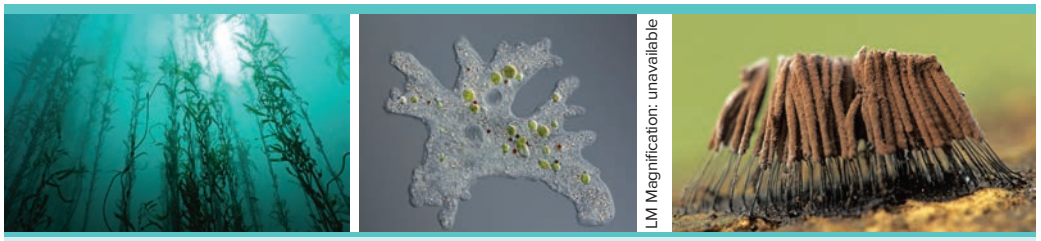
TEM Magnification: unavailable

Figure 15 This electron microscope image of *Staphylothermus marinus* shows the cell wall (green) and cell contents (pink). *S. marinus* is an extremophile found in deep ocean thermal vents.

WORD ORIGINS

archaea

comes from the Greek word *archaios*, meaning *ancient* or *primitive*



Kelp Amoeba Slime mold

Figure 16 These protists look different, but they all are eukaryotes, live in moist environments, and do not have organs.

Infer *how these protists are plantlike, animal-like, or funguslike.*

Domain Eukarya

Cells with a membrane-bound nucleus and other membranebound organelles are called eukaryotic cells. All organisms with these cells are called eukaryotes and are classified in Domain Eukarya. Domain Eukarya contains Kingdom Protista, Kingdom Fungi, Kingdom Plantae, and Kingdom Animalia.

Kingdom Protista

The wide variety of species shown in **Figure 16** belong to Kingdom Protista. Members of Kingdom Protista are called protists. **Protists** are eukaryotic organisms that can be unicellular, colonial, or multicellular. Unlike plants or animals, protists do not have organs. Though protists are not necessarily similar to each other, they do not fit in any other kingdoms. They are classified into three broad groups.

The plantlike protists are called algae. All algae, such as kelp, are autotrophs that perform photosynthesis. Animal-like protists are called protozoans. Protozoans, such as amoebas, are heterotrophs. Funguslike protists include slime molds and mildews, and they comprise the third group of protists. Euglenoids (yoo GLEE noyds) are a type of protist that has both plantlike and animal-like characteristics. They are usually grouped with the plantlike protists because they have chloroplasts and can perform photosynthesis.

Kingdom Fungi

A **fungus** is a unicellular or multicellular eukaryote that absorbs nutrients from organic materials in its environment. Members of Kingdom Fungi are heterotrophic, lack motility—the ability to move—and have cell walls. Their cell walls contain a substance called chitin (KI tun)—a rigid polymer that provides structural support. A fungus consists of a mass of threadlike filaments called hyphae (HI fee). Hyphae are responsible for the fungus's growth, feeding, and reproduction. Fungi fossils exist that are over 400 million years old, and there are more than 70,000 known species.

Get It?

Describe the basic structure characteristics of a fungus.

Fungi, such as the mold in **Figure 17**, are heterotrophic organisms. Some fungi are parasites—organisms that grow and feed on other organisms. Other fungi are saprobes—organisms that get their nourishment from dead or decaying organic matter. Unlike heterotrophs that digest their food internally, fungi secrete digestive enzymes into their food source and then absorb digested materials directly into their cells. Fungi that live in a mutualistic relationship with algae are called lichens. Lichens get their food from the algae that live among their hyphae.

Figure 17 Fungi come in a variety of sizes, from microscopic yeasts to multicellular forms, such as the mold shown here.

Kingdom Plantae

There are more than 250,000 species of plants in Kingdom Plantae (PLAN tuh). These organisms form the base of all terrestrial habitats. All plants are multicellular and have cell walls composed of cellulose. Most plants contain chloroplasts, where photosynthesis is carried out, but a few plants are heterotrophic. For example, the parasitic dodder plant has no green parts and extracts its food from host plants through suckers.

All plants possess cells that are organized into tissues, and many plants also possess organs such as roots, stems, and leaves. Like the fungi, plants lack motility. However, some plants do have reproductive cells that have flagella, which propel them through water. The characteristics of plants and members of the other five kingdoms are summarized in **Table 3**.

Get It?

Describe three characteristics of plants.

Table 3 Kingdom Characteristics

Domain	Bacteria	Archaea	Eukarya			
Kingdom	Bacteria	Archaea	Protista	Fungi	Plantae	Animalia
Example	*Pseudomonas*  SEM Magnification: 5500x	*Methanosarcina*  SEM Magnification: unavailable	Diatom  LM Magnification: 150x	Mushroom 	Flowers 	Bat 
Cell Type	Prokaryote		Eukaryote			
Cell walls	Cell walls with peptidoglycan	Cell walls without peptidoglycan	Cell walls with cellulose in some	Cell walls with chitin	Cell walls with cellulose	No cell walls
Number of cells	Unicellular		Unicellular and multicelluar	Most multicellular	Multicellular	
Nutrition	Autotroph or heterotroph			Heterotroph	Autotroph	Heterotroph

Figure 18 Members of Kingdom Animalia can look very different from each other, even though they are in the same kingdom.

Kingdom Animalia

Members of Kingdom Animalia are commonly called animals. More than one million animal species have been identified. All animals are heterotrophic, multicellular eukaryotes. Animal cells do not have cell walls. All animal cells are organized into tissues, and most tissues are organized into organs, such as skin, a stomach, and a brain. Animal organs often are organized into complex organ systems, like digestive, circulatory, or nervous systems. Animals range in size from a few millimeters to many meters. They live in the water, on land, and in the air. **Figure 18** shows some of the variety of organisms classified in Kingdom Animalia.

Viruses—an exception

A virus is a nucleic acid surrounded by a protein coat. Viruses do not possess cells, nor are they cells, and are not considered to be living. Because they are nonliving, they usually are not placed in the biological classification system.

Check Your Progress

Summary

- Domains Bacteria and Archaea contain prokaryotes.
- Organisms are classified at the kingdom level based on cell type, structures, and nutrition.
- Domain Eukarya contains four kingdoms of eukaryotes.
- Because viruses are not living, they are not included in the biological classification system.

Demonstrate Understanding

1. **State** the three domains and the kingdoms in each of the domains.
2. **Compare and contrast** characteristics of the three domains.
3. **Explain** the difference between Kingdom Protista and Kingdom Fungi.
4. **Classify** to the kingdom level an organism that has organ systems, lacks cell walls, and ingests food.

Explain Your Thinking

5. **Summarize** the reasons why systematists separated Domain Bacteria from Domain Archaea.
6. **WRITING Connection** Write an essay for or against including viruses in the biological classification system.

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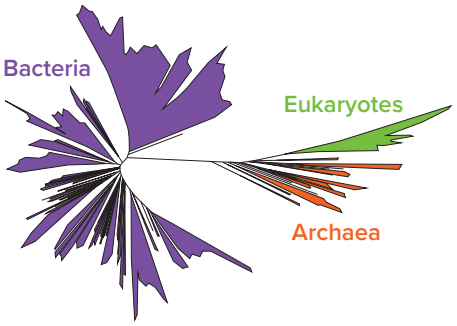
SCIENTIFIC BREAKTHROUGHS

The Tree of Life

Scientists have been working on a "tree of life" that maps the evolution of all living things since Charles Darwin compared evolution to a branching tree in his book "On the Origin of Species," published in 1859. In 2016, researchers published a new, expanded tree of life. It has little resemblance to an actual tree and shows that most of life's diversity comes from bacteria.



The tree of life illustrates the genetic diversity of life on Earth. It shows that bacteria make up much of the diversity of life.

The new tree shows the genetic diversity of life. It has three main trunks (domains). Eukaryotes make up one relatively small trunk. The other two bigger trunks are made up of bacteria and archaea. Many of the archaea and bacteria are newly discovered and researchers believe there may be many more that are still unknown.

Piecing together new genomes

DNA sequencing technology has sped up the mapping of the tree and has allowed connections to be made between the DNA of different organisms. Adding to the tree has been a challenge because many of the unknown organisms live in harsh environments, such as deep-sea vents, or researchers have not known how to find them. Researchers have also not been able to cultivate many of the organisms in their laboratories. Scientists know that certain bacteria exist only from studying their genes.

Technology has allowed researchers to take DNA fragments out of the environment and piece them together to find new organisms that fit on the tree. Researchers have put together DNA pieces from environments such as meadow soils and animals' mouths.

The study of genetic material recovered from samples in the environment is called metagenomics. Supercomputers are used to help determine possible tree configurations and to find the tree configuration supported by the most genetic evidence.

ASK QUESTIONS TO CLARIFY

Ask questions to clarify how scientists found new organisms to add to the tree of life. Find out more about how fragments of DNA are pieced together. Share your findings with a partner.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 THE HISTORY OF CLASSIFICATION

- Aristotle developed the first widely accepted biological classification system.
- Linnaeus used morphology and behavior to classify plants and animals.
- Binomial nomenclature uses the Latin genus and species to give an organism a scientific name.
- Organisms are classified according to a nested hierarchical system.

- taxon
- classification
- taxonomy
- binomial nomenclature
- genus
- family
- order
- class
- phylum
- division
- kingdom
- domain

Lesson 2 MODERN CLASSIFICATION

- The definition of species has changed over time.
- Phylogeny is the inferred evolutionary history of a species, evidence for which comes from a variety of studies.
- A molecular clock uses comparisons of DNA sequences to estimate phylogeny and rate of evolutionary change.
- Cladistic analysis models evolutionary relationships based on sequencing derived characters.

- phylogeny
- character
- molecular clock
- cladistics
- cladogram

Lesson 3 DOMAINS AND KINGDOMS

- Domains Bacteria and Archaea contain prokaryotes.
- Organisms are classified at the kingdom level based on cell type, structures, and nutrition
- Domain Eukarya contains four kingdoms of eukaryotes.
- Because viruses are not living, they are not included in the biological classification system.

- archaea
- protist
- fungus

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

Why are these butterflies similar in structure but different in color?

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

Are African elephants a separate species?

Efforts to count and protect elephant populations in Africa were based on the assumption that all African elephants belong to the same species. Evidence from a project originally designed to trace ivory samples changed that assumption. A group of scientists studied the DNA variation among 195 African elephants from 21 populations in 11 of the 37 nations in which African elephants range and from seven Asian elephants. They used biopsy darts to obtain plugs of skin from the African elephants. The researchers focused on a total of 1732 nucleotides from four nuclear genes that are not subject to natural selection. The following paragraph shows the results of the samples.

Data and Observations "Phylogenetic distinctions between African forest elephant and savannah elephant population corresponded to 58% of the difference in the same genes between elephant genera *Loxodonta* (African) and *Elephas* (Asian)."

CER Analyze and Interpret Data

1. **Describe** the type of evidence used in the study.
2. **Claim, Evidence** Explain the evidence that there are two species of elephants in Africa.
3. **Reasoning** Propose other kinds of data that could be used to support three different scientific names for elephants.
4. **Reasoning** Currently, *Loxodonta africana* is protected from being hunted. How might reclassification affect the conservation of forest elephants?

*Data obtained from: Roca, A.L., et al. 2001. Genetic evidence for two species of elephants in Africa. *Science* 293(5534): 1473–1477.

BACTERIA AND VIRUSES

ENCOUNTER THE PHENOMENON

What is alive in this photo?

SEP Ask Questions

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

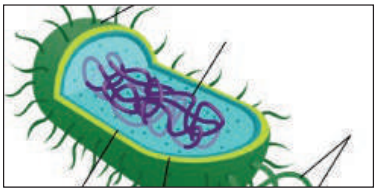
CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about what is alive in this photo. Explain your reasoning.

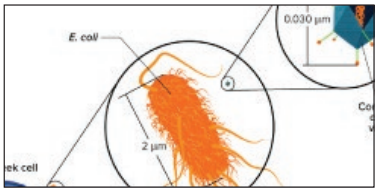
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

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: Prokaryote Structure and Function



LESSON 2: Explore & Explain: Viruses

LESSON 1

BACTERIA

FOCUS QUESTION

What are the differences between the domains of prokaryotes?

Diversity of Prokaryotes

Many scientists think that the first organisms on Earth were microscopic, unicellular organisms called prokaryotes. Today, prokaryotes are the most numerous organisms on Earth. They are found everywhere from the depths of the oceans to the highest mountaintops. Some prokaryotes are the only organisms able to survive in hostile environments, such as the water in hot sulfur springs or the Great Salt Lake. The word *prokaryote* is a Greek word that means *before a nucleus*.

All prokaryotes were once classified into one group—Kingdom Monera—based on their lack of a nucleus and membrane-bound organelles. However, modern research has shown that great differences exist among prokaryotes. They are now divided into two domains—Domain Bacteria and Domain Archaea. **Bacteria** (sometimes called eubacteria) are prokaryotic organisms that belong to Domain Bacteria. Bacteria live in nearly every environment on Earth and are important in the human body, industry, and food production. Archaea (previously called archaeabacteria) live in extreme environments and are sometimes called extremophiles. Archaea have been found to have some similarities with eukaryotic cells, such as cytoplasm proteins and histones. **Figure 1** shows representatives of these two domains.

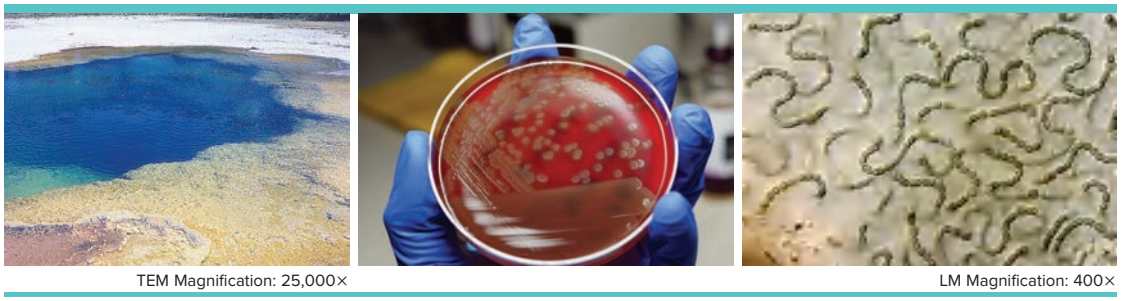


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Figure 1 Archaea live in extreme environments like this hot spring. The middle photo shows a culture of bacteria. The photo on the right shows cyanobacteria.

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 the most effective antibiotics be determined?
Plan and carry out an investigation to determine the effects of antibiotics in treating bacterial infections.

Quick Investigation: Classify Bacteria
Draw a pictorial model of the structures of bacteria.

Sulfur hot spring Great Salt Lake

Figure 2 Some members of Domain Archaea can live in hostile environments, such as the sulfur hot springs in Danakil Depression, Ethiopia and the Great Salt Lake in Utah.

Bacteria

Bacteria are the most-studied organisms and are found almost everywhere except in extreme environments, where mostly archaea are found. Bacteria have strong cell walls that contain peptidoglycan. Some bacteria have a second cell wall, a property that can be used to classify them. Additionally, some bacteria, such as the cyanobacteria in **Figure 1**, are photosynthetic.

Archaea

In extreme environments that are hostile to most other forms of life, archaea predominate. Some archaea called thermoacidophiles (thur muh uh SIH duh filz) live in hot, acidic environments, including sulfur hot springs, shown in **Figure 2**, thermal vents on the ocean floor, and around volcanoes. These archaea thrive in temperatures above 80°C and pH levels of 1–2. Some of these archaea cannot survive temperatures as low as 55°C. Many are strict anaerobes, which means that they die in the presence of oxygen.

Other archaea called halophiles (HA luh filz) live in very salty environments. The salt concentration in your cells is 0.9 percent, oceans average 3.5 percent salt, and the salt concentrations in the Great Salt Lake, shown in **Figure 2**, and the Dead Sea can be greater than 15 percent. Halophiles have several adaptations that allow them to live in salty environments.

The methanogens (meh THAHN oh jenz) are the third group of archaea. These organisms are obligate anaerobes, which means they cannot live in the presence of oxygen. They use carbon dioxide during respiration and give off methane as a waste product. Methanogens are found in sewage treatment plants, swamps, bogs, and near volcanic vents. Methanogens even thrive in the gastrointestinal tract of humans and other animals and are responsible for the gases that are released from the lower digestive tract.

Differences between bacteria and archaea

Bacteria and archaea have many differences that have led them to be classified in different domains. Recall that there are three domains. Based on their classification, we understand that bacteria and archaea are as different from each other as they are from eukaryotic cells. Some differences include: bacterial cell walls contain peptidoglycan but archaea do not; different lipids in their plasma membranes; and different ribosomal proteins and RNA. The ribosomal proteins in archaea are similar to those of eukaryotic cells.

Prokaryote Structure

Prokaryotes are microscopic, unicellular organisms. They have some characteristics of all cells, such as DNA and ribosomes, but they lack a nuclear membrane and other membrane-bound organelles, such as mitochondria and chloroplasts. Although a prokaryotic cell is very small and doesn't have membrane-bound organelles, it has all it needs to carry out life functions. Examine **Figure 3** as you read about the structure of prokaryotic cells.

Chromosomes

The chromosomes in prokaryotes are arranged differently from the chromosomes found in eukaryotic cells. Their genes are found on a large, circular chromosome in an area of the cell called the **nucleoid.** Many prokaryotes also have at least one smaller piece of DNA, called a plasmid, which also has a circular arrangement.

Capsule

Some prokaryotes secrete a layer of polysaccharides around the cell wall, forming a **capsule,** illustrated in **Figure 3**. The capsule has several important functions, including preventing the cell from drying out and helping the cell attach to surfaces in its environment. The capsule also helps prevent bacteria from being engulfed by white blood cells and shelters the cells from the effects of antibiotics.

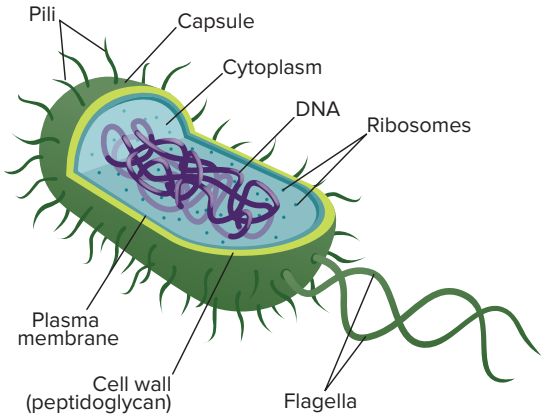

Figure 3 Prokaryotic cells have structures that are necessary for carrying out life processes. Compare and contrast how a bacterial cell differs structurally from a eukaryotic cell.

Pili

Structures called pili are found on the outer surface of some bacteria. **Pili** (singular, pilus) are submicroscopic, hairlike structures that are made of protein. Pili help bacterial cells attach to surfaces. Pili also can serve as a bridge between cells. Copies of plasmids can be sent across the bridge, thus providing some prokaryotes with new genetic characteristics. This is one way of transferring resistance to antibiotics.

Size

Even when using a typical light microscope, prokaryotes are small when magnified 400 times. Prokaryotes are typically only 1 to 10 micrometers long and 0.7 to 1.5 micrometers wide. Study **Figure 4**, which shows a bacterial cell and a human cell. Notice the relative size of bacterial cells found adjacent to a cheek cell.

Recall that small cells have a larger, more favorable surface area-to-volume ratio than large cells. Because prokaryotes are so small, nutrients and other substances the cells need can diffuse to all parts of the cell easily.

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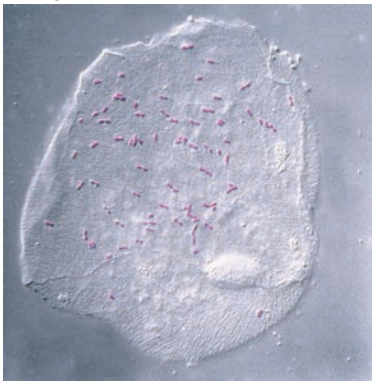


Figure 4 A size comparison shows how a human cheek cell is much larger than bacteria found in a human mouth.

Prokaryote Characteristics

As with other types of organisms, prokaryotes now can be identified using molecular techniques. By comparing DNA and other molecular markers such as proteins, scientists can determine evolutionary relationships. Historically, scientists identified and classified prokaryotes using criteria such as shape, cell wall, and movement.

Shape

Three shapes of prokaryotes are shown in **Figure 5**. Spherical, or round, prokaryotes are called cocci (KAHK ki) (singular, coccus), rod-shaped prokaryotes are called bacilli (buh SIH li) (singular, bacillus), and spiral-shaped prokaryotes are called spirilli (spi RIH li) (singular, spirillium).

Cell walls

Scientists also classify bacteria according to the composition of their cell walls. All bacterial cells have peptidoglycan in their cell walls. Peptidoglycan is made of disaccharides and peptide fragments. Biologists add dyes to the bacteria to identify the two major types of bacteria—those with and those without an outer layer of lipid—in a technique called Gram's stain.

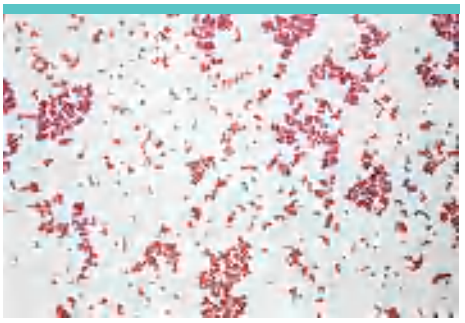
Bacteria with a large amount of peptidoglycan appear dark purple once they are stained and are called Gram-positive. Bacteria with the lipid layer have less peptidoglycan and appear light pink after staining. These bacteria are called Gram-negative. Because some antibiotics work by attacking the cell wall of bacteria, physicians need to know the type of cell wall that is present in the bacteria that they suspect is causing illness to prescribe the proper antibiotic.

Movement

Although some prokaryotes are stationary, others use flagella for movement. Prokaryotic flagella are made of filaments, unlike the flagella of eukaryotes, which are made of microtubules. Flagella help prokaryotes move toward light, higher oxygen concentration, or chemicals such as sugar or amino acids that they need to survive. Other prokaryotes move by gliding over a layer of secreted slime.

Get It?

Explain the difference between prokaryotic and eukaryotic flagella.



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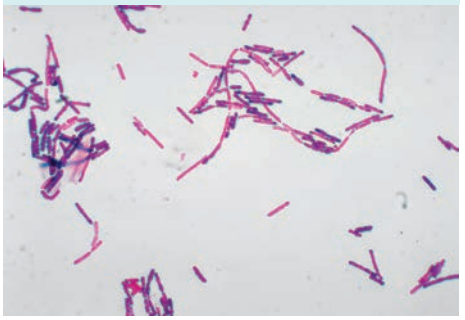
Cocci



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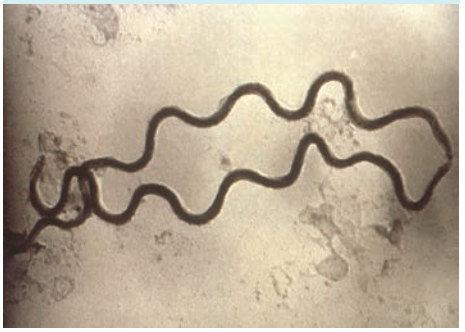
Bacilli



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Spirilli

Figure 5 There are three shapes of prokaryotes: cocci, bacilli, and spirilli.

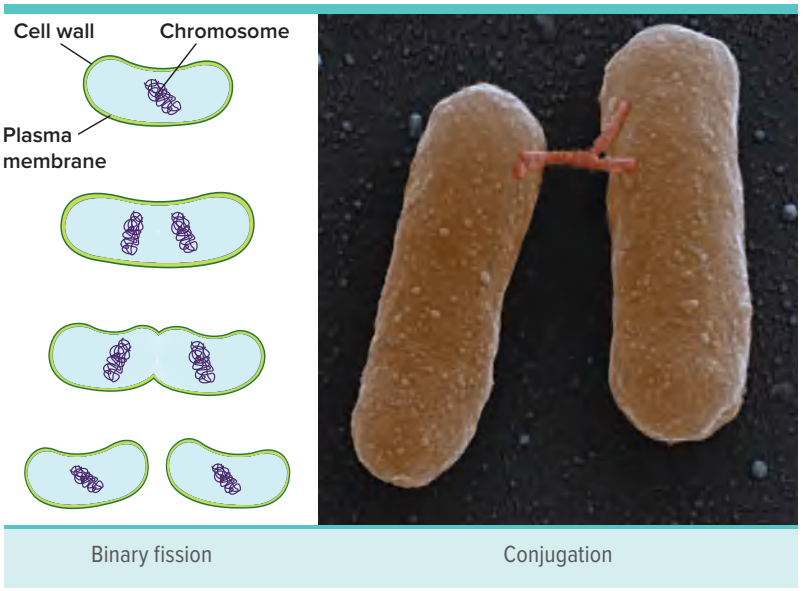

Figure 6 Binary fission is an asexual form of reproduction used by some prokaryotes. Conjugation is a method of exchanging genetic material used by some prokaryotes.

Analyze *Which means of reproducing shown here exchanges genetic information?*

Reproduction of Prokaryotes

Most prokaryotes reproduce by an asexual process called binary fission, illustrated in **Figure 6**. In **binary fission,** the cell divides into two genetically identical cells. The prokaryotic chromosome replicates, and the original chromosome and the new copy separate. The cell gets larger by elongating. A new piece of plasma membrane and cell wall forms and separates the cell into two identical cells. Under ideal conditions, this can occur quickly—as often as every 20 minutes. If conditions are just right, one bacterium could become one billion bacteria through binary fission in just ten hours.

Some prokaryotes exhibit a form of reproduction called **conjugation,** in which two prokaryotes attach to each other and exchange genetic information. As shown in **Figure 6**, the pilus is important for the attachment of the two cells so that there can be a transfer of genetic material from one cell to the other. In this way, new gene combinations are created and diversity of prokaryote populations is increased.

Metabolism of Prokaryotes

Photosynthesis and cellular respiration, including fermentation, provide most of the energy for life processes. Prokaryotes are classified by how they obtain energy for cellular respiration or fermentation, as shown in **Figure 7**. They also are classified by how they use oxygen. Anaerobic prokaryotes do not use oxygen for metabolism. Obligate anaerobes cannot tolerate the presence of oxygen. Facultative anaerobes can grow either with or without oxygen present. Obligate aerobes require oxygen to grow.

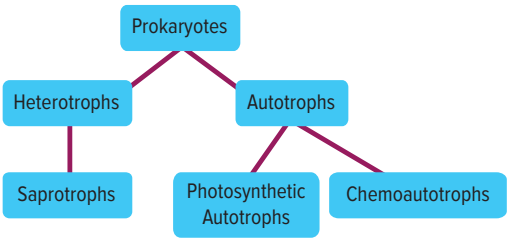

Figure 7 Prokaryotes are grouped according to how they obtain nutrients for energy. Heterotrophic bacteria can also be saprotrophs; autotrophs can be photosynthetic or chemoautotrophic.

Heterotrophs

Some prokaryotes are heterotrophs; they cannot synthesize their own food and must take in nutrients. Many heterotrophic bacteria are saprotrophs, or saprobes. They obtain their energy by decomposing organic molecules associated with dead organisms or organic waste.

Photoautotrophs

Some bacteria are photosynthetic autotrophs (AW tuh trohfs); they carry out photosynthesis in a manner similar to plants. These bacteria must live in areas where there is light, such as shallow ponds and streams, to synthesize organic molecules to use as food.

Scientists once thought that these organisms were eukaryotes and called them blue-green algae. Later, it was discovered that they were prokaryotes and they were renamed cyanobacteria. Cyanobacteria are thought to have been the first group of organisms to release oxygen into Earth's early atmosphere, approximately three billion years ago.

Chemoautotrophs

Autotrophs that do not require light for energy are called chemoautotrophs. They break down and release inorganic compounds that contain nitrogen or sulfur, such as ammonia and hydrogen sulfide, in a process called chemosynthesis. Some chemoautotrophs have important roles in cycling nitrogen and other inorganic compounds through ecosystems.

Get It?

Summarize the importance of photosynthesis and cellular metabolism in bacterial metabolism.

Survival of Bacteria

How can bacteria survive if their environment becomes unfavorable? Several mechanisms help them survive environmental challenges such as a lack of water, an extreme temperature change, or a lack of nutrients.

Endospores

When environmental conditions are harsh, some types of bacteria produce a structure called an **endospore**. The bacteria that cause anthrax, botulism, and tetanus are examples of endospore producers. An endospore can be thought of as a dormant cell. Endospores are resistant to harsh environments and might be able to survive extreme heat, extreme cold, dehydration, and large amounts of ultraviolet radiation.

As illustrated in **Figure 8**, when a bacterium is exposed to harsh environments, a spore coat surrounds a copy of the bacterial cell's chromosome and a small part of the cytoplasm. The bacterium itself might die, but the endospore remains. When environmental conditions become favorable again, the endospore grows, or germinates, into a new bacterial cell. Endospores are able to survive for long periods of time.

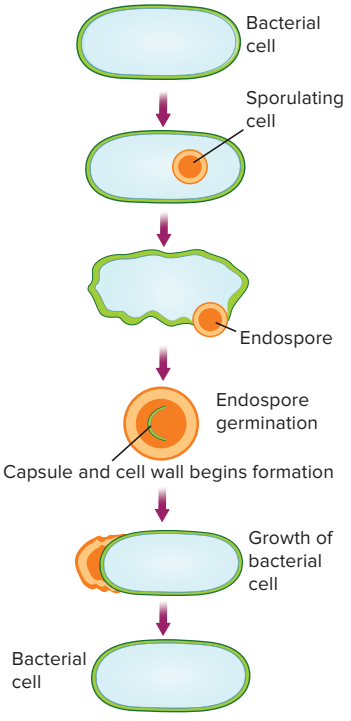

Figure 8 Endospores can survive extreme environmental conditions.

Mutations

If the environment changes and bacteria are not well adapted to the new conditions, the bacteria could become extinct. Species become extinct because they can no longer survive and reproduce in their environment. Because bacteria reproduce quickly and their population grows rapidly, genetic mutations can help bacteria survive in changing environments. Mutations, which are changes or random errors in a DNA sequence, lead to new forms of genes, new gene combinations, new characteristics, new adaptations, and genetic diversity. If the environment changes, some bacteria in a population might have the right combination of genes to allow them to survive and reproduce. However, if the population of bacteria cannot adjust to change fast enough, the opportunity for evolution is lost. When the distribution of traits in the population of bacteria changes, the bacteria have adapted to the new environment.

Get It?

Explain how mutations can help a population of bacteria develop new adapations in response to a change in the environment.

Ecology of Bacteria

When many people think of bacteria, they think of germs or disease. However, many bacteria are beneficial. In fact, bacteria help fertilize fields, recycle nutrients, protect the body, and produce foods and medicines.

Nutrient cycling and nitrogen fixation

Nutrients are cycled in an ecosystem. Organisms that obtain energy from dead organisms and are called decomposers or detrivores. Saprobes are decomposers, returning vital nutrients to the environment. Without nutrient recycling, all raw materials necessary for life would be used up.

All forms of life require nitrogen. Nitrogen is a key component of amino acids, the building blocks of proteins, and the nucleic acids DNA and RNA. Most of Earth's nitrogen is found in the atmosphere in the form of nitrogen gas (N_2). Certain types of bacteria can use nitrogen gas directly. These bacteria have enzymes that can convert nitrogen gas into nitrogen compounds by nitrogen fixation. Some of them live in soil.

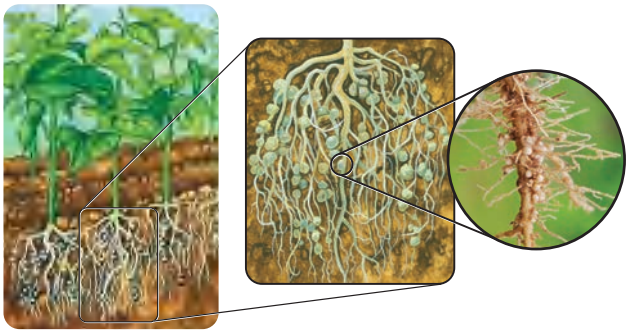

Figure 9 Nitrogen-fixing bacteria on a plant root nodule are able to remove nitrogen from the air and convert it into a form the plant can use.

CCC CROSSCUTTING CONCEPTS

Energy and Matter Describe how energy and matter are cycled through an ecosystem using nitrogen fixation as an example.

STUDY TIP

Summarization Write a summary paragraph that addresses the diversity of prokaryotes, how they reproduce, and the importance of prokaryotes.

Some nitrogen-fixing bacteria live in a symbiotic relationship in the root nodules of plants such as soybeans, clover, and alfalfa. The bacteria use the nitrogen in the atmosphere to produce forms of nitrogen the plant can use. The plants then are able to take up ammonia (NH_3) and other forms of nitrogen from the soil. These plants are at the base of a food chain, and the nitrogen is passed along to organisms that eat them. **Figure 9**, on the previous page, shows where nitrogen-fixing bacteria live on root nodules.

Normal flora

Your body is covered with bacteria inside and out. Scientists refer to the communities of bacteria that live in and on your body as the microbiome. Most of these bacteria are harmless, or even helpful. These important bacteria are called normal flora.

By living and replicating on the body, normal flora compete with harmful bacteria and prevent them from taking hold and causing disease.

Magnification: unavailable

Figure 10 *E. coli* that live in the intestine are important for survival.

A certain type of bacterium called *Escherichia coli* (*E. coli*) lives inside your intestines and is illustrated in **Figure 10**. Some *E. coli* strains can cause food poisoning. The type that lives in the digestive tracts of humans and other mammals is harmless and important for survival. The *E. coli* that live in humans make vitamin K, which humans absorb and use in blood clotting. In this symbiotic relationship, *E. coli* are provided with a warm place and food with which to live. In return, the bacteria provide the body with an essential nutrient.

Foods and medicines

Think about what you have eaten in the last few days. Have you had pizza? How about a cheeseburger? Cheese, yogurt, buttermilk, and pickles, as well as other foods, are made with the aid of bacteria.

Bacteria are even used in the production of chocolate. Although bacteria are not found in the chocolate products you eat, bacteria are used to break down the covering of cocoa beans during the production of cocoa. Bacteria also are responsible for the commercial production of vitamins, such as vitamin B12 and riboflavin.

Bacteria are important in the fields of medicine and research. Although some bacteria cause disease, others are useful in fighting disease. Streptomycin, bacitracin, tetracycline, and vancomycin are commonly prescribed antibiotics that were originally made by bacteria.

Get It?

Describe examples that show that bacteria are the dominant life forms on Earth.

Disease-causing bacteria

Only a small percentage of bacteria cause disease. Some of the diseases caused by bacteria are listed in **Table 1**. The small percentage of bacteria that cause disease do so in two ways. Some bacteria multiply quickly at the site of infection before the body's defense systems can destroy them. In cases of serious infections, bacteria then might spread to other parts of the body.

Other bacteria secrete a toxin or other substance that might cause harm. The bacteria that cause botulism secrete a toxin that paralyzes cells in the nervous system. Bacteria that cause cavities in teeth use sugar in the mouth for energy and in turn secrete acids that erode the teeth.

Bacteria also can cause disease in plants, and most plants can become infected. Such infections can destroy entire crops and have long-ranging consequences on local ecosystems. For example, citrus canker, a bacterial disease that kills orange trees, has severely impacted the Florida citrus crop and prompted eradication programs.

Table 1

Human Bacterial Diseases

Category	Disease
Sexually transmitted diseases	Syphilis, gonorrhea, chlamydia
Respiratory diseases	Strep throat, pneumonia, whooping cough, tuberculosis, anthrax
Skin diseases	Acne, boils, infections of wounds or burns
Digestive tract diseases	Gastroenteritis, many types of food poisoning, cholera
Nervous system diseases	Botulism, tetanus, bacterial meningitis
Other diseases	Lyme disease, typhoid fever

Check Your Progress

Summary

- Many scientists think that prokaryotes were the first organisms on Earth.
- Prokaryotes belong to two domains.
- Most prokaryotes are beneficial.
- Prokaryotes have a variety of survival mechanisms.
- Some bacteria cause disease.

Demonstrate Understanding

1. **Diagram** a bacterium.
2. **Discuss** possible rationales that taxonomists might have used when deciding to group prokaryotes into two distinct domains instead of in one group.
3. **Explain** survival mechanisms of bacteria at both the individual and population levels.
4. **List** three ways bacteria are beneficial to humans.

Explain Your Thinking

5. **Analyze** the difficulty in understanding the diversity in prokaryotes compared to plants and animals.
6. **MATH Connection** Imagine that today at 1 p.m., a single *Salmonella* bacterial cell landed on potato salad sitting on your kitchen counter. Assuming your kitchen provides an optimal environment for bacterial growth, how many bacterial cells will be present at 3 p.m. today?

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LESSON 2

VIRUSES AND PRIONS

FOCUS QUESTION

How are viruses classified? Are they alive?

Viruses

Although some viruses are not harmful, other viruses are known to infect and harm all types of living organisms. A **virus** is a nonliving strand of genetic material within a protein coat. Most biologists don't consider viruses to be living because they do not exhibit all of the characteristics of life. Viruses have no organelles to take in nutrients or use energy, they cannot make proteins, they cannot move, and they cannot replicate on their own. In humans, some diseases, such as those listed in **Table 2**, are caused by viruses. Just as there are some bacteria that cause sexually transmitted disease, some viruses can cause sexually transmitted diseases—such as genital herpes and acquired immune deficiency syndrome (AIDS). These viruses can be spread through sexual contact.

Virus size

Viruses are some of the smallest disease-causing structures that are known. They are so small that powerful electron microscopes are needed to study them. Most viruses range in size from 5 to 300 nanometers (a nanometer is one billionth of a meter). It would take about 10,000 cold viruses to span the period at the end of this sentence.

Table 2

Human Viral Diseases

Category	Disease
Sexually transmitted diseases	AIDS (HIV), genital herpes
Childhood diseases	Measles, mumps, chicken pox
Respiratory diseases	Common cold, influenza
Skin diseases	Warts, shingles
Digestive tract diseases	Gastroenteritis
Nervous system diseases	Polio, viral meningitis, rabies
Other diseases	Smallpox, hepatitis

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 viruses. Evaluate your source and communicate your findings to your class.

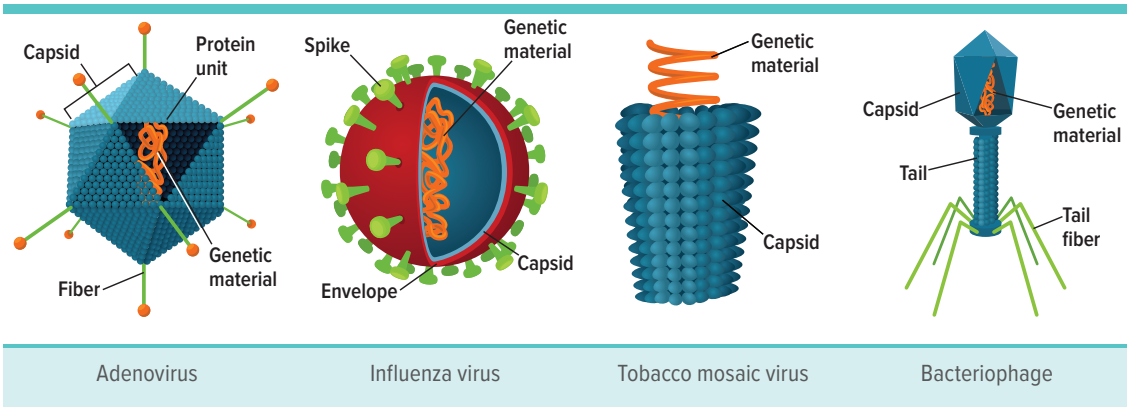


Figure 11 Viruses have several different types of arrangements, but all viruses have at least two parts: an outer capsid portion made of proteins and genetic material.

Virus origin

Although the origin of viruses is not known, scientists have several hypotheses about how viruses evolved. One idea, now considered to be the most likely, is that viruses came from parts of cells. Scientists have found that the genetic material of viruses is similar to cellular genes. These genes somehow developed the ability to exist outside of the cell.

Virus structure

Figure 11 shows the structures of adenovirus, influenza virus, bacteriophage, and tobacco mosaic virus. Adenovirus infection causes the common cold, and influenza virus is responsible for causing the flu. A virus that infects bacteria is called a bacteriophage (bak TIHR ee uh fayj). Tobacco mosaic virus causes disease in tobacco leaves. The outer layer of all viruses is made of proteins and is called a **capsid.** Inside the capsid is the genetic material, which could be DNA or RNA, but never both. Viruses generally are classified by the type of nucleic acid they contain.

HISTORY Connection The virus that causes smallpox is a DNA virus. Outbreaks of smallpox have occurred in the human population for thousands of years. A successful program of worldwide vaccination eliminated the disease, and routine vaccination was stopped. For a closer look at the history of the discovery of the virus that causes smallpox and smallpox vaccination, examine **Figure 12** on the next page.

Viral Infection

To replicate, a virus must enter a host cell. The virus attaches to the host cell using specific receptors on the plasma membrane of the host. Different types of organisms have receptors for different types of viruses, which explains why many viruses cannot be transmitted between different species.

Once the virus successfully attaches to a host cell, the genetic material of the virus enters the cytoplasm of the host. In some cases, the entire virus enters the cell and the capsid is broken down quickly, exposing the genetic material. The virus then uses the host cell to replicate by either the lytic cycle or the lysogenic cycle.

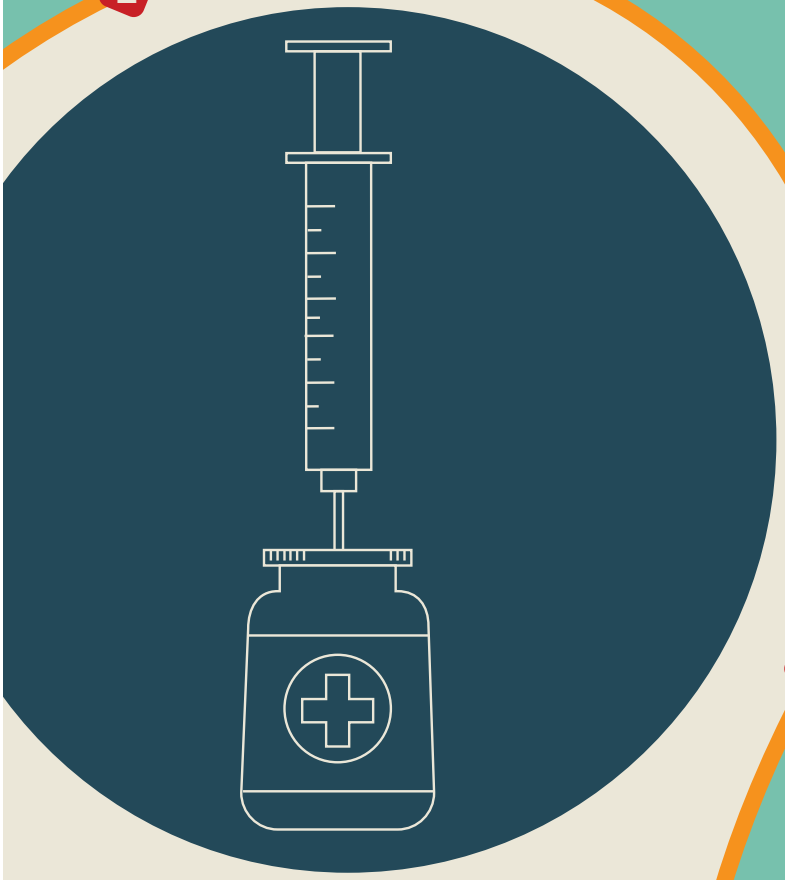


Figure 12

The History of Smallpox

Though it has been eradicated, smallpox has been an important and deadly disease throughout history.

1 **1157 B.C.** Smallpox kills Egyptian Pharaoh Ramses V. Two centuries earlier, Egyptian prisoners caused the first known smallpox epidemic when they were captured by the Hittites in Syria.

2 **1017** A hermit in China introduces mild cases of smallpox into humans to build immunity (variolation).

3 **1519** Hernando Cortes and his crew spread smallpox to Mexico, which decimates the Aztec population.

4 **1717** Mary Wortley Montagu introduces variolation to England after observing the technique in Turkey.

5 **1796** Edward Jenner develops a smallpox vaccine from cowpox pustules.

6 **1959** The World Health Organization adopts a plan to eradicate smallpox. Eight years later, freeze-dried vaccines become available.

7 **1977** The last case of smallpox occurs in Somalia.

8 **1980** On May 8, 1980, the World Health Organization declares that the world is free of smallpox, a devastating disease.

Lytic cycle

In the **lytic cycle,** illustrated in **Figure 13**, on the next page. the host cell makes many copies of the viral RNA or DNA. The viral genes instruct the host cell to make more viral protein capsids and enzymes needed for viral replication. The protein coat forms around the nucleic acid of new viruses. These new viruses leave the cell by exocytosis or by causing the cell to burst, or lyse, releasing new viruses that are free to infect other cells. Viruses that replicate by the lytic cycle often produce active infections. Active infections usually are immediate, meaning that symptoms of the illness caused by the virus start to appear one to four days after exposure. The common cold and influenza are two examples of widespread viral diseases that are active infections.

Lysogenic cycle

In some cases, the viral DNA might enter the nucleus of the host cell. In the **lysogenic cycle,** also illustrated in **Figure 13**, the viral DNA inserts, or integrates, into a chromosome in a host cell. Once integrated, the infected cell will have the viral genes permanently. The viral genes might remain dormant for months or years. Then, at some future time, the viral genes might be activated by many different factors. Activation results in the lytic cycle. The viral genes instruct the host cell to manufacture more viruses. The new viruses will leave the cell by exocytosis or by causing the cell to lyse.

Many disease-causing viruses have lysogenic cycles. Herpes simplex I is an example of a virus that causes a latent infection. This virus is transmitted orally, and a symptom of this infection is cold sores. When the viral DNA enters the nucleus, it is inactive. It is thought that during times of stress, whether physical, emotional, or environmental, the herpes genes become activated and the production of viruses occurs.

Retroviruses

Some viruses have RNA instead of DNA for their genetic material. This type of virus is called a **retrovirus** and has a complex replication cycle. The best-known retrovirus is the human immunodeficiency virus (HIV), which is the viruses that causes AIDS. Some cancer-causing viruses also belong to this group.

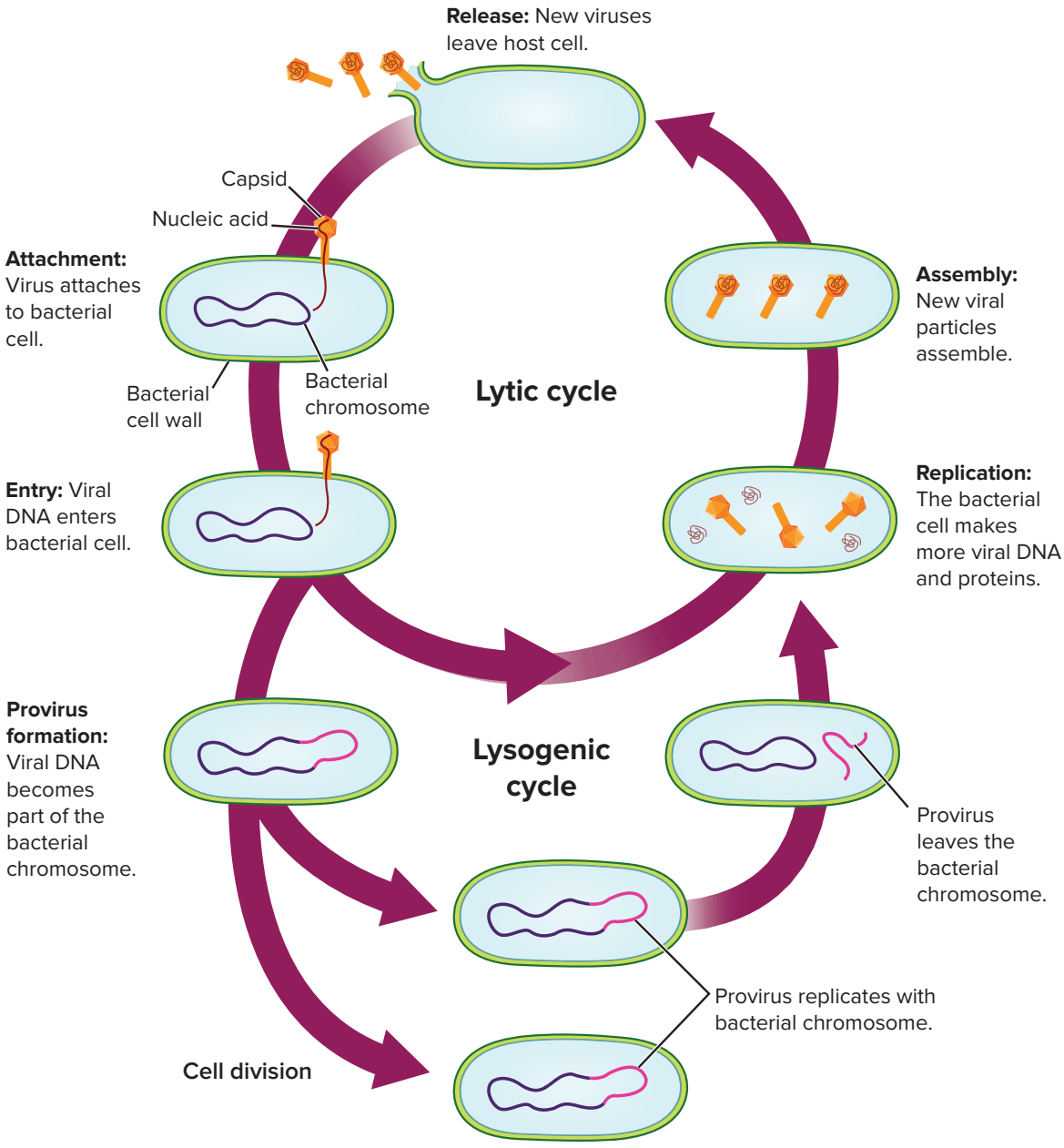
Figure 14, on page 466, shows the structure of HIV. Like all viruses, retroviruses have a protein capsid. Surrounding the capsid is a lipid envelope, which was obtained from the plasma membrane of a host cell. RNA and an enzyme called reverse transcriptase are in the core of the virus. Reverse transcriptase is the enzyme that transcribes DNA from the viral RNA.

Refer to **Figure 14** as you learn about the replication cycle of HIV. When HIV attaches to a cell, the virus moves into the cytoplasm of the host cell and the viral RNA is released. Reverse transcriptase synthesizes DNA using the viral RNA as a template. Then, the DNA moves into the nucleus of the host cell and integrates into a chromosome. The viral DNA might lie inactive for a period of years before it is activated. Once it is activated, RNA is transcribed from the viral DNA, and the host cell manufactures and assembles new HIV particles.

Figure 13 Visualizing Viral Replication

In the lytic cycle, the entire replication process occurs in the cytoplasm. The viruses' genetic material enters the cell, and the cell replicates the viral RNA or DNA. The viral genes instruct the host cell to manufacture capsids and assemble new viral particles. The new viruses then leave the cells.

In the lysogenic cycle, the viral DNA inserts into a chromosome of the host cell. Many times, the genes are not activated until later. Then, the viral DNA instructs the host cell to make more viruses.



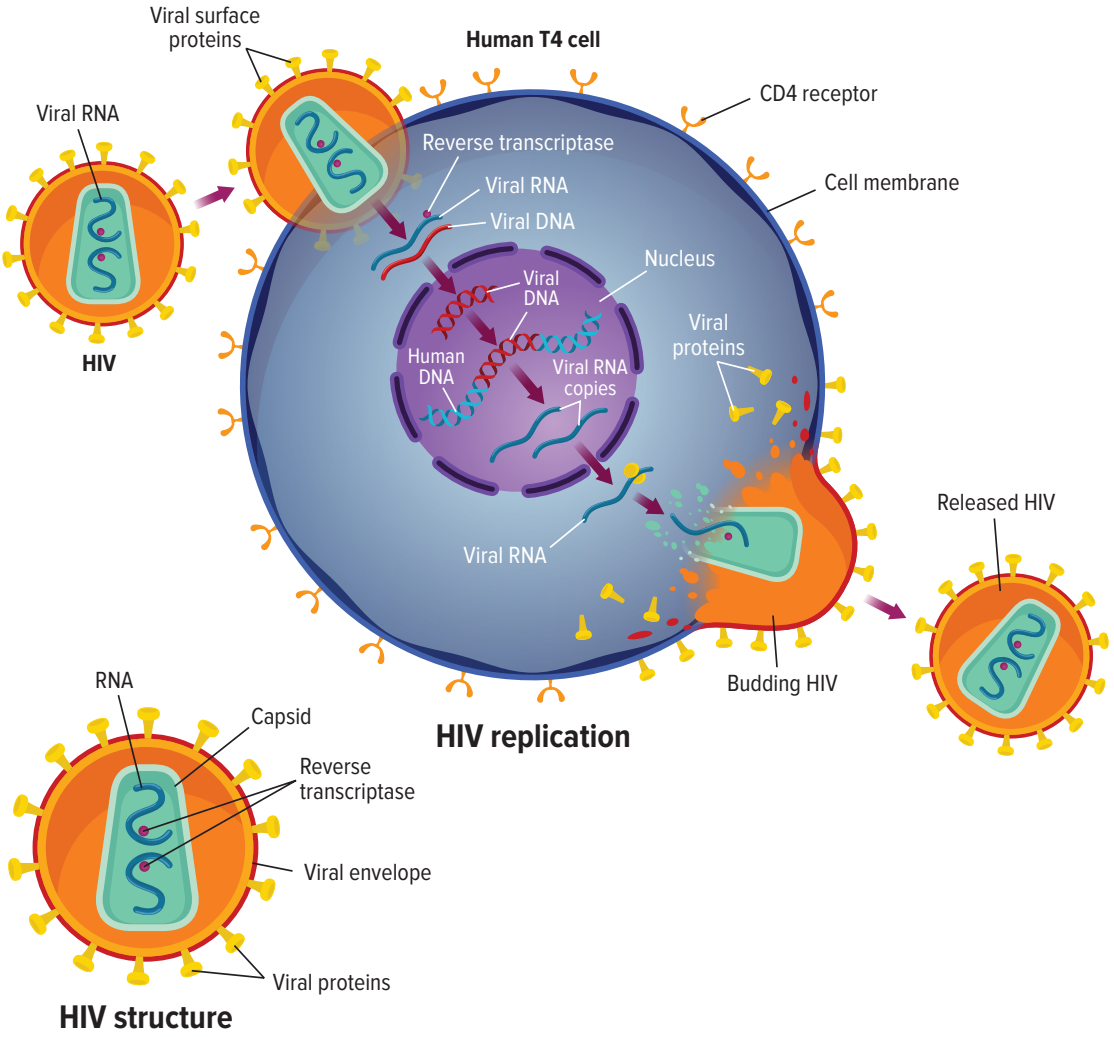


Figure 14 The genetic material and replication cycle of a retrovirus, such as HIV, is different from that of DNA viruses.

Infer *what is unique about the function of reverse transcriptase.*

Prions

A protein that can cause infection or disease is called a proteinaceous (pro te NAY shuhs) infectious particle, or a **prion** (PREE ahn). Although diseases now believed to be caused by prions have been studied for decades, they were not well understood until 1982, when Stanley B. Prusiner first identified that the infectious particle was a protein.

Prions normally exist in cells, although their function is not well understood. Normal prions are shaped like a coil. Mutations in the genes that code for these proteins occur, causing the proteins to be misfolded. Mutated prions are shaped like a piece of paper folded many times. Mutated prions are associated with diseases known as transmissible spongiform encephalopathies (SPUN gee form • in SEH fuh la pah thees) (TSE). Examples of diseases caused by prions include mad cow disease in cattle, Creutzfeldt-Jakob disease (CJD) in humans, scrapie (SKRAY pee) in sheep, and chronic wasting disease in deer and elk.

Prion infection

Figure 15 shows the size of a normal brain compared with the size of a brain infected with prions. In CJD, prions cause damage that shrinks the brain. What scientists find fascinating about these misfolded proteins is that these prions can cause normal proteins to mutate. These prions infect nerve cells in the brain, causing them to burst. This results in spaces in the brain, hence the description of spongiform (spongelike) encephalopathy (brain disease).

In the mid-1980s, a new variant of CJD, or nvCJD, was discovered in England. Scientists do not fully agree on the origin of nvCJD, but a leading hypothesis is that the prions are transmitted from cattle. Abnormal prions can be found in the brains and spinal cords of cattle. The hypothesis is that if the spinal cord is cut in the butchering process, the prions might contaminate the meat and then be transmitted to humans that eat the beef. Although this mode of transmission is not agreed upon, the United States government has strict regulations concerning the importation of cattle and beef from other countries.

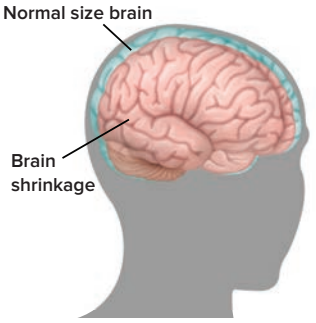


Figure 15 Here, the size of a normal brain compared with the size of a brain of a patient with CJD.

Check Your Progress

Summary

- Viruses have a nucleic acid core and a protein-containing coat.
- Viruses are classified by their genetic material.
- Viruses have three different patterns of replication.
- Many viruses cause disease.
- Proteins called prions also might cause disease.

Demonstrate Understanding

1. **Describe** how viruses and prions can alter cell functions.
2. **Compare and contrast** similarities and differences in the replication of a herpes simplex virus with a human immunodeficiency virus.
3. **Draw** a diagram of a virus and label the parts.
4. **Sequence** the steps in the process of how prions might be transmitted from cattle to humans.

Explain Your Thinking

5. **Propose** ideas for the development of drugs that could stop viral replication cycles.
6. WRITING Connection **Write** a paragraph explaining why it is difficult to make drugs or vaccines that effectively fight against HIV, given the fact that each time reverse transcriptase works, it makes a slight miscopy.

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NATURE OF SCIENCE

Solving Big Mysteries – Giant Viruses

Viruses have long been described as small and simple. Wrap a protein envelope around a bit of genetic material and you have a typical virus. These viruses do not perform any functions of life. They must hijack the machinery of a host cell to replicate their genetic material and build their protein envelopes.

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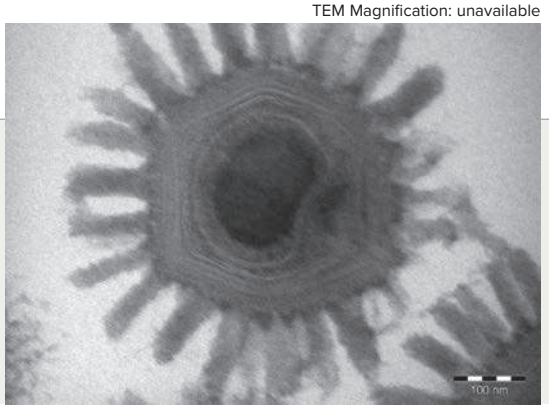


This is a transmission electron micrograph (TEM) of a giant Mimivirus, which is the largest known virus.

The Discovery of Giant Viruses

Scientists have discovered giant viruses that are larger and more complex than many bacteria. As early as 2003, researchers reported giant viruses named Mimiviruses, like that shown in the figure. They contain genes for making their own proteins, which suggests they evolved from ancestors that could live independently – without a host cell.

In 2017, Klosneuviruses were "accidentally" discovered by researchers in Austria who were studying how bacteria break down sewage in treatment plants. The genetic material in these viruses also contains codes for enzymes and other components used to make proteins. Some of these genes had never been seen in viruses before – not even in Mimiviruses.

The Evolution of Giant Viruses

These discoveries have reopened debates about the nature of viruses. What is the origin of viruses? Did giant viruses acquire genes from host cells? Did viruses originally contain more complete genomes, similar to living organisms, which have been parsed into the smaller fragments as seen in most viruses today? Should viruses be classified in their own domain in the tree of life?

In an effort to answer these questions, some scientists are using computer models to try to trace the evolutionary history of the genomes. One model suggests that the genes of giant viruses were acquired one by one from hosts over millions of years. However, others warn that more evidence and modeling is needed to settle the debate on the origin and evolution of giant viruses.

APPLY SCIENTIFIC EVIDENCE AND REASONING

Use an online search engine to read more about the original research describing the two types of giant viruses. Using evidence and reasoning, write an essay about why or why not scientists should reconsider their classification in the tree of life.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 BACTERIA

- Many scientists think that prokaryotes were the first organisms on Earth.
- Prokaryotes belong to two domains.
- Most prokaryotes are beneficial.
- Prokaryotes have a variety of survival mechanisms.
- Some bacteria cause disease.

- bacteria
- nucleiod
- capsule
- pilus
- binary fission
- conjugation
- endospore

Lesson 2 VIRUSES AND PRIONS

- Viruses have a nucleic acid core and a protein-containing coat.
- Viruses are classified by their genetic material.
- Viruses have three different patterns of replication.
- Many viruses cause disease.
- Proteins called prions also might cause disease.

- virus
- capsid
- lytic cycle
- lysogenic cycle
- retrovirus
- prion

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

What is alive in this photo?

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

Is protein or DNA the genetic material?

In 1952, Alfred Hershey and Martha Chase designed experiments to find out whether protein or DNA provides genetic information. Hershey and Chase labeled the DNA of bacteriophages—viruses that infect bacteria—with a phosphorus isotope and the protein in the capsid with a sulfur isotope. The bacteriophages were allowed to infect the bacteria *E. coli.*

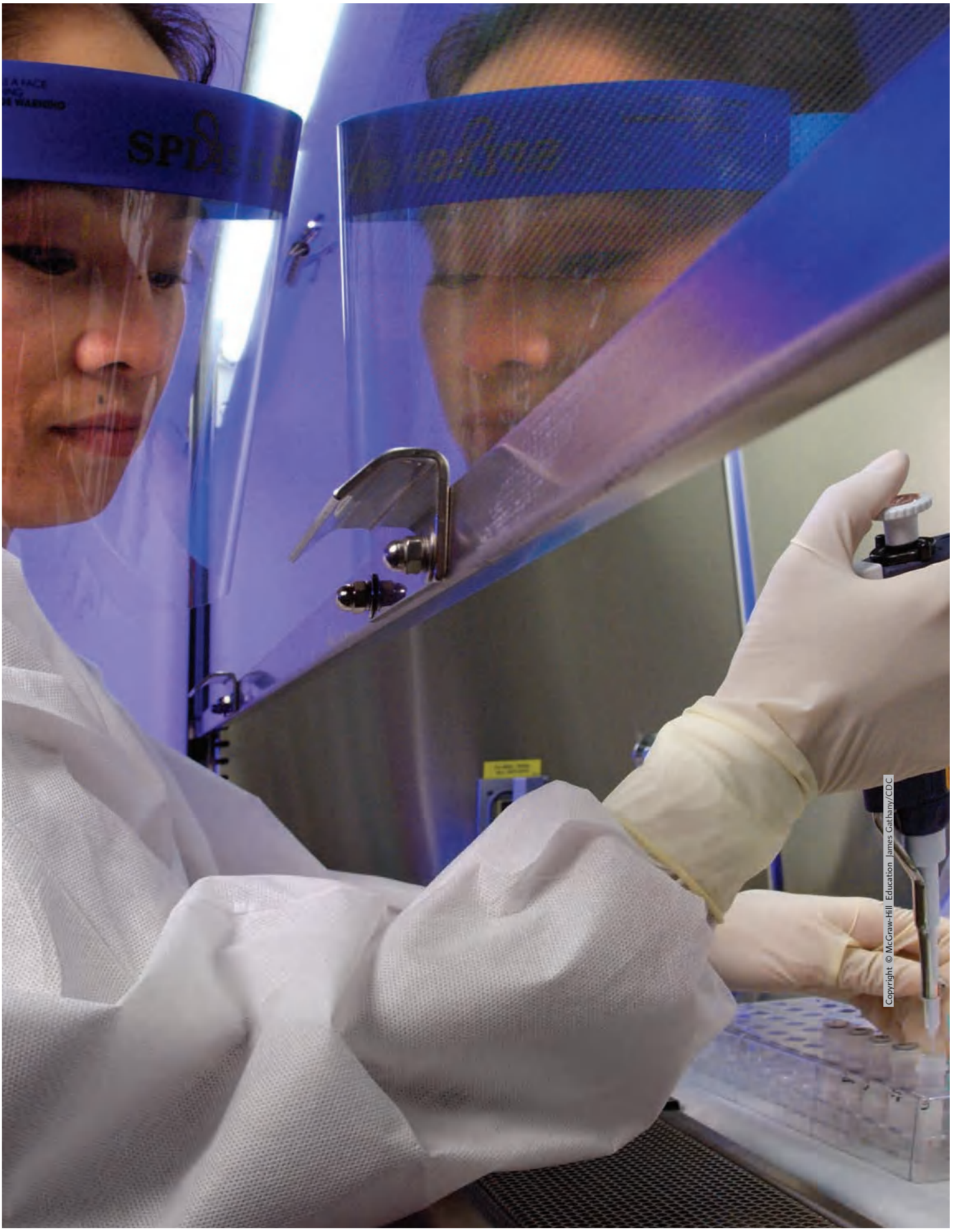
Data and Observations

- At least 80 percent of the sulfur-containing proteins stayed on the surface of the host cell.
- Most of the viral DNA entered the host cell upon infection.
- After replication inside the host cell, 30 percent or more of the copies of the virus contained radioactive phosphorus.

CER Analyze and Interpret Data

1. **Claim, Reasoning** Do the results of these experiments support the idea that proteins are the genetic material or DNA is the genetic material? Explain.
2. **Reasoning** If proteins and DNA had entered the cell, would these data be useful to answer Hershey and Chase's question?

*Data obtained from: Hershey, A.D. and Chase, M. 1952. Independent functions of viral protein and nucleic acid in growth of bacteriophage. *Journal of General Physiology* 36: 39–56.



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.

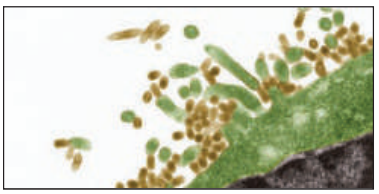
CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about why this scientist would need all this protection. Explain your reasoning.

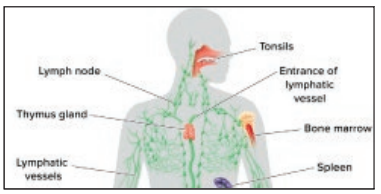
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

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.

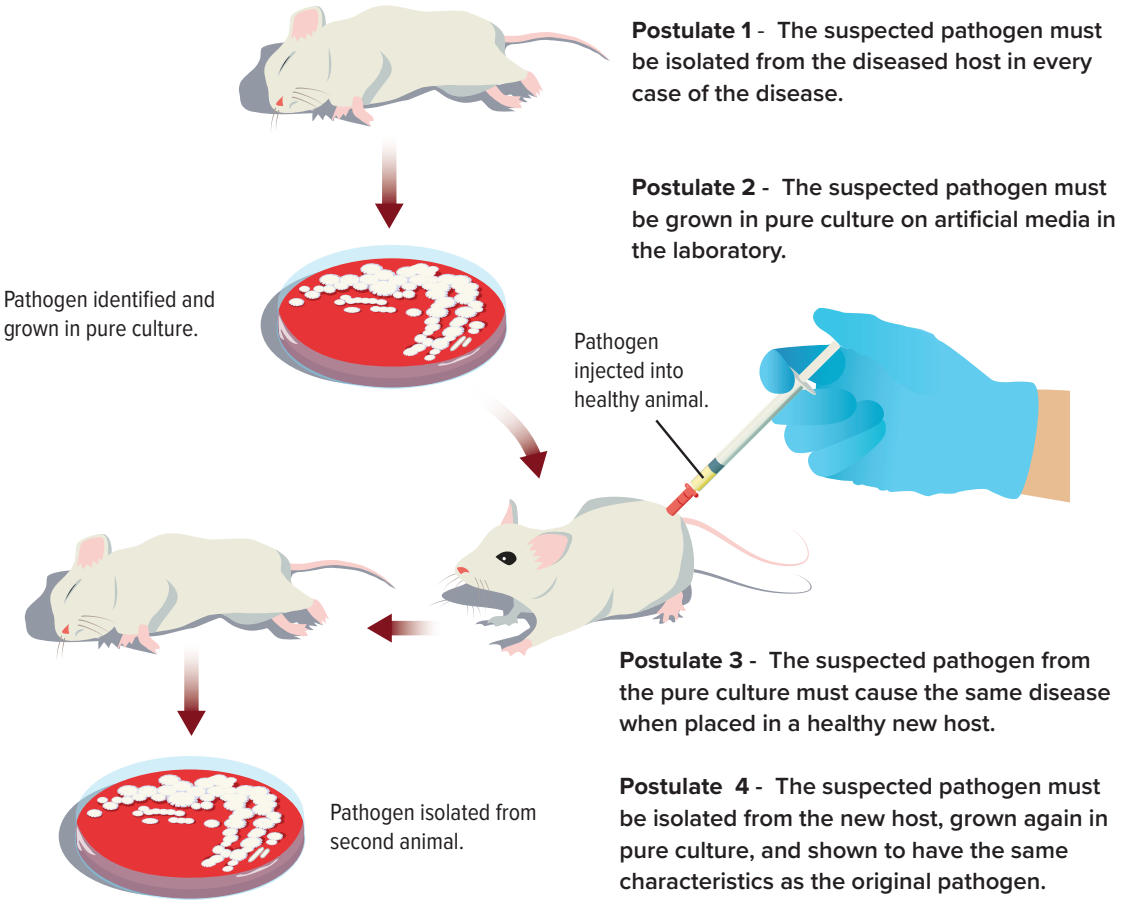


Figure 2 Koch's postulates demonstrate that a specific pathogen causes a specific disease.

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.

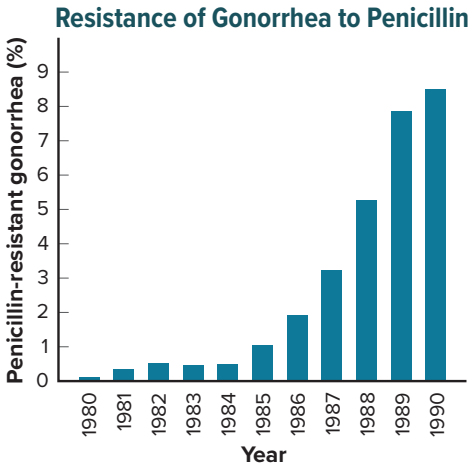


Figure 7 The graph shows the reported incidence of penicillin-resistant gonorrhea in the U.S. from 1980–1990.

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**.

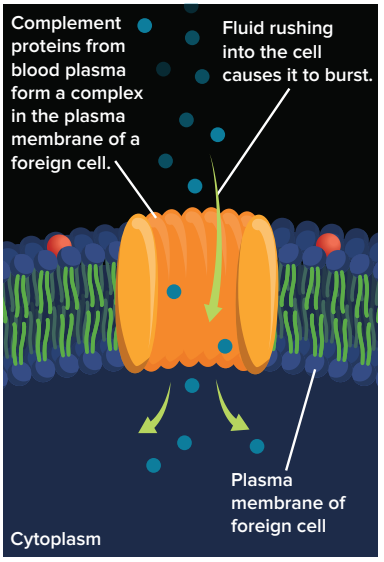


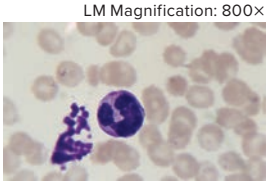
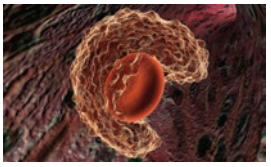
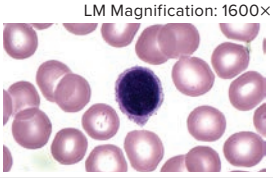
Figure 9 For some pathogens, complement proteins can form a pore in the plasma membrane of the invading cell.

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.

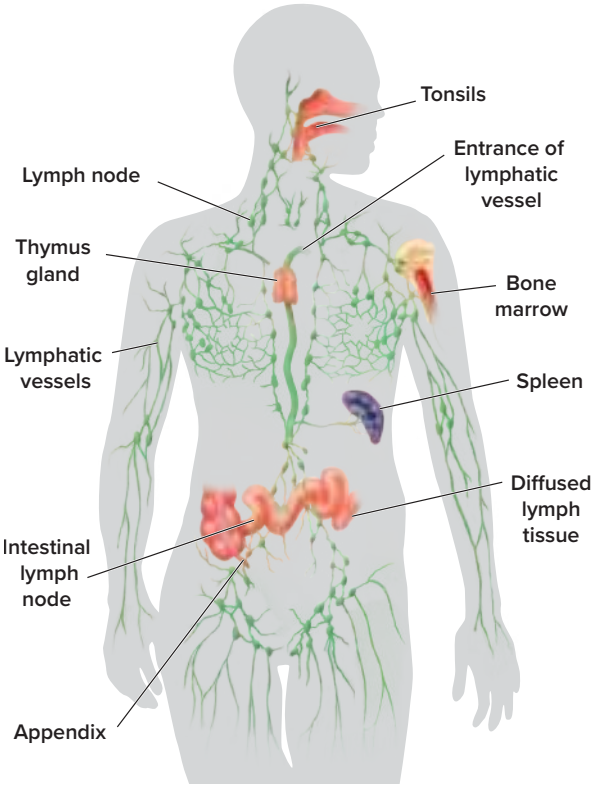


Figure 10 The lymphatic system contains the organs involved in the specific immune response.

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.

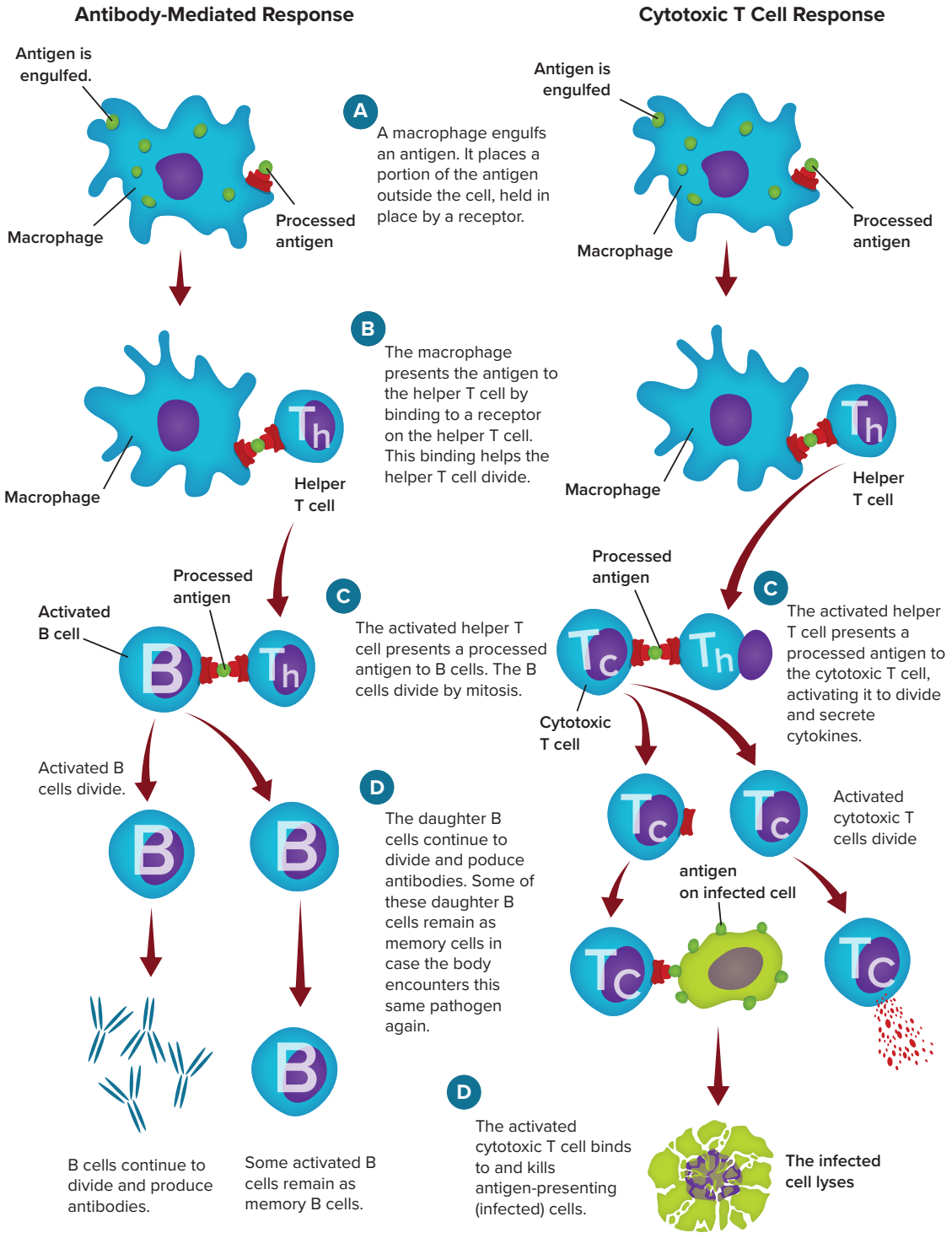
WORD ORIGIN

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).

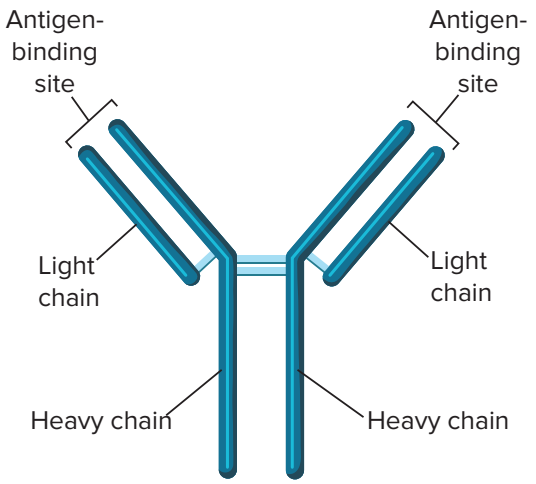


Figure 12 Antibodies are made up of two types of protein chains—heavy and light chains.

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.

Get It?

Analyze how immunizations help prevent disease.

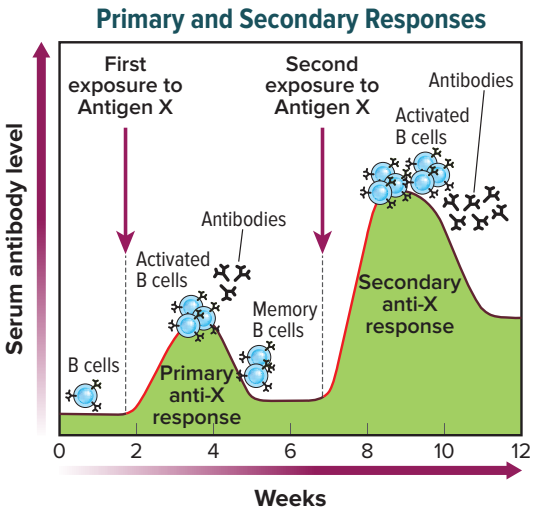


Figure 13 This graph shows the difference between the primary and secondary immune responses to exposure to an antigen.

Analyze *the differences between the primary and secondary immune responses.*

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.

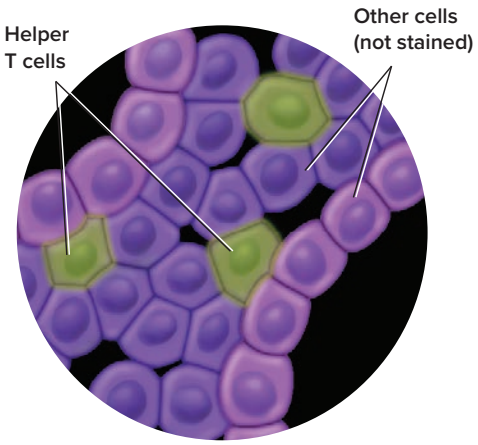


Figure 14 Helper T cells have receptors on the surface that are used to identify them in the laboratory.

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.

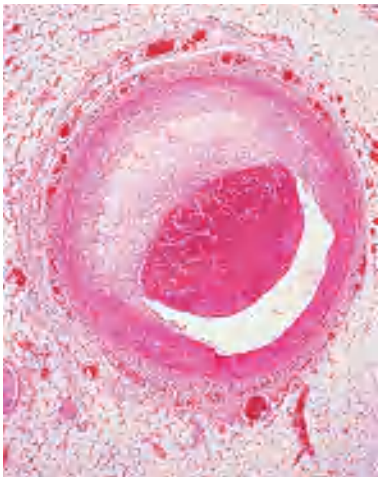


Figure 15 When blood cannot flow through a coronary artery, such as the diseased artery shown here, a heart attack or sudden death can result.

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.

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.

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.

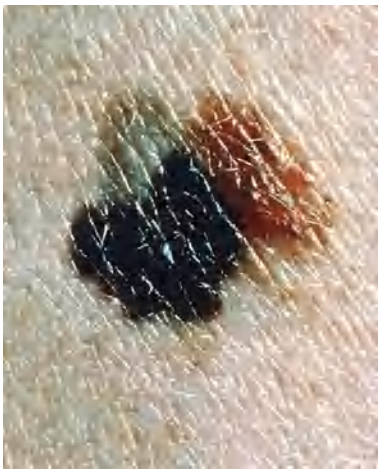


Figure 16 Cancer is due to an abnormal increase in cell division in the body, resulting in a tumor such as this skin tumor.

Infer *why this growth is so life-threatening.*

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.

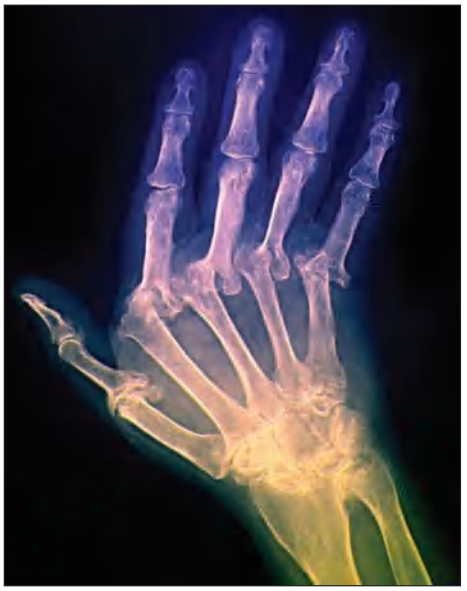


Figure 17 The large knobs and deformaties of these fingers are due to rheumatoid arthritis, an autoimmune disease.

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

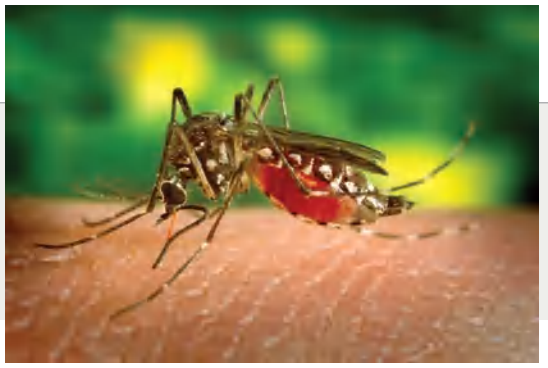
5. **Hypothesize** several causes of chronic bronchitis (inflammation of the bronchioles) found in coal miners.
6. **Create** a plan that limits a child's exposure to cat dander when the child is found to be allergic to that allergen.
7. **WRITING Connection** Create a pamphlet listing common allergens 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?

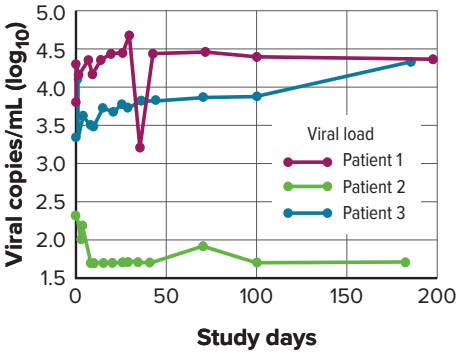
The standard treatment for a patient with an HIV infection is antiviral drug therapy. Unfortunately, the side effects and increasing prevalence of drug-resistant viruses create a need for additional therapies. One area being studied is passive immune therapy.

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.

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.

Patient Response



*Data obtained from: Stiegler G., et al. 2002. Antiviral activity of the neutralizing antibodies 2FS and 2F12 in asymptomatic HIV-1-infected humans: a phase I evaluation. *AIDS* 16: 2019–2025.

DIGESTIVE AND ENDOCRINE SYSTEMS

ENCOUNTER THE PHENOMENON

Why do we need a variety of foods in our diet?

SEP Ask Questions

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

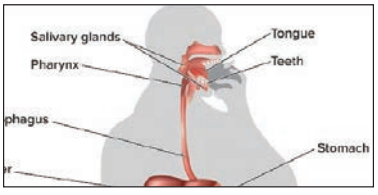
CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about why we need a variety of foods in our diet. Explain your reasoning.

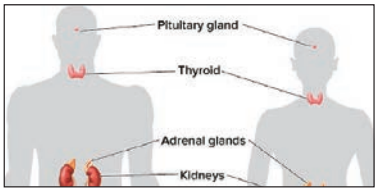
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

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 Digestive System



LESSON 3: Explore & Explain: The Endocrine System

LESSON 1

THE DIGESTIVE SYSTEM

FOCUS QUESTION

What are the structures and functions of the digestive system?

Functions of the Digestive System

There are three main functions of the digestive system. The digestive system ingests food, breaks it down so nutrients can be absorbed, and eliminates what cannot be digested. Refer to **Figure 1** below and **Figure 2** on the next page as you learn about the structure and function of the digestive system.

Digestion

Mechanical digestion involves chewing food to break it down into smaller pieces. It also includes the action of smooth muscles in the stomach and small intestine that churn the food. **Chemical digestion** involves the breakdown of large molecules in food into smaller substances by enzymes, proteins that speed up chemical reactions. The smaller substances are absorbed into the body's cells. When you chew food, **amylase,** an enzyme in saliva, begins the process of chemical digestion by breaking down starches into sugars.

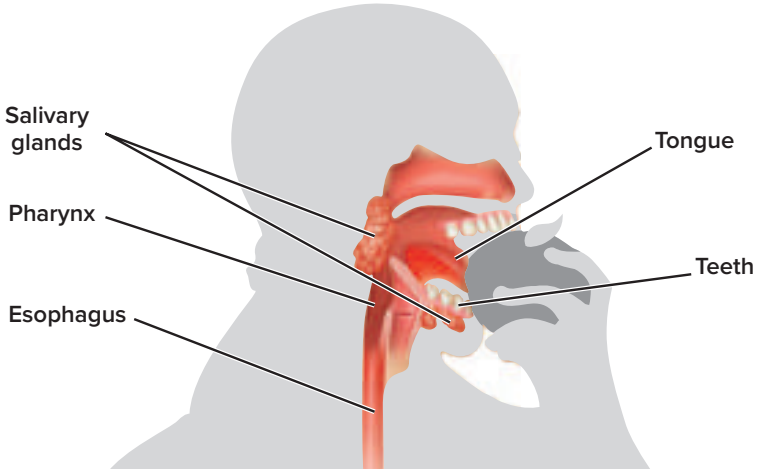


Figure 1 Mechanical digestion starts in the mouth. Secretions from the salivary glands keep food moist and begin the process of chemical digestion. Food moves through the pharynx into the esophagus.

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 does the rate of starch digestion compare among crackers?
Plan and carry out an investigation to determine the amount of time needed for starch to digest.

Virtual Investigation: The Digestive and Endocrine Systems
Use a model to determine the effect a healthy diet has on the digestive and endocrine systems.

Esophagus

When the tongue pushes chewed food to the back of the mouth, the swallowing reflex is stimulated. The food is forced by the action of the tongue into the upper portion of the esophagus. The **esophagus** (ih SAH fuh gus) is a muscular tube that connects the pharynx, or throat, to the stomach, as illustrated in **Figure 2**. The wall of the esophagus is lined with smooth muscles that contract rhythmically to move the food through the digestive system in a process called **peristalsis** (per uh STAHL sus). Peristalsis continues throughout the digestive tract. Even if a person were upside down, food would still move toward the stomach.

When a person swallows, the small plate of cartilage called the epiglottis covers the trachea. If this opening is not closed, food can enter the trachea and cause a person to choke. The body responds to this by initiating the coughing reflex in an attempt to expel the food to keep the food from entering the lungs.

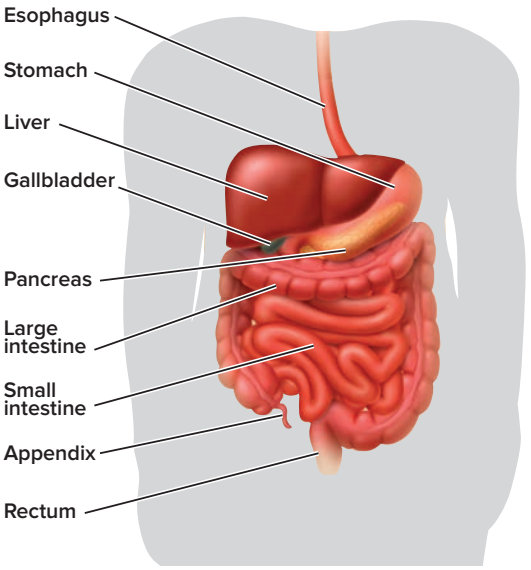


Figure 2 The human digestive system is made up of numerous parts, including the esophagus, which extends from the pharynx to the stomach and is approximately 25 cm long.

Get It?

Explain the importance of peristalsis to digestion.

Stomach

When food leaves the esophagus, it passes through a circular muscle called a sphincter, and into the stomach. The sphincter between the esophagus and stomach is the cardiac sphincter. The walls of the stomach are composed of three overlapping layers of smooth muscle that are involved with mechanical digestion. As the muscles contract, they further break down the food and mix it with the secretions of glands that line the inner wall of the stomach.

CHEMISTRY Connection Recall that pH is a measure of a solution's acidity. The environment inside the stomach is very acidic. Stomach glands, called gastric glands, secrete an acidic solution, which lowers the pH in the stomach to about 2. This is about the same level of acidity as lemon juice. If the sphincter in the upper portion of the stomach allows any leakage, some of this acid might move back into the esophagus, causing what is commonly known as heartburn.

The acidic environment in the stomach is favorable to the action of **pepsin,** an enzyme involved in the process of the chemical digestion of proteins. Cells in the lining of the stomach secrete mucus to help prevent damage from pepsin and the acidic environment. Although most absorption occurs in the small intestine, some substances, such as alcohol and aspirin, are absorbed by cells that line the stomach. While empty, the capacity of the stomach is about 50 mL. When full, it can expand to 2–4 L.

Get It?

Explain how both mechanical and chemical digestion occur in the stomach.

The muscular walls of the stomach contract and push food farther along the digestive tract. As the result of chemical and mechanical digestion in the stomach, the consistency of the food resembles tomato soup as it passes through the pyloric sphincter at the lower end of the stomach into the small intestine.

Get It?

Compare digestion in the mouth with digestion in the stomach.

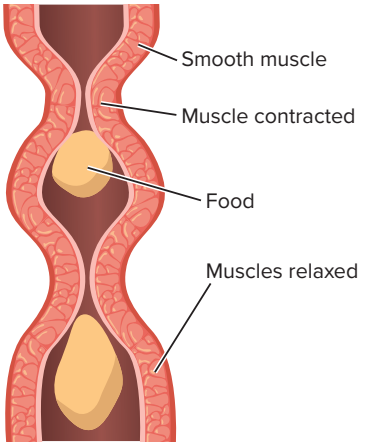


Figure 3 The smooth muscles in the walls of the digestive tract contract in the process of peristalsis.

Small intestine

The **small intestine** is approximately 7 m in length and is the longest part of the digestive tract. It is called small because its diameter is 2.5 cm compared to the 6.5 cm diameter of the large intestine. The smooth muscles in the wall of the small intestine continue the process of mechanical digestion and push the food farther through the digestive tract by peristalsis, as shown in **Figure 3.**

The completion of chemical digestion in the small intestine depends on three accessory organs—the pancreas, liver, and gallbladder, as illustrated in **Figure 4**. The pancreas serves two main functions. One is to produce enzymes that digest carbohydrates, proteins, and fats. The other is to produce hormones, which will be discussed later in this module. The pancreas secretes an alkaline fluid to raise the pH in the small intestine to slightly above 7, which creates a favorable environment for the action of intestinal enzymes.

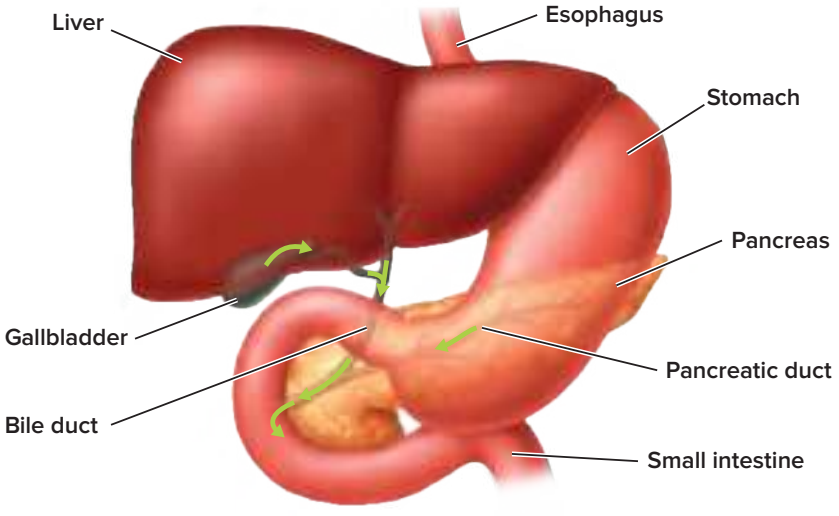


Figure 4 Chemical digestion in the small intestine depends on the activities of the liver, pancreas, and gallbladder.

Discuss *the importance of each of these organs in the process of chemical digestion.*

The **liver** is the largest internal organ of the body and produces bile, which helps to break down fats. About 1 L of bile is produced every day, and excess bile is stored in the gallbladder to be released into the small intestine when needed. **Figure 5** shows gallstones, which are cholesterol crystals that can form in the gallbladder.

Figure 5 Gallstones can obstruct the flow of bile from the gallbladder. Gallstones can be removed through surgery.

Chemical digestion is completed and most of the nutrients from food are absorbed from the small intestine into the bloodstream through fingerlike structures called **villi** (VIH li) (singular, villus). Villi, shown in **Figure 6**, increase surface area, giving the small intestine approximately the same surface area as a tennis court.

Refer again to **Figure 1** and **Figure 2** to follow the movement of digested food through the digestive system. Once digestion is complete, the remaining food, now in a semiliquid form called chyme (KIME), moves into the large intestine. Chyme is made up of materials that cannot be digested or absorbed by villi in the small intestine.

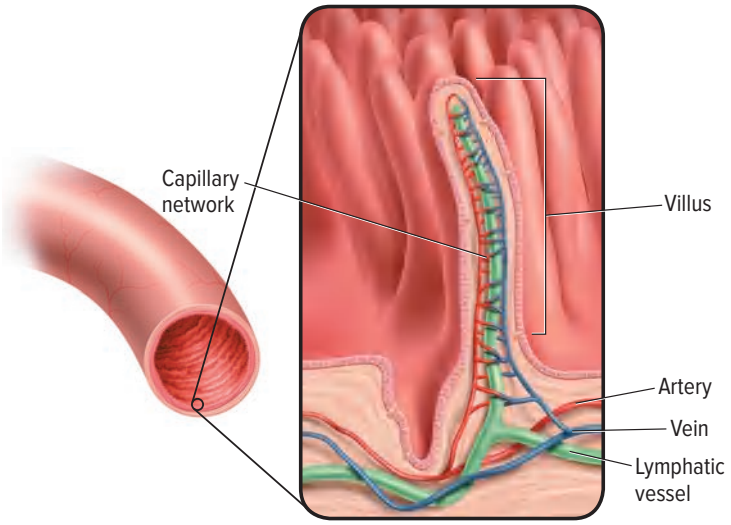


Figure 6 A villus is a fingerlike extension of the lining of the small intestine. Nutrients diffuse into capillaries in the villi and reach body cells by means of circulating blood.

STUDY TIP

Sequence and Order Using your notes, work with a partner to review the functions of the organs in the digestive system. Ask questions of one another for deeper learning.

CCC CROSSCUTTING CONCEPTS

Systems and Systems Models With a partner, review the information about the structures of the digestive system. Then, work with your partner to develop a model, such as a flow chart, to describe how matter flows within the digestive system.

Table 1 Time for Digestion

Digestive Structure	Primary Function	Time Food is in Structure
Mouth	Mechanical and chemical digestion	5–30 s
Esophagus	Transport (swallowing)	10 s
Stomach	Mechanical and chemical digestion	2–24 h
Small Intestine	Mechanical and chemical digestion	3–4 h
Large Intestine	Water absorption	18 h–2 days

Large intestine

The **large intestine** is the end portion of the digestive tract. It is about 1.5 m long and includes the colon, the rectum, and a small saclike appendage called the appendix. The appendix has no known function. Some kinds of beneficial bacteria are normal in the colon. These bacteria produce vitamin K and some B vitamins.

A primary function of the colon is to absorb water from the chyme. The indigestible material then becomes more solid and is called feces. Peristalsis continues to move feces toward the rectum, causing the walls of the rectum to stretch. This initiates a reflex that causes the final sphincter muscle to relax, and the feces are eliminated from the body through the anus. Refer to **Table 1** to review the primary function of each structure of the digestive system and how long food usually remains in each structure as it is being digested.

Check Your Progress

Summary

- The digestive system has three main functions.
- Digestion can be categorized as mechanical or chemical.
- Most nutrients are absorbed in the small intestine.
- Accessory organs provide enzymes and bile to aid digestion.
- Water is absorbed from chyme in the colon.

Demonstrate Understanding

1. **Describe** the process that breaks down food so that nutrients can be absorbed by the body.
2. **Analyze** the difference between mechanical digestion and chemical digestion. Explain why chemical digestion is necessary for the body.
3. **Summarize** the main functions of the digestive system.
4. **Analyze** what the consequence might be if the lining of the small intestine were completely smooth instead of having villi.

Explain Your Thinking

5. **Explain** why the pH in the digestive system changes. Design an experiment to gather data about the effect of pH on the digestion of different types of food.
6. **MATH Connection** A can of carbonated beverage typically holds about 354 mL of fluid. Compare this amount with the volume of an empty stomach. Give a ratio.

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LESSON 2

NUTRITION

FOCUS QUESTION

How can you maintain a healthy and balanced diet?

Calories

Nutrition is the process by which a person takes in and uses food. Foods supply the building blocks and energy to maintain body mass. The daily input of energy from food should equal the amount of energy a person uses daily. A **Calorie** (with an uppercase C) is the unit used to measure the energy content of foods. A Calorie is equal to 1 kilocalorie, or 1000 calories (with a lowercase c). A calorie is the amount of heat needed to raise the temperature of 1 mL of water by 1°C.

The energy content of a food can be measured by burning the food and converting the stored energy to heat. Not all foods have the same energy content. The same mass of different foods does not always equal the same number of Calories. For example, one gram of carbohydrate or protein contains four Calories. One gram of fat contains nine Calories. To lose weight, more Calories must be used than consumed. The opposite is true to gain weight. **Table 2** compares average Calorie usage with different activities. The exact number of calories burned will vary depending on weight and gender.

Table 2 Activities and Average Calories Usage

Activity	Calories Used Per Hour	Activity	Calories Used Per Hour
Baseball	282	Hiking and backpacking	564
Basketball	564	Hockey (field and ice)	546
Bicycling	240–410	Jogging	740–920
Football	540	Soccer	540

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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.

Open Inquiry: The Human Body

Plan and carry out an investigation to determine the effect sugar has on mood.

Identify Crosscutting Concepts

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

Carbohydrates

Cereal, pasta, potatoes, strawberries, and rice all contain a high proportion of carbohydrates. Recall that sugars, such as glucose, fructose, and sucrose, are simple carbohydrates that are found in fruits, soda pop, and candy. Complex carbohydrates are macromolecules such as starches, which are long chains of sugars. Foods such as those in **Figure 7** have a high starch content, as do some vegetables.

Figure 7 Your body needs carbohydrate-rich foods like these every day.

Complex carbohydrates are broken down into simple sugars in the digestive tract. Simple sugars are absorbed through villi in the small intestine into the bloodstream and circulated throughout the body to provide energy for cells. Excess glucose is stored in the liver in the form of glycogen. Cellulose, sometimes called dietary fiber, is another complex carbohydrate found in plant foods. Although humans cannot digest fiber, it is important because fiber helps keep food moving through the digestive tract and helps with the elimination of wastes. Bran, whole-grain breads, and beans are good sources of fiber.

Get It?

Identify examples of carbohydrates shown in the photo at the beginning of the module.

Fats

In proper amounts, fats are an essential part of a healthful diet. Fats are the most concentrated energy source available to the body, and they are building blocks for the body. Fats also protect some internal organs and help maintain homeostasis by providing energy and by storing and transporting certain vitamins. However, not all fats are beneficial to the body.

HEALTH Connection Recall that fats, some of which are shown in **Figure 8**, are classified according to their chemical structure as saturated or unsaturated. Meats, cheeses, and other dairy products are sources of saturated fats. A diet high in saturated fats might result in high blood levels of cholesterol, which can lead to heart problems. Plants are the main source of unsaturated fats, which are not associated with the development of heart disease.

Figure 8 The oils here are sources of unsaturated fat. The butter is a source of saturated fat.

A general rule is that saturated fats are solid at room temperature and unsaturated fats are liquid at room temperature. The olive oil in **Figure 8** contains less saturated fat than the butter, which is why the olive oil is liquid at room temperature. Recall that, as matter moves through the body, chemical elements are recombined to form different products. Fats are digested in the small intestine and are broken down into fatty acids and glycerol. Fatty acids can be absorbed through the villi and circulated in the blood throughout the body.

Proteins

You have learned that proteins are basic structural components of all cells. Enzymes, hormones, neurotransmitters, and membrane receptors are just a few important proteins in the body.

During digestion, proteins are broken down into amino acids. The amino acids are absorbed into the bloodstream and carried to various body cells. These body cells recombine and reassemble the amino acids into proteins needed for body structures and functions.

Figure 9 Beans and rice can be combined to provide all the essential amino acids.

The human body can produce 12 of the 20 amino acids needed for cellular function. Essential amino acids are the eight amino acids that the body cannot produce, and must be included in a person's diet. Animal products, such as eggs and fish, are sources of all eight essential amino acids. Vegetables, fruits, and grains contain amino acids, but very few single plant food sources contain all eight essential amino acids. Certain combinations of plant foods, such as the beans and rice shown in **Figure 9**, provide all of the essential amino acids.

MyPlate

In 2011, the United States Department of Agriculture published a new nutrition guide, MyPlate, shown in **Figure 10**. MyPlate emphasizes the ratios of food groups rather than exact serving sizes. It recommends that a person eat about 30 percent grains, 30 percent vegetables, 20 percent fruits, 20 percent protein, with a small side of dairy such as a yogurt cup or glass of skim milk.

Figure 10 MyPlate can help you choose the foods and their amounts that are right for you.

Vitamins and Minerals

In addition to carbohydrates, fats, and proteins, your body needs vitamins and minerals to function properly. **Vitamins** are organic compounds that are needed in small amounts for metabolic activities. Many vitamins help enzymes function properly. Some vitamins are produced within the body. Vitamin D is made by cells in your skin. Some B vitamins and vitamin K are produced by bacteria living in the large intestine. However, sufficient quantities of most vitamins cannot be made by the body, but a well-balanced diet can provide the vitamins that are needed. Some vitamins that are fat-soluble can be stored in small quantities in the liver and fatty tissues of the body. Other vitamins are water-soluble and cannot be stored in the body. Foods providing an adequate level of these vitamins should be included in a person's diet on a regular basis.

Minerals are inorganic compounds used by the body as building materials, and they are involved with metabolic functions. For example, the mineral iron is needed to make hemoglobin. Recall that oxygen binds to hemoglobin in red blood cells and is delivered to body cells as blood circulates in the body. Calcium, another mineral, is an important component of bones.

Get It?

Compare and contrast vitamins and minerals.

Vitamins and minerals are essential parts of a healthy diet. **Table 3** on the next page lists some important vitamins and minerals, their benefits, and some food sources that can provide these necessary nutrients. Over-the-counter vitamins and minerals, like those shown in **Figure 11**, are also available. Taking more than the recommended daily allowance, however, can be dangerous and should not be done without consulting a doctor.

Sometimes people suffer from a vitamin or mineral deficiency, meaning they do not get enough of the vitamin or mineral to maintain homeostasis. For example, children who do not get enough vitamin D can suffer from rickets, a disorder in which the bones are soft and do not develop properly. People who do not get enough iodine may develop problems with their thyroid.

Figure 11 Vitamins and minerals can be taken as supplements to vitamins and minerals obtained in food.

STEM CAREER Connection

Chef

Do you enjoy preparing healthful and delicious foods? Do you understand the science of cooking? You might want to think about becoming a chef. A chef might plan menus, oversee other workers, or prepare foods. Many chefs work in restaurants, but some work in hospitals, nursing homes, or other facilities where food is served.

CCC CROSSCUTTING CONCEPTS

Energy and Matter With a small group, discuss evidence of how the energy and matter in food is used by the body. Write a bulleted list that summarizes the main points of your group's discussion.

Table 3 Major Roles of Some Vitamin and Minerals

Vitamin	Major Role in the Body	Possible Sources	Mineral	Major Role in the Body
A	• Vision • Health of skin and bones		Ca	• Strengthening of teeth and bone • Nerve conduction • Contraction of muscle
D	• Health of bones and teeth		P	• Strengthening of teeth and bones
E	• Strengthening of red blood cell membrane		Mg	• Synthesis of proteins
Riboflavin (B_2)	• Metabolism		Fe	• Synthesis of hemoglobin
Folic Acid	• Formation of red blood cells • Formation of DNA and RNA		Cu	• Synthesis of hemoglobin
Thiamine	• Metabolism of carbohydrates		Zn	• Healing of wounds
Niacin (B_3)	• Metabolism		Cl	• Balance of water
Pyridoxine (B_6)	• Metabolism of amino acids		I	• Synthesis of thyroid hormone
B_{12}	• Formation of red blood cells		Na	• Nerve conduction • Balance of pH
C	• Formation of collagen		K	• Nerve conduction • Contraction of muscle

Figure 12 When you read a nutrition label, notice how many servings are in each food container. The percent daily values are based on an individual serving, not the entire package.

Nutrition Labels

Nutrition labels are provided on commercially packaged foods like those shown in **Figure 12**. These labels are based on a 2000 Calorie per day diet. Labels can be especially useful for monitoring fat and sodium intake, which are two nutrients that need to be consumed in moderation. The FDA requires that food labels list the following information:

- name of the food
- the net weight or volume
- the name and address of manufacturer, distributor, or packager
- the ingredients
- nutrient content

Get It?

Explain why nutrition labels are important.

Check Your Progress

Summary

- The energy content of food is measured in Calories.
- Carbohydrates, fats, and proteins are three major groups of nutrients.
- Carbohydrates are a major source of energy for the body.
- Fats and proteins provide energy and are important building blocks for the body.
- Vitamins and minerals are essential for proper metabolic functioning.
- MyPlate and food labels are tools that you can use to eat healthfully.

Demonstrate Understanding

1. **Explain** the roles of vitamins and minerals in the process of maintaining homeostasis.
2. **Describe** what proteins, carbohydrates, and fats are used for in the body.
3. **Recommend** what nutrients a vegetarian should add to his or her diet.
4. **Explain** why keeping a count of Calories consumed and Calories used is important in maintaining proper functioning of the body.

Explain Your Thinking

5. **Summarize** how many Calories you consume during one day by recording everything you eat or drink. Compare this to how many Calories you burn in an average day.
6. **WRITING Connection** Write a short article for your school newspaper describing what is needed for a well-balanced diet.

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LESSON 3

THE ENDOCRINE SYSTEM

FOCUS QUESTION

What are the structures and functions of the endocrine system?

Actions of Hormones

The endocrine system is composed of glands and functions as a communication system. **Endocrine glands** produce hormones, which are released into the bloodstream and distributed to body cells. A **hormone** is a substance that acts on certain target cells and tissues to produce a specific response. Hormones are classified as steroid hormones and nonsteroid or amino acid hormones, based on their structure and mechanism of action.

Steroid hormones

Estrogen and testosterone are two examples of steroid hormones. All steroid hormones work by causing the target cells to initiate protein synthesis, as illustrated in **Figure 13**.

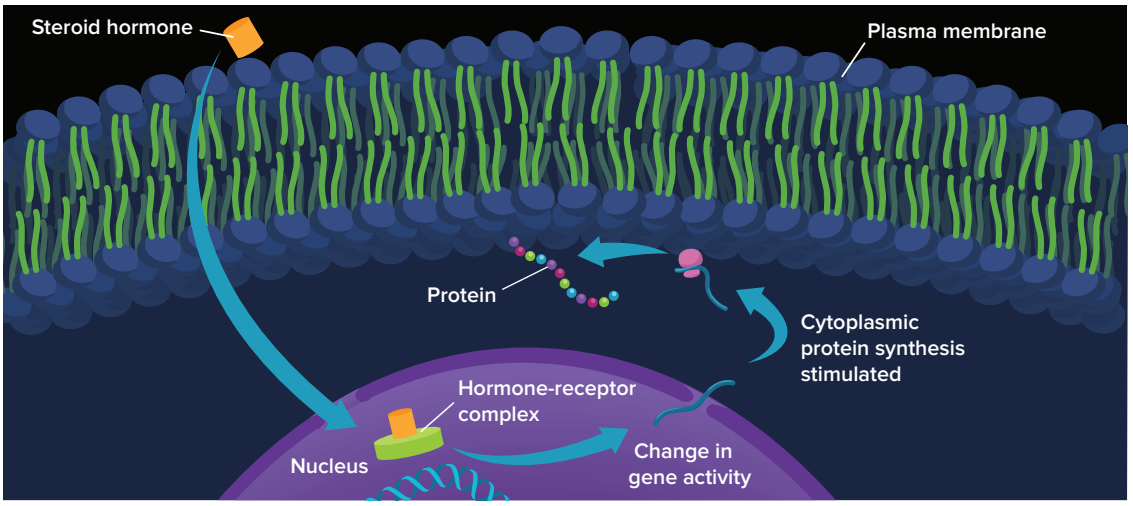

Figure 13 A steroid hormone passes through a cell membrane, binds to a receptor within the cell, and stimulates protein synthesis.

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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: Investigate Homeostasis in the Human Body

HS-LS1-3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

Steroid hormones are soluble in lipids and therefore can diffuse through the plasma membrane of a target cell. Once inside a target cell, they bind to a receptor in the cell. The hormone and the receptor that are bound together bind to DNA in the nucleus, which activates specific genes.

Amino acid hormones

Insulin and growth hormones are two examples of nonsteroid, or amino acid, hormones. As the name implies, these hormones are composed of amino acids. Amino acid hormones must bind to receptors found on the plasma membrane of a target cell because they cannot diffuse through the plasma membrane. Once the hormone binds to the receptor, the receptor activates an enzyme found on the inside of the membrane. This usually initiates a biochemical pathway, eventually causing the cell to produce the desired response, as illustrated in **Figure 14**.

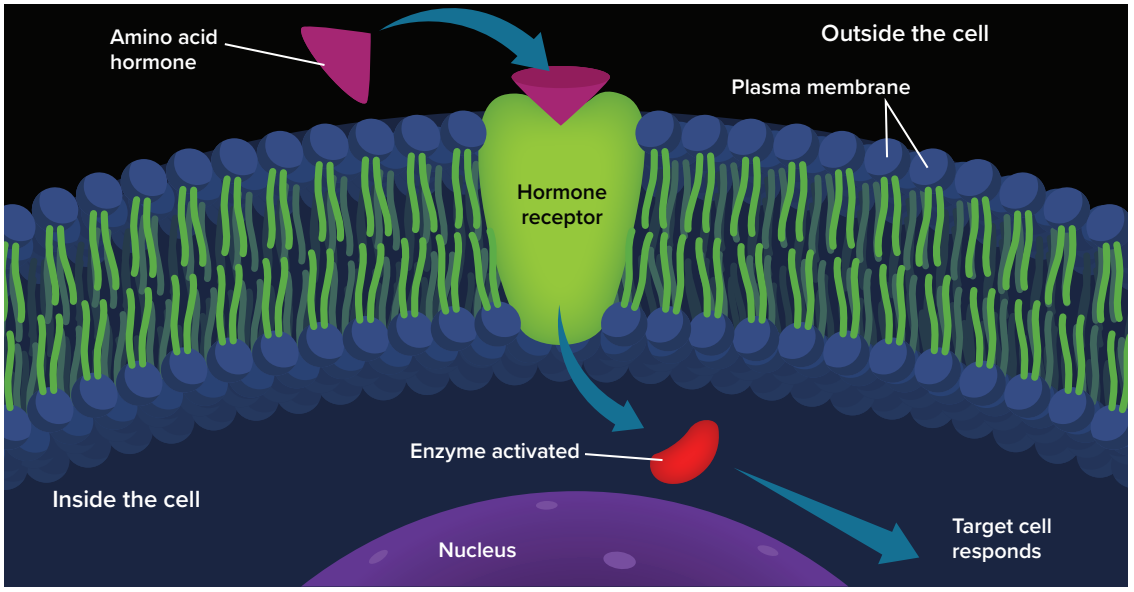


Figure 14 An amino acid hormone binds to a receptor on the plasma membrane before entering the cell.

Explain *the difference between amino acid hormones and steroid hormones.*

Negative Feedback

Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (through negative feedback) what is going on inside the living system. Negative feedback systems usually control conditions that remain in a steady state over long periods of time, stabilizing a system. You might be familiar with an example of a negative feedback system in your own home—the thermostat that controls temperature.

Get It?

Explain how feedback can stabilize a system.

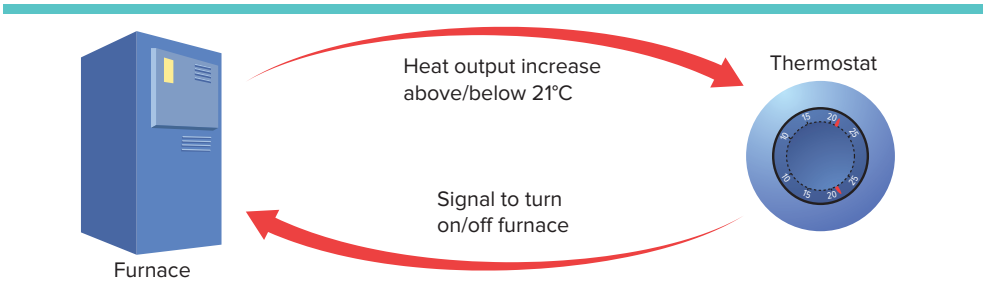


Figure 15 A furnace turns on or off based on the relationship of the detected room temperature and the set point.

Study **Figure 15**. In this example, the temperature in a house is maintained at 21˚C. The thermostat in the house detects the temperature, and when the temperature drops below 21˚C, the thermostat sends a signal to the heat source, which turns it on and produces more heat. Soon the temperature rises above 21˚C, and the thermostat sends a signal to the heat source to shut off. The heat source will not turn on again until the room temperature drops below 21˚C and is detected by the thermostat. Because this process can go on indefinitely, negative feedback often is described as a loop.

Endocrine Glands and Their Hormones

The endocrine system includes all the glands that secrete hormones—pituitary, thyroid, parathyroid, adrenal glands, pancreas, ovaries, testes, pineal gland, and the thymus gland. Some of these glands are shown in **Figure 16**.

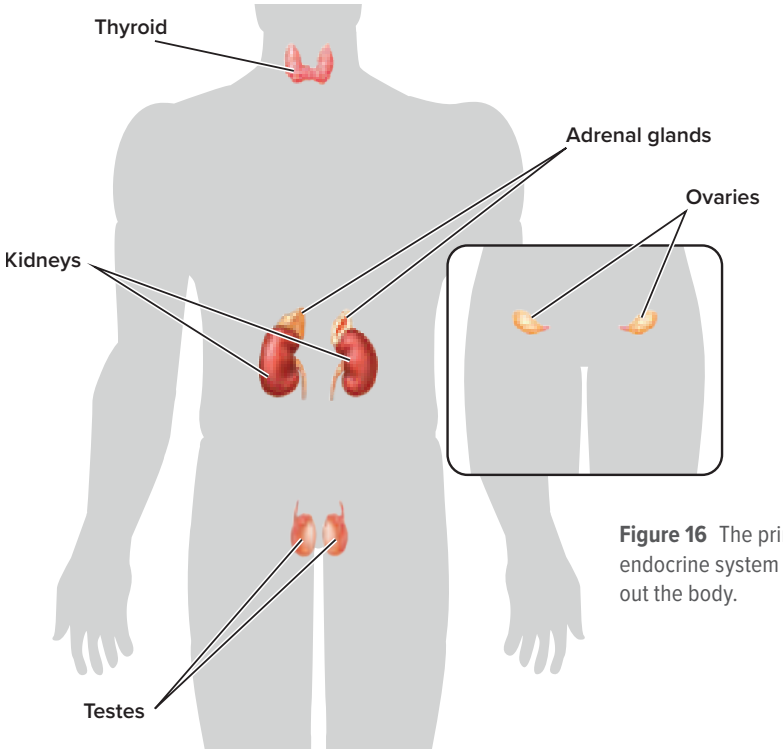


Figure 16 The principal glands of the endocrine system are located throughout the body.

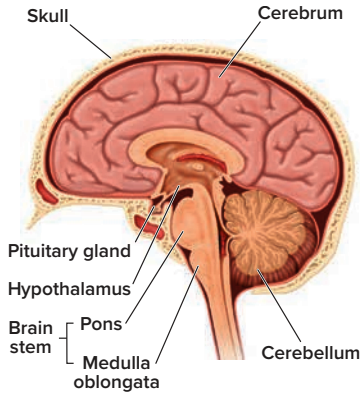


Figure 17 The pituitary gland is located at the base of the brain.

Pituitary gland

The pituitary gland is situated at the base of the brain, as illustrated in **Figure 17**. This gland is sometimes called the "master gland" because it regulates so many body functions. Despite its small size, it is the most important endocrine gland. The **pituitary gland** secretes hormones that regulate many body functions. It also regulates other endocrine glands, such as the thyroid gland, adrenal glands, testes, and ovaries.

Several pituitary hormones act on tissues in the body rather than on specific organs. Human growth hormone (hGH) regulates the body's physical growth by stimulating cell division in muscle and bone tissue. This hormone is especially active during childhood and adolescence.

Thyroid and parathyroid glands

Identify the thyroid and parathyroid glands in **Figure 18**. One hormone produced by the thyroid gland is thyroxine. Like hGH, **thyroxine** does not act on specific organs; rather, it causes cells of the body to have a higher rate of metabolism. The thyroid gland also produces calcitonin. **Calcitonin** (kal suh TOH nun) is a hormone that is partly responsible for the regulation of calcium, an important mineral for bone formation, blood clotting, nerve function, and muscle contraction. Calcitonin lowers blood calcium levels by signaling bones to increase calcium absorption and also signaling the kidneys to excrete more calcium.

When blood calcium levels are too low, the parathyroid glands increase production of parathyroid hormone. **Parathyroid hormone** increases blood calcium levels by stimulating the bones to release calcium. The action of this hormone also causes the kidneys to reabsorb more calcium and the intestines to absorb more calcium from food. The thyroid and parathyroid glands have opposite effects on blood calcium levels. However, as they work together, they maintain homeostasis.

Get It?

Explain how negative feedback is important in maintaining homeostasis.

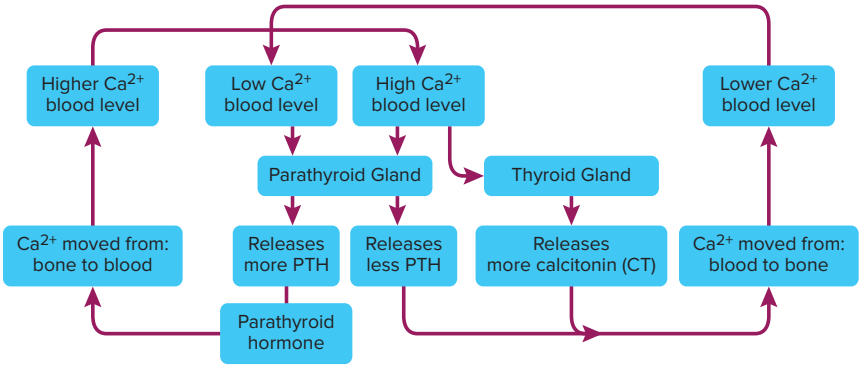


Figure 18 Parathyroid hormone (PTH) and calcitonin (CT) regulate the level of calcium in the blood.

Explain *how PTH and CT illustrate negative feedback.*

Pancreas

As discussed in Lesson 1, the pancreas has a crucial role in the production of enzymes that digest carbohydrates, proteins, and fats. The pancreas also secretes the hormones insulin and glucagon, which work together to maintain homeostasis, as illustrated in **Figure 19**. When blood glucose levels are high, the pancreas releases insulin. **Insulin** signals body cells, especially liver and muscle cells, to accelerate the conversion of glucose to glycogen, which is stored in the liver. When blood glucose levels are low, glucagon is released from the pancreas. **Glucagon** (GLEW kuh gahn) binds to liver cells, signaling them to convert glycogen to glucose and release the glucose into the blood.

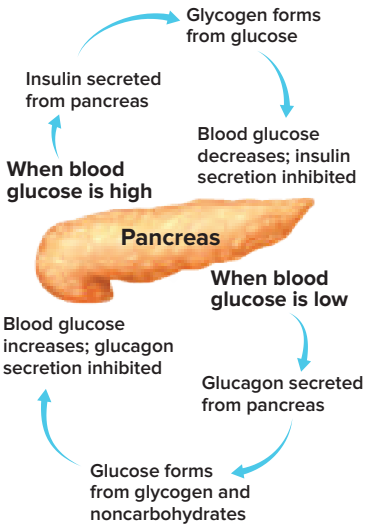


Figure 19 Glucagon and insulin work together to maintain the level of sugar in the blood.

Diabetes is a disease that results from the body not producing enough insulin or not properly using insulin. Type 1 diabetes, which usually appears in people by the age of 20, occurs when the body cannot produce insulin. Type 2 diabetes occurs in 70–80 percent of people diagnosed with diabetes, and usually occurs after the age of 40. It results from the cells of the body becoming insensitive to insulin. In both types of diabetes, the blood glucose levels must be monitored and maintained to prevent complications from the disease.

Adrenal glands

Refer again to **Figure 16**. The adrenal glands are located just above the kidneys. The outer part of the adrenals is called the cortex, which manufactures the steroid hormone aldosterone and a group of hormones called glucocorticoids. **Aldosterone** (al DAWS tuh rohn) primarily affects the kidneys and is important for reabsorbing sodium. **Cortisol,** another glucocorticoid, raises blood glucose levels and also reduces inflammation.

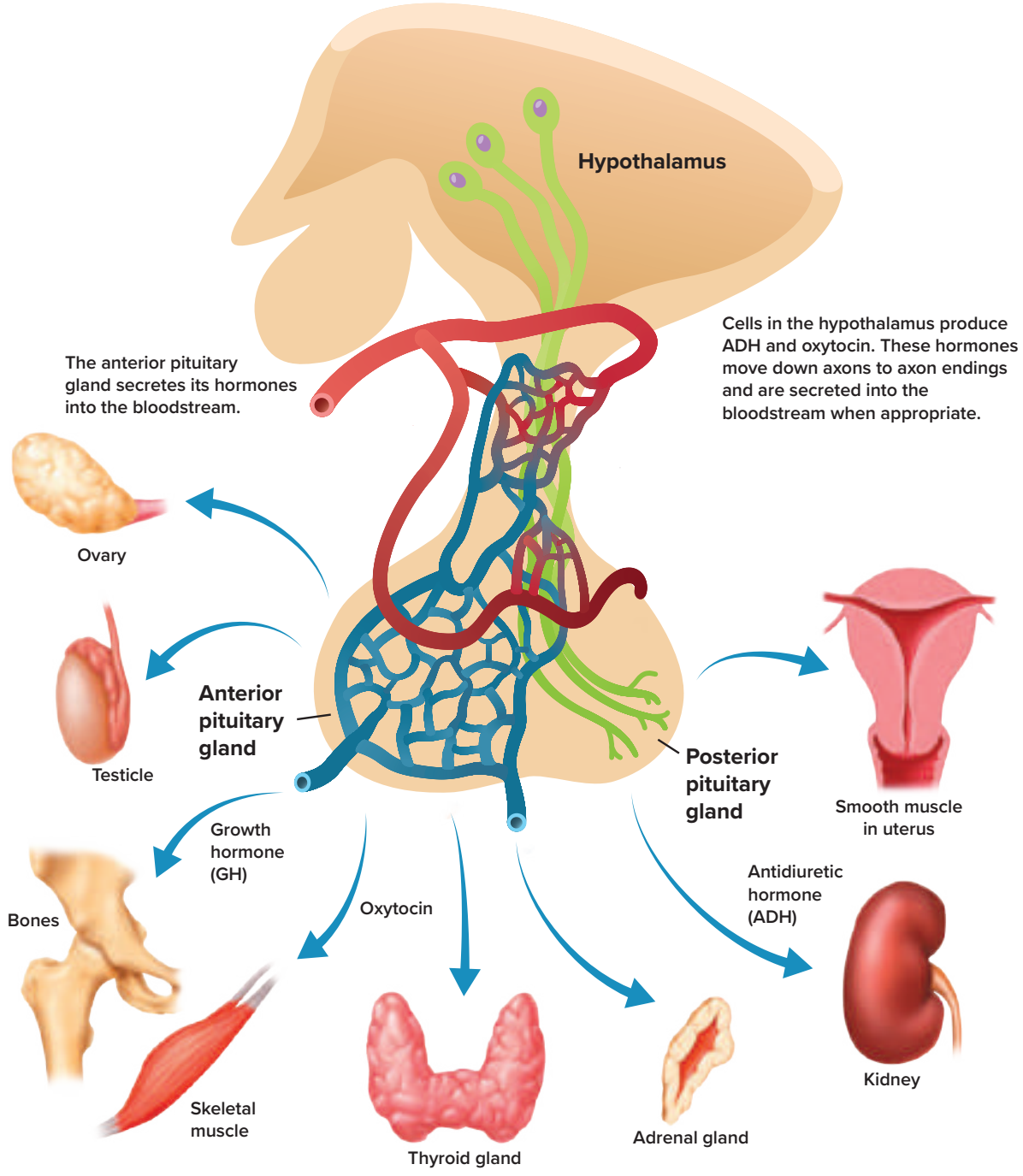
The body has different mechanisms for responding to stress, such as the role of the nervous system and the "fight or flight response." The endocrine system also is involved with these types of responses. During a stressful situation the inner portions of the adrenal glands secrete epinephrine (eh puh NEH frun) and norepinephrine. Together, these hormones increase heart rate, blood pressure, breathing rate, and blood sugar levels, all of which are important in increasing the activity of body cells.

CCC CROSSCUTTING CONCEPTS

Stability and Change Write a paragraph that provides evidence that negative feedback stabilizes blood glucose levels, helping the body maintain homeostasis. Cite specific information from **Figure 19** in your paragraph.

Figure 20 Visualizing the Endocrine System

The hypothalamus maintains homeostasis by serving as a link between the nervous system and the endocrine system. The pituitary gland releases growth hormone, ADH, and oxytocin as needed by the body. The pituitary gland also manufactures and secretes hormones that regulate the testes, the ovaries, and the thyroid and adrenal glands.



Link to the Nervous System

The nervous and endocrine systems are similar in that they both are involved in regulating the activities of the body and maintaining homeostasis. Refer to **Figure 20** on the previous page to study the role of the hypothalamus in homeostasis. Recall that this part of the brain is involved with many aspects of homeostasis. The hypothalamus produces two hormones, oxytocin (ahk sih TOH sun) and antidiuretic hormone (ADH).

The **antidiuretic** (AN ti DY yuh REH tic) **hormone** (ADH) functions in homeostasis by regulating water balance. As illustrated in **Figure 21**, ADH travels in the blood to the kidneys, where it binds to receptors on certain kidney cells. This causes the kidneys to reabsorb more water and decrease the amount of water in the urine, increasing the water level in the blood. If there is too much water in a person's blood, the hypothalamus decreases the release of ADH, and the urine tends to be more dilute. ADH production is stimulated by nausea and vomiting, both of which cause dehydration. Blood loss of 20 percent by hemorrhage results in the release of ADH.

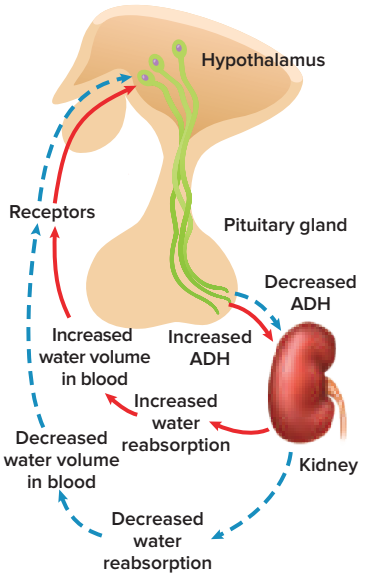


Figure 21 Antidiuretic hormone (ADH) helps to control the concentration of water in the blood.

Check Your Progress

Summary

- Endocrine glands produce substances called hormones.
- Hormones travel throughout the body in the bloodstream.
- Hormones are classified as steroid hormones or amino acid hormones.
- Hormone levels are influenced by feedback systems.
- The endocrine system helps to maintain homeostasis with signals from internal mechanisms called negative feedback.

Demonstrate Understanding

1. **Explain** the reasons why a feedback system would be referred to as "negative feedback."
2. **Predict** when high levels of insulin would be found in a person's blood and when high levels of glucagon would be found in a person's blood.
3. **Explain** how the endocrine and nervous systems work together to maintain homeostasis.
4. **Identify** and describe the functions of pituitary, thyroid, parathyroid, pancreas, and adrenal glands.

Explain Your Thinking

5. **Research** Iodine is essential for thyroid gland function. Fetal and childhood iodine deficiency is a major cause of mental retardation in the world, yet the deficiency is preventable. Predict how iodine deficiency might lead to mental retardation or other health issues. Research what has been and what is being done to alleviate this concern. Include information about sources of iodine in your response.

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

SCIENCE & SOCIETY

By the Skin of Your Teeth

Teeth are an important part of the digestive system. Mechanical digestion begins as teeth break down food into smaller pieces. Chewing allows amylase to begin the process of chemical digestion. Tooth decay can have a negative impact on the process of digestion.

The chemistry of tooth decay

The surface of teeth is made of enamel, which consists mostly of a solid, called hydroxyapatite, composed of calcium and phosphate ions. Ions move in and out of hydroxyapatite, depending on pH. When ions are added, it is called mineralization. Demineralization is the process of ions leaving the enamel. Ideally, the rates of mineralization and demineralization are the same, resulting in no net loss of enamel.

Bacteria produce acids in the mouth in the presence of sugar or starch. Acidity causes demineralization. Cavities result when demineralization destroys tooth enamel and acids start destroying dentin, the layer under the enamel.

The consequences of tooth decay

Tooth decay can cause significant pain and tooth loss, which can impact the ability to thoroughly chew food. If unchecked, tooth decay can affect an individual's ability to get the nutrition they need.

Dental care can help prevent tooth decay.

Preventing and treating tooth decay

A variety of strategies help prevent tooth decay. Consuming fluoride in drinking water and having sealants applied are effective ways to slow tooth decay. Regular brushing and dental visits are also key factors in the prevention of tooth decay. Reducing the amount of sugar and starch consumed can also contribute to healthy teeth.

Traditional treatment for tooth decay includes filling cavities with metal or porcelain. However, some new techniques are being developed that can reverse tooth decay. For example, a treatment is being developed that uses stem cells to stimulate the tooth to repair damaged areas. Another treatment being developed uses electric currents to stimulate remineralization of a damaged area. Other researchers are exploring the use of aspirin to stimulate the gene that codes for the production of new dentin.

COMMUNICATE SCIENTIFIC INFORMATION

Work with a small group to develop a plan for communicating the importance of healthy teeth to other students in the school. Be sure to relate the health of the teeth to digestion, nutrition, and overall health.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 THE DIGESTIVE SYSTEM

- The digestive system has three main functions.
- Digestion can be categorized as mechanical or chemical.
- Most nutrients are absorbed in the small intestine.
- Accessory organs provide enzymes and bile to aid digestion.
- Water is absorbed from chyme in the colon.

- mechanical digestion
- chemical digestion
- amylase
- esophagus
- peristalsis
- pepsin
- small intestine
- liver
- villus
- large intestine

Lesson 2 NUTRITION

- The energy content of food is measured in Calories.
- Carbohydrates, fats, and proteins are three major groups of nutrients.
- Carbohydrates are a major source of energy for the body.
- Fats and proteins provide energy and are important building blocks for the body.
- Vitamins and minerals are essential for proper metabolic functioning.
- MyPlate and food labels are tools you can use to eat healthfully.

- nutrition
- Calorie
- vitamin
- mineral

Lesson 3 THE ENDOCRINE SYSTEM

- Endocrine glands produce substances called hormones.
- Hormones travel throughout the body in the bloodstream.
- Hormones are classified as steroid hormones or amino acid hormones.
- Hormone levels are influenced by feedback systems.
- The endocrine system helps to maintain homeostasis with signals from internal mechanisms called negative feedback.

- endocrine gland
- hormone
- pituitary gland
- thyroxine
- calcitonin
- parathyroid hormone
- insulin
- glucagon
- aldosterone
- cortisol
- antidiuretic hormone

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

Why do we need a variety of foods in our diet?

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 reliable are food labels?

In a study conducted at the U.S. Department of Agriculture Human Nutrition Research Center, scientists measured the mass of 99 single-serving food products.

Data and Observations The table compares the mass listed on the food package label with the actual mass of the food in five single-serving packages.

CER Analyze and Interpret Data

1. **Calculate** the percent difference in mass between the label mass and the actual mass of the cookies.
2. **Evidence, Reasoning** Compare the trend in the percent differences.

Food (1 serving)	Label Mass (g)	Actual Mass (g)
Cereal, bran flakes with raisins (1 box)	39	54.2
Cereal, toasted grains with supplement (1 box)	23	39.6
Cookie, chocolate sandwich	57	67.0
Mini danish, apple (1 per serving)	35	44.8
Mini donut, chocolate covered (4 per serving)	100	116.5

*Data obtained from: Conway, J.M., D.G. Rhodes, and W.V. Rumpler. 2004. Commercial portion-controlled foods in research studies: how accurate are label weights? *Journal of the American Dietetic Association* 104: 1420–1424.

CIRCULATORY, RESPIRATORY, AND EXCRETORY SYSTEMS

CIRCULATORY, RESPIRATORY, AND EXCRETORY SYSTEMS

ENCOUNTER THE PHENOMENON

What is the woman's body doing in response to lifting? Why?

SEP Ask Questions

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

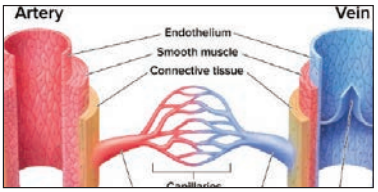
CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about what the woman's body is doing in response to lifting and why. Explain your reasoning.

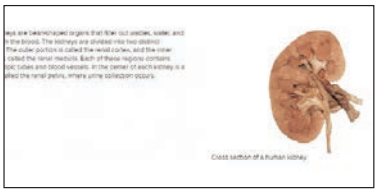
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

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 Circulatory System: Blood Vessels and Blood Components



LESSON 3: Explore & Explain: The Excretory System: How Kidneys Work

LESSON 1

CIRCULATORY SYSTEM

FOCUS QUESTION

How does exercise, such as lifting weights, positively affect the circulatory system?

Blood Vessels

Highways have lanes that separate traffic. They also have access ramps that take vehicles to and from roads. Similarly, the body has a network of channels—the blood vessels. Blood vessels circulate blood throughout the body and help keep the blood flowing to and from the heart.

As illustrated in **Figure 1**, the three major blood vessels are arteries, capillaries, and veins. **Figure 2,** on the next page, shows that Greek physician Praxagoras first observed the three types of blood vessels. Other discoveries and medical advances are shown in **Figure 2**, including the establishment of the first blood banks for blood transfusions and the successful implantation of the first artificial heart.

Arteries

Oxygen-rich blood, or oxygenated blood, is carried away from the heart in large blood vessels called **arteries.** These strong, thick-walled vessels are elastic and durable. They are capable of withstanding high pressures exerted by blood as it is pumped by the heart. As shown in **Figure 1**, arteries are composed of three layers: an outer layer of connective tissue, a middle layer of smooth muscle, and an inner layer of endothelial tissue. The endothelial layer of the artery is thicker than that of the other blood vessels. The endothelial layer of arteries needs to be thicker because blood is under higher pressure when it is pumped from the heart into the arteries.

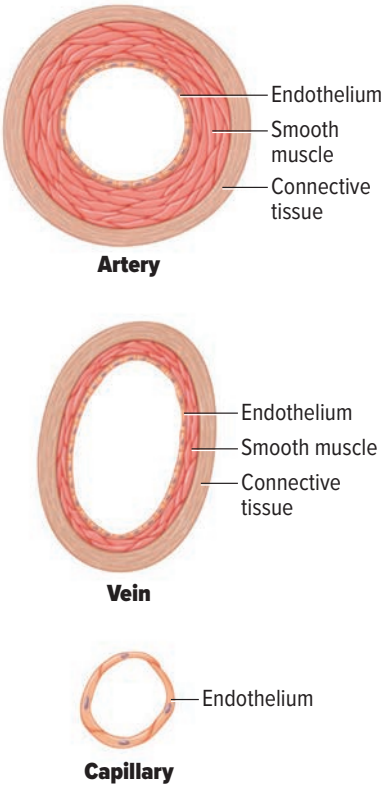


Figure 1 The three major blood vessels in the body are arteries, veins, and capillaries.

Predict *By what process do you think materials cross the walls of capillaries?*

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 Blood Pressure

Carry out an investigation to determine the effects of exercise on blood pressure.

Virtual Investigation: Blood Pressure

Use a model to determine the cause of hypertension.

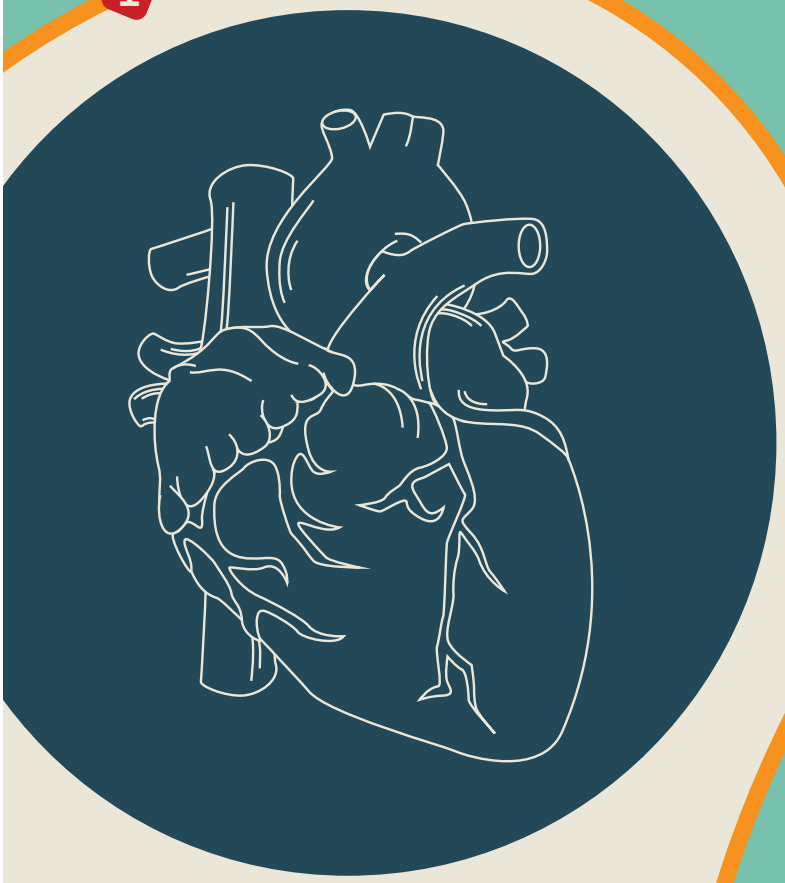


Figure 2

From Cadavers to Artificial Hearts

The human circulatory system has been studied for thousands of years, leading to great advances in medical technology.

1. **350 B.C.** Greek physician Praxagoras recognizes that veins and arteries are two different kinds of vessels.
2. **1628** The first accurate description is made of the human heart—a pump that circulates blood in a one-way system.
3. **1903** The first electrocardiograph records the electrical activity of the heart.
4. **1940–1941** Dr. Charles R. Drew establishes the first blood banks for blood transfusions.
5. **1967–1969** Surgeons perform the first heart transplants.
6. **1982** The first artificial heart intended for permanent use is implanted by William DeVries, a surgeon.
7. **2004** Research shows that cardiac stem cells can generate new muscle cells.
8. **2008** Scientists successfully transplant rat hearts grown from the rats' own stem cells.

Capillaries

Arteries branch into smaller vessels called arterioles, which become smaller in diameter as they grow farther away from the main vessel. The smallest branches are capillaries. **Capillaries** are microscopic blood vessels where the exchange of important substances and wastes occurs. Capillary walls are only one cell thick, as illustrated in **Figure 1**. This permits the easy exchange of materials between the blood and body cells through the process of diffusion. Capillaries are so small that red blood cells move single-file through these vessels.

The diameter of blood vessels changes in response to the needs of the body. For example, when you are exercising, muscle capillaries expand, or dilate. This increases blood flow to working muscles, which brings more oxygen to cells and removes extra wastes from cells.

Veins

After blood moves through the tiny capillaries, it enters the larger vessels called venules, and then enters the largest blood vessels, called veins. **Veins** carry oxygen-poor blood, or deoxygenated blood, back to the heart. The endothelial walls of veins are much thinner than the walls of arteries. The pressure of the blood decreases when the blood flows through capillaries before it enters the veins. By the time blood flows into the veins, the heart's original pushing force has less effect on making the blood move. So how does the blood keep moving? Many veins are located near skeletal muscles, and the contraction of these muscles helps keep the blood moving. Larger veins in the body also have flaps of tissue called **valves,** such as the one in **Figure 3**, which prevent blood from flowing backward. Lastly, breathing movements exert a squeezing pressure against veins in the chest, forcing blood back to the heart.

Get It?

Describe the differences in structure among arteries, capillaries, and veins.

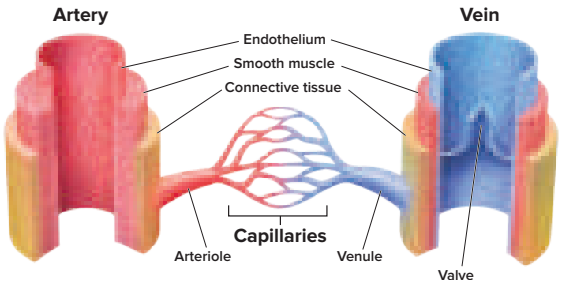


Figure 3 Blood circulates throughout the body inside blood vessels.

Hypothesize *how body temperature can be regulated by the diameter of blood vessels.*

The Heart

The **heart** is a muscular organ that is about as large as your fist and is located at the center of your chest. This hollow organ pumps blood throughout the body. The heart performs two pumping functions at the same time. The heart pumps oxygenated blood to the body, and it pumps deoxygenated blood to the lungs.

Structure of the heart

Recall that the heart is made of cardiac muscle. It is capable of conducting electrical impulses for muscular contractions. The heart is divided into four compartments called chambers, as illustrated in **Figure 4**. The two chambers in the top half of the heart, the right atrium and the left atrium (plural, atria), receive blood that is returning to the heart. Below the atria are the right and left ventricles, which pump blood away from the heart.

A strong muscular wall separates the left side of the heart from the right side of the heart. The right and left atria have thinner muscular walls and do less work than the ventricles. Notice the valves in **Figure 4** that separate the atria from the ventricles and keep blood flowing in one direction. Valves, such as the aortic valve shown in a opened position in **Figure 4**, are also located between each ventricle and the large blood vessels that carry blood away from the heart.

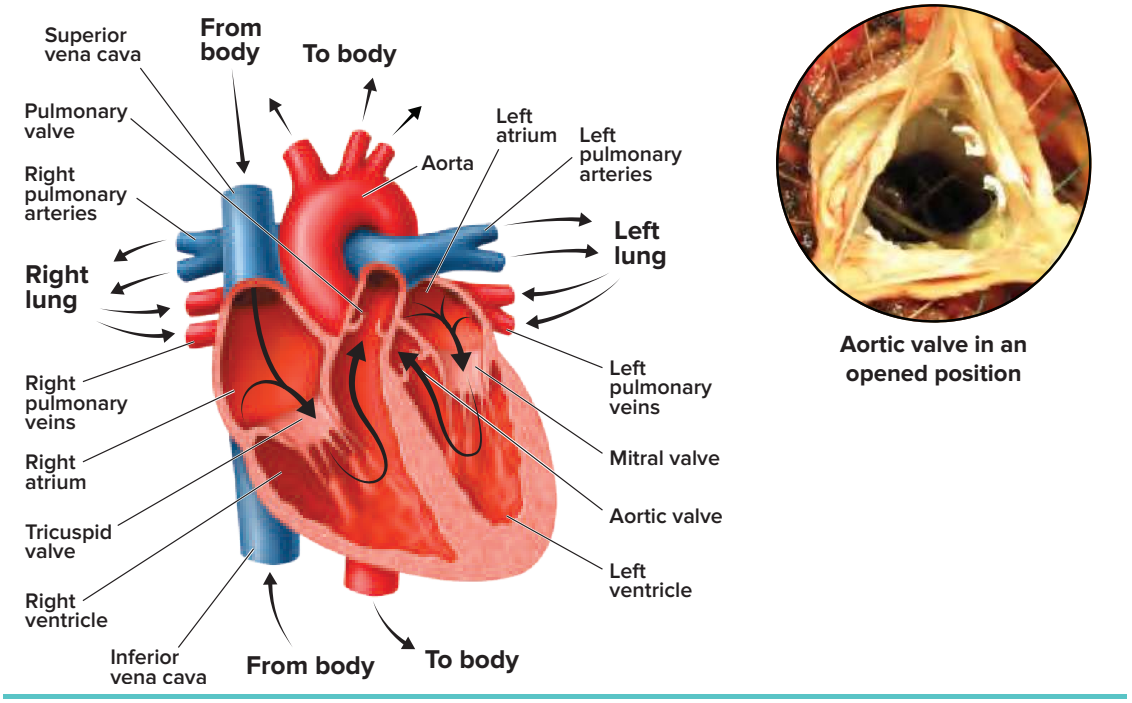


Figure 4 The arrows map the path of blood as it circulates through the heart.

Diagram *the path of blood through the heart.*

STEM CAREER Connection

Cardiovascular Invasive Specialists

These technologists help physicians determine whether patients have structural or electrical heart problems or blocked vessels. They assist with cardiac catherization, a procedure that involves guiding a tube through a patient's blood vessels into their heart. They also help prepare patients for other cardiovascular interventions.

CCC CROSSCUTTING CONCEPTS

Systems and System Models Review the information about the functions of the different blood vessels. Work with a partner to develop a model, such as a flow chart, to explain the role played by each type of vessel.

How the heart beats

The heart acts in two main phases. In the first phase, the atria fill with blood. The atria contract, filling the ventricles with blood. In the second phase, the ventricles contract to pump blood out of the heart, into the lungs, and forward into the body.

The heart works in a regular rhythm. A group of cells located in the right atrium, called the **pacemaker** or sinoatrial (SA) node, send out signals that tell the heart muscle to contract. The SA node receives internal stimuli about the body's oxygen needs, and then it responds by adjusting the heart rate. The signal initiated by the SA node causes both atria to contract. Then the signal travels to another area in the heart called the atrioventricular (AV) node, as illustrated in **Figure 5**. The signal moves through fibers, causing both ventricles to contract. This two-step contraction makes up one complete heartbeat.

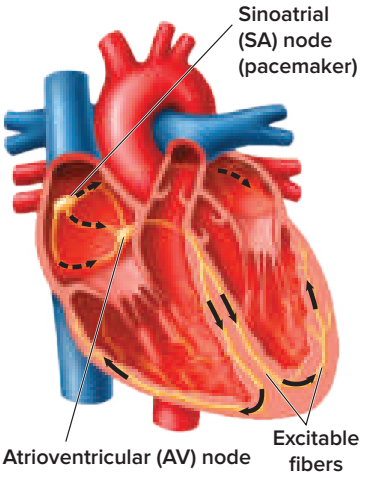


Figure 5 The SA node initiates the contraction of the heart, which spreads through both atria to the AV node. The AV node transmits the signal through excitable fibers that stimulate both ventricles.

Get It?

Compare and contrast the SA node and the AV node.

Pulse The heart pulses about 70 times each minute. If you touch the inside of your wrist just below your thumb, you can feel the artery in your wrist rise and fall. This pulse is the alternating expansion and relaxation of the artery wall caused by the contraction of the left ventricle. The number of times the artery in your wrist pulses is the number of times your heart beats.

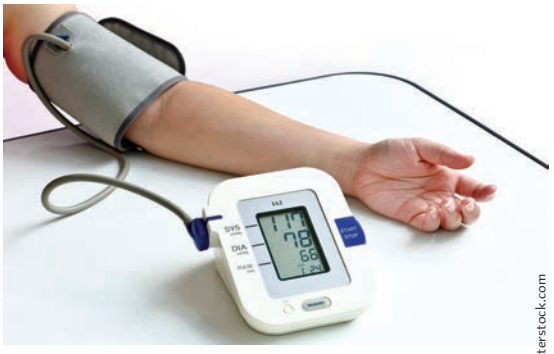


Figure 6 A sphygmomanometer measures the blood pressure in an artery.

Determine *What is this person's blood pressure? Is it normal? Explain.*

Blood pressure Blood pressure is a measure of how much pressure is exerted against the vessel walls by the blood. Blood-pressure readings can provide information about the condition of arteries. The contraction of the heart, or systole (SIS tuh lee), causes blood pressure to rise to its highest point, and the relaxation of the heart, or diastole (di AS tuh lee), brings blood pressure down to its lowest point. The ideal normal blood-pressure reading for a healthy adult is 120 (systolic pressure)/80 (diastolic pressure). Blood pressure is measured using an instrument called a sphygmomanometer (sfig moh muh NOM i ter), like the one shown in **Figure 6**. When reading the results, the top number is the systolic pressure and the number underneath that is the diastolic pressure.

High blood pressure can develop over a period of many years, and many people do not experience symptoms. However, damage to blood vessels and the heart still occur. High blood pressure that remains untreated can lead to an increased risk of heart attack and stroke. Treatment for high blood pressure includes lifestyle changes such as exercising, eating a healthy diet, and maintaining a healthy weight. If needed, medication is prescribed to help lower blood pressure.

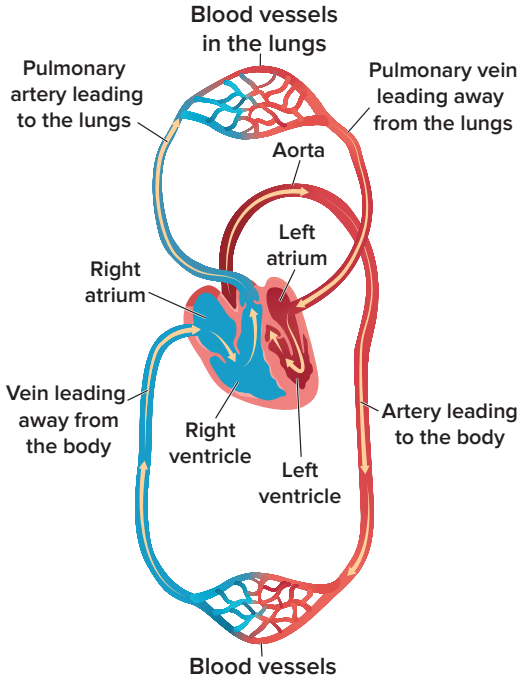


Figure 7 Blood flow through the body consists of two different circulatory loops.

Blood flow in the body

If you follow the flow of blood shown in **Figure 7**, you will notice that it flows in two loops. First, the blood travels from the heart to the lungs and back to the heart. Then, the blood is pumped in another loop from the heart through the body and back. The right side of the heart pumps deoxygenated blood to the lungs, and the left side of the heart pumps oxygenated blood to the rest of the body.

To the lungs and back When blood from the body flows into the right atrium, it has a low concentration of oxygen but a high concentration of carbon dioxide. The blood flows from the right atrium into the right ventricle and is pumped into the pulmonary arteries that lead to the lungs, as shown in **Figure 7**.

Eventually, blood flows into capillaries in the lungs that are in close contact with the air that enters the lungs. The air in the lungs has a greater concentration of oxygen than the blood in the capillaries does, so oxygen diffuses from the lungs into the blood. At the same time, carbon dioxide diffuses in the opposite direction—from the blood into the airspace in the lungs. Oxygenated blood flows to the left atrium of the heart to be pumped out to the body.

To the body and back The second loop begins as the blood moves from the left atrium into the left ventricle. As shown in **Figure 7**, the left ventricle then pumps the blood into the largest artery in the body called the aorta. Eventually, blood flows into the capillaries that branch throughout the body. The capillaries are in close contact with body cells. Oxygen is released from the blood into the body cells by diffusion, and carbon dioxide moves from the cells to the blood by diffusion. The deoxygenated blood then flows back to the right atrium through veins.

Functions of the Circulatory System

The circulatory system is the body's transport system. Blood carries important substances, such as oxygen and nutrients, to all parts of the body. It carries waste products, such as carbon dioxide, away from body cells. The blood also carries disease-fighting materials produced by the immune system. The blood contains cell fragments and proteins for blood clotting. The heart pumps blood through blood vessels. The lymphatic system is considered part of the circulatory and immune systems. All of these components work together to maintain homeostasis in the body. Finally, the circulatory system distributes heat throughout the body to help regulate body temperature.

Blood Components

Blood is the fluid of life because it transports important substances throughout the body. Blood is made up of a liquid medium called plasma, red blood cells, platelets, and white blood cells.

Plasma

The clear, yellowish fluid portion of blood is the **plasma,** shown in **Figure 8**. More than 50 percent of blood is plasma. Ninety percent of plasma is water, and nearly 10 percent is dissolved materials. Plasma carries the broken-down products of digested food, such as glucose and fats. Plasma also transports vitamins, minerals, and chemical messengers including hormones that signal body activities, such as the uptake of glucose by the cells. In addition, waste products from the cells are carried away by plasma.

There are three groups of plasma proteins that give plasma its yellow color. One group helps to regulate the amount of water in blood. The second group, produced by white blood cells, helps fight disease. The third group helps to form blood clots.

Figure 8 Plasma is the clear, yellowish portion of the blood, made up mostly water.

Get It?

Explain the functions of plasma.

Red blood cells

The **red blood cells** carry oxygen to all of the body's cells. Red blood cells resemble discs with pinched-in centers, as shown in **Figure 9**. Recall that red blood cells develop in the marrow—the center portion of large bones. Red blood cells have no nuclei and live for only about 120 days.

Red blood cells mostly consist of an iron-containing protein called hemoglobin. Hemoglobin chemically binds with oxygen molecules and carries oxygen to the body's cells. Red blood cells also carry carbon dioxide away from cells to the lungs, where it is exhaled.

Because hemoglobin is an iron-containing protein, eating foods that are high in iron is an important part of keeping red blood cells healthy. Foods that contain iron include dark green leafy vegetables, such as spinach and kale, beans, red meat, and iron-enriched cereals.

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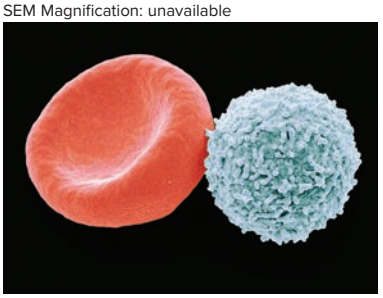

Figure 9 Blood is composed of liquid plasma, red blood cells (dimpled disc on the left), white blood cells (irregularly shaped cell on the right), and platelets (flat fragments, not shown).

Infer *What might be occurring if there are too many white blood cells?*

Platelets

Have you ever cut your finger? If so, you probably noticed that in a short while, the blood flowing from the cut slowed down and then stopped as a blood clot formed a scab. **Platelets** are cell fragments that are important in forming blood clots.

When a blood vessel is cut, platelets collect and stick to the vessel at the site of the wound. The platelets then release chemicals that produce a protein called fibrin. Fibrin weaves a network of fibers across the cut that traps blood platelets and red blood cells, as shown in **Figure 10**. As more and more platelets and blood cells are trapped, a blood clot forms.

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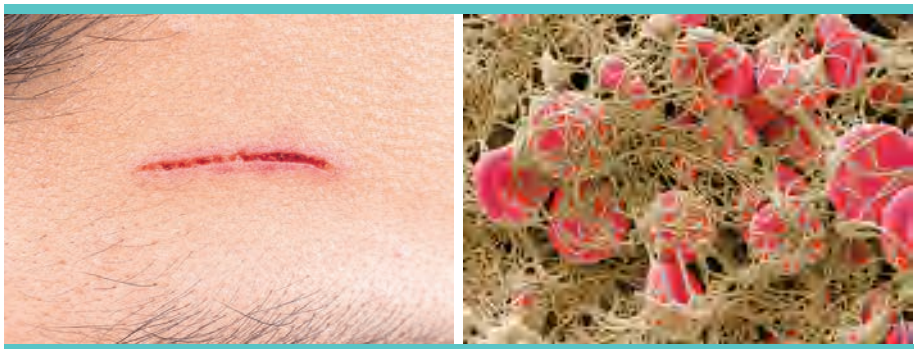


Figure 10 A scab forms as fibrin threads trap blood cells and platelets.

White blood cells

The body's disease fighters are the **white blood cells.** Like red blood cells, white blood cells are produced in bone marrow. Some white blood cells recognize disease-causing organisms, such as bacteria, and alert the body that it has been invaded. Other white blood cells produce chemicals to fight the invaders. Still, other white blood cells surround and kill the invaders.

White blood cells are different from red blood cells in important ways. Many white blood cells move from the marrow to other sites in the body to mature. Unlike red blood cells, there are fewer white blood cells—only about one white blood cell for every 500 to 1000 red blood cells. Also, white blood cells have nuclei. Finally, most white blood cells live for months or years.

Blood Groups

How do you know what type of blood you have? There are marker molecules attached to red blood cells. These markers are called blood groups, which determine blood type.

STUDY TIP

Graphic Organizer Make a word map with the word blood in a large circle in the middle. Place the words components, blood groups, circulation, and heart in smaller circles around the large circle. Find information you learned in the module and add it to the appropriate smaller circles.

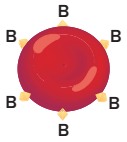
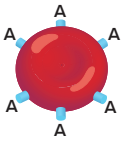
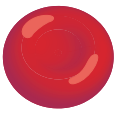
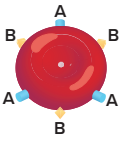
ABO blood group

There are four types of blood: A, B, AB, and O. If your blood type is A, you have A markers on your blood cells. If your blood type is B, you have B markers on your blood cells. If your blood type is AB, you have both A and B markers. If your blood type is O, you do not have A or B markers.

Importance of blood type

If you ever need a blood transfusion, you will be able to receive only certain blood types, as shown in **Table 1**. This is because plasma contains proteins called antibodies that recognize red blood cells with foreign markers and cause those cells to clump together. For example, if you have blood type B, your blood contains antibodies that cause cells with A markers to clump. If you received a transfusion of type-A blood, your clumping proteins would make the type-A cells clump together. Clumping of blood cells can be dangerous because it can block blood flow.

Table 1 Blood Types

Blood Type	A	B	AB	O
Marker molecule and antibody	Marker molecule: A Antibody: anti-B	Marker molecules: B Antibody: anti-A	Marker molecules: AB Antibody: none	Marker molecules: none Antibodies: anti-A, anti-B
Example				
Can donate blood to:	A or AB	B or AB	AB	A, B, AB, or O
Can receive blood from:	A or O	B or O	A, B, AB, or O	O

Rh blood group

The Rh factor, another marker on red blood cells, can cause complications during some pregnancies. If a fetus's Rh-positive blood mixes with the mother's Rh-negative blood, the mother will make anti-Rh antibodies. During another pregnancy, these antibodies can cross the placenta and destroy red blood cells if the fetus has Rh-positive blood.

STEM CAREER Connection

Blood Bank Technician

Blood bank technicians play a key role in collecting, analyzing, and properly storing blood used for transfusions. A career as a blood bank technician requires a desire to work with blood donors and an understanding of human blood types. Most blood bank technicians have an associates degree.

Figure 11 A stroke is associated with ruptured blood vessels in the brain, as shown in red.

Circulatory System Disorders

Several disorders of the blood vessels, heart, and brain are associated with the circulatory system. Blood clots and other matter, such as fat deposits, can reduce the flow of oxygen-rich and nutrient-rich blood traveling through arteries. Physicians refer to the condition of blocked arteries as **atherosclerosis** (a thuh roh skluh ROH sus). When blood flow is reduced or blocked, the heart must work even harder to pump blood, and vessels can burst.

Atherosclerosis can lead to a heart attack or stroke. A heart attack occurs when blood does not reach the heart muscle. This can result in damage to the heart, and can even result in death if not treated. A stroke occurs when clots form in the blood vessels that supply oxygen to the brain. This can lead to ruptured blood vessels and internal bleeding, as shown in **Figure 11**. Parts of the brain die because brain cells are deprived of oxygen.

Check Your Progress

Summary

- Blood vessels transport important substances throughout the body.
- The top half of the heart is made up of two atria, and the bottom half is made up of two ventricles.
- The heart pumps deoxygenated blood to the lungs, and it pumps oxygenated blood to the body.
- Blood is made up of plasma, red blood cells, white blood cells, and platelets.
- Blood is classified by the following four blood types: A, B, AB, and O.

Demonstrate Understanding

1. **Diagram** the path of blood through the heart and body.
2. **Compare and contrast** the structure of arteries and the structure of veins.
3. **Calculate** the average number of red blood cells for every 100 white blood cells in the human body.
4. **Summarize** the main functions of the circulatory system.
5. **Explain** the essential functions of life performed by the specialized cells that make up blood.

Explain Your Thinking

6. **Cause and Effect** If a pacemaker received faulty signals from the brain, what would happen?
7. **Hypothesize** why exercise helps to maintain a healthy heart.
8. **MATH Connection** Count the number of times your heart beats during 15 seconds. What is your heart rate per minute?

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LESSON 2

RESPIRATORY SYSTEM

FOCUS QUESTION

Why is exercise good for the respiratory system?

The Importance of Respiration

Your body's cells require oxygen. Recall that oxygen and glucose are used by cells to produce energy-rich ATP molecules needed to maintain cellular metabolism. This process is called cellular respiration. In addition to releasing energy, cellular respiration releases carbon dioxide and water.

Breathing and respiration

The respiratory system sustains cellular respiration by supplying oxygen to body cells and by removing carbon dioxide waste from cells.

The functions of the respiratory system can be divided into two processes: breathing and respiration. First, air must enter the body through breathing. **Breathing** is the mechanical movement of air into and out of your lungs. **Figure 12** illustrates air being released from the lungs into the air. Second, gases are exchanged in the body. **External respiration** is the exchange of gases between the atmosphere and the blood, which occurs in the lungs. **Internal respiration** is the exchange of gases between the blood and the body's cells.

Get It?

Compare and contrast external respiration and internal respiration.

Figure 12 Exhaled air from a person's lungs can be seen on a chilly day.

Infer *how the air that you inhale is different from the air that you exhale.*

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 Blood Pressure

Carry out an investigation to determine the cause and effect exercise has on the circulatory and respiratory systems.

CCC **Identify Crosscutting Concepts**

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

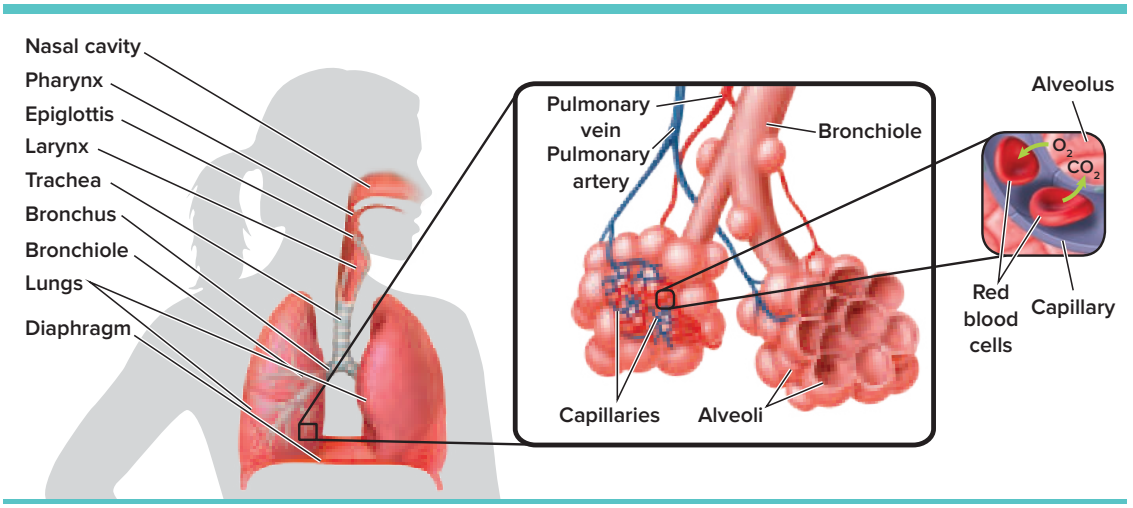


Figure 13 Air travels into the alveoli of the lungs, where gases are exchanged across thin capillary walls.
Diagram *Trace the path of oxygen from the atmosphere to the alveoli in the lungs.*

The Path of Air

The respiratory system is made up of the nasal passages, pharynx (FER ingks), larynx (LER ingks) or voice box, epiglottis, trachea, lungs, bronchi, bronchioles, alveoli (al VEE uh li), and diaphragm. Air travels from the outside environment to the lungs, where it passes through the alveoli, as shown in **Figure 13**.

First, air enters the mouth or nose. Hairs in the nose filter out dust and other large particles in the air. Hairlike structures called cilia, shown in **Figure 14**, also line the nasal passages, as well as other respiratory tubes. Cilia trap foreign particles from the air and sweep them toward the throat so that they do not enter the lungs. Mucous membranes beneath the cilia in the nasal passages, also shown in **Figure 14**, warm and moisten the air while trapping foreign materials.

Get It?

Identify the role of cilia in the respiratory system.

Filtered air then passes through the upper throat, called the pharynx. A flap of tissue called the epiglottis, which covers the opening to the larynx, prevents food particles from entering the respiratory tubes. The epiglottis allows air to pass from the larynx to a long tube in the chest cavity called the **trachea,** or windpipe. The trachea branches into two large tubes, called **bronchi** (BRAHN ki) (singular, bronchus), which lead to the lungs. The **lungs** are the largest organs in the respiratory system, and gas exchange takes place in the lungs. Each bronchus branches into smaller tubes called bronchioles (BRAHN kee ohlz), which continue to branch into even smaller passageways. Each of these ends in an individual air sac called an **alveolus** (plural, alveoli). Each alveolus has a thin wall—only one cell thick—and is surrounded by very thin capillaries.

Color-Enhanced SEM Magnification: unknown

Figure 14 Hairlike cilia line the mucous membranes of the nasal cavity.

Gas exchange in the lungs

Air travels to individual alveoli, where oxygen diffuses across the moist, thin walls into capillaries and then into red blood cells. The oxygen is then transported to be released to tissue cells in the body during internal respiration. Meanwhile, carbon dioxide in the blood crosses capillary walls and diffuses into the alveoli to be returned to the atmosphere during external respiration. Carbon dioxide in the blood is found as carbonic acid in the red blood cells, dissolved in plasma, and bound to hemoglobin in red blood cells.

Breathing

The brain directs the rate of breathing by responding to internal stimuli that indicate how much oxygen the body needs. When the concentration of carbon dioxide in the blood is high, the breathing rate increases because cells need more oxygen.

Inhalation is the act of taking air into the lungs. During inhalation, as shown in **Figure 15**, the diaphragm contracts. This causes the chest cavity to expand as the diaphragm moves down, allowing air to move into the lungs. During exhalation, the diaphragm relaxes and returns to its normal resting position. This reduces the size of the chest cavity as the diaphragm moves up. Air naturally flows out from the greater pressure of the lungs. Follow **Figure 16** on the next page to learn how circulation and respiration work together to supply the needed oxygen and to get rid of carbon dioxide.

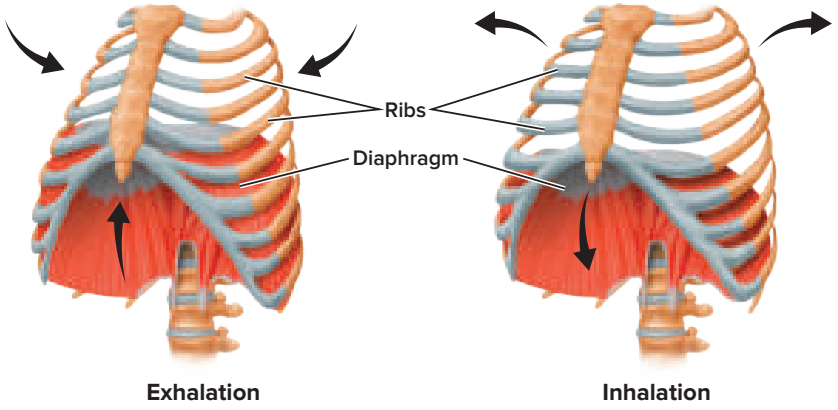


Figure 15 Rib and diaphragm muscles contract and relax during breathing.
Analyze *how air pressure is involved in breathing.*

WORD ORIGINS

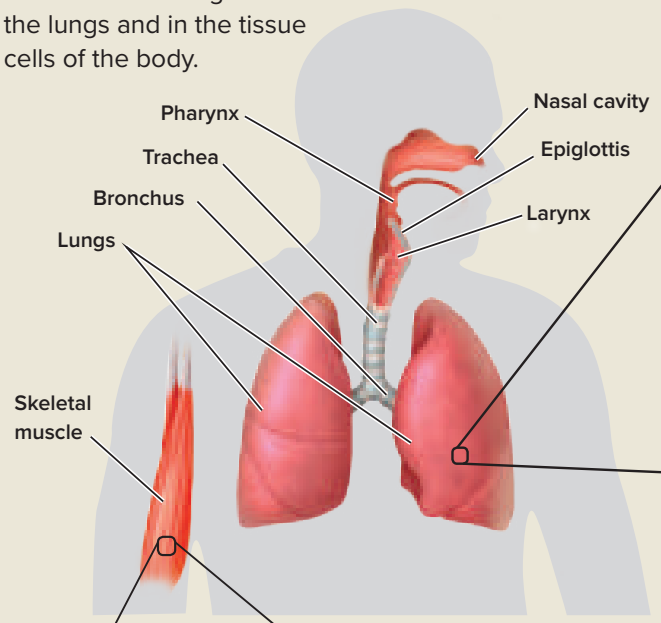
alveolus
comes from the Latin word *alveus*, meaning *belly* or *hollow space*

CCC CROSSCUTTING CONCEPTS

Systems and System Models Design a model of the respiratory system. Define the system and discuss how the model provides a tool for understanding the system. What are the limitations of your model? How could you improve your model?

Figure 16 Visualizing Gas Exchange

Gases are exchanged in the lungs and in the tissue cells of the body.



In the lungs, oxygen (O_2) that is inhaled moves into capillaries and is transported to body cells. Carbon dioxide (CO_2) leaves the capillaries and is exhaled from the lungs.

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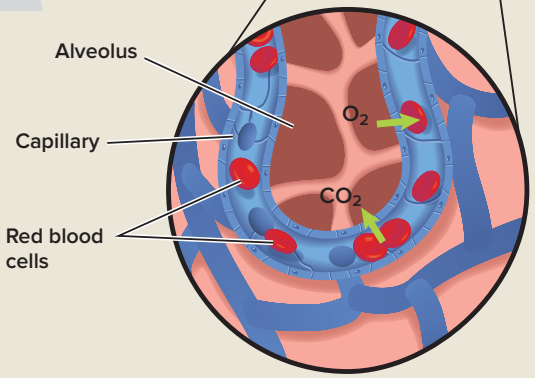

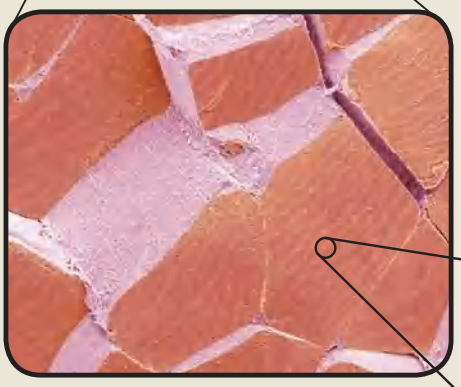

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In body tissues, such as muscle tissues, oxygen (O_2) moves from capillaries into tissue cells. Carbon dioxide (CO_2) produced by cellular respiration leaves tissue cells and moves into capillaries, and then it is transported to the lungs.

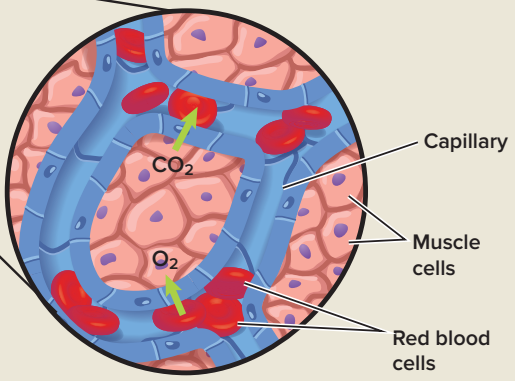

Table 2 Common Respiratory Disorders

Disorder	Brief Description
Asthma	Respiratory pathways become irritated, and bronchioles constrict.
Bronchitis	Respiratory pathways become infected, resulting in coughing and production of mucus.
Emphysema	Alveoli break down, resulting in reduced surface area needed for gas exchange with the alveoli's blood capillaries.
Pneumonia	Infection of the lungs causes the alveoli to collect mucous material.
Lung cancer	Uncontrolled cell growth in lung tissue can lead to a persistent cough, shortness of breath, bronchitis, or pneumonia, and can lead to death.

Respiratory Disorders

Some diseases and disorders irritate, inflame, or infect the respiratory system, as described in **Table 2**. These disorders can produce tissue damage that reduces the effectiveness of the bronchi and alveoli. When these tissues become damaged, respiration becomes difficult. Smoking also causes chronic irritation to respiratory tissues and inhibits cellular metabolism. Finally, exposure to airborne materials, such as pollen, can produce respiratory problems in some people who have allergic reactions.

Check Your Progress

Summary

- Alveoli in the lungs are the sites of gas exchange between the respiratory and circulatory systems.
- The pathway of air starts with the mouth or nose and ends at the alveoli located in the lungs.
- Inhalation and exhalation are the processes of taking in and expelling air.
- Respiratory disorders can inhibit respiration.

Demonstrate Understanding

1. **Identify** the main function of the respiratory system.
2. **Distinguish** between internal and external respiration.
3. **Sequence** the path of air from the nasal passages to the bloodstream.
4. **Describe** the mechanics of inhalation and exhalation.
5. **Infer** how the respiratory system would compensate for a circulatory disorder.
6. **Describe** three disorders of the respiratory system.

Explain Your Thinking

7. **Hypothesize** an advantage of heating and moisturizing air before it reaches the alveoli.
8. **MATH Connection** The total surface area of the alveoli tissue in your lungs is approximately 70 m^2. This is more than 40 times the surface area of the skin. What is the surface area of your skin?

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LESSON 3

THE EXCRETORY SYSTEM

FOCUS QUESTION

Can exercise affect the excretory system?

Parts of the Excretory System

As you breathe, eat, walk, study, and sleep, your body collects wastes. These wastes include toxins, waste products, and carbon dioxide, that result from metabolic functions that occur in your body constantly and without you thinking about it.

What happens to all of these wastes? The excretory system removes them from the body. In addition, the excretory system regulates the amount of fluid and salts in the body, and it maintains the pH of the blood. All of these functions help to maintain homeostasis.

The components that make up the excretory system include the lungs, skin, and kidneys, as illustrated in **Figure 17**. The lungs primarily excrete carbon dioxide. The skin primarily excretes water and salts contained in sweat. The kidneys, however, are the major excretory organs in the body. The kidneys filter wastes and other substances from the blood. The ureters carry urine produced in the kidneys to the bladder. Urine exits the body through the urethra.

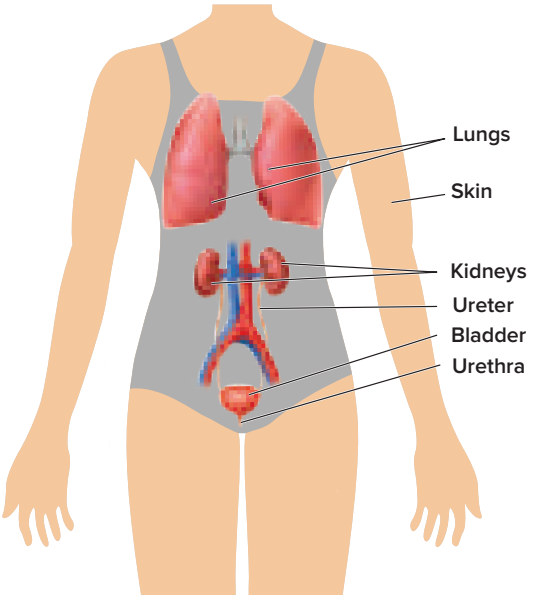

Figure 17 The organs of excretion work together to eliminate wastes from the body. These organs include the lungs, skin, and kidneys.

Get It?

Identify the components of the excretory system.

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: Internet: Make Positive Health Choices

Plan and carry out an investigation to determine how lifestyle choices affect the function of the circulatory, respiratory, and excretory systems.

Revisit the Encounter the Phenomenon Question

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

The Kidneys

As shown in **Figure 18**, the **kidneys** are bean-shaped organs that filter out wastes, water, and salts from the blood. The kidneys are divided into two distinct regions, also illustrated in **Figure 18**. The outer portion is called the renal cortex and the inner region is called the renal medulla. Each of these regions contains microscopic tubes and blood vessels. In the center of each kidney is a region called the renal pelvis, where urine collection occurs. Follow **Figure 18** as you read about how the kidneys function.

Nephron filtration

Each kidney contains approximately one million filtering units called nephrons. Blood enters each nephron through a long tube that is surrounded by a ball of capillaries called the glomerulus (gluh MER uh lus) (plural, glomeruli). The glomerulus is surrounded by a structure called the Bowman's capsule.

The renal artery transports nutrients and wastes to the kidney and branches into smaller and smaller blood vessels, eventually reaching the tiny capillaries in the glomerulus. The walls of the capillaries are very thin, and the blood is under great pressure. As a result, water and substances dissolved in the water, such as the nitrogenous waste product called **urea**, are pushed through the capillary walls into the Bowman's capsule. Larger molecules, such as red blood cells and proteins, remain in the bloodstream.

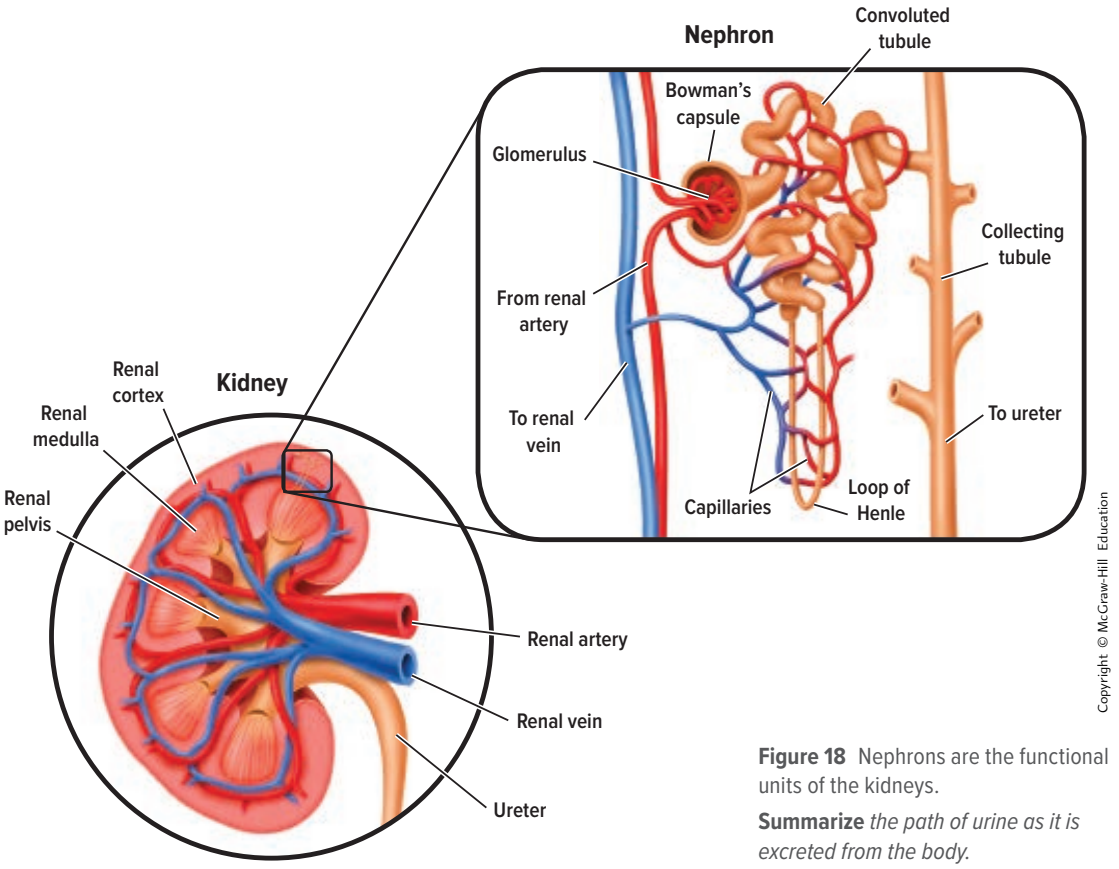

Figure 18 Nephrons are the functional units of the kidneys.

Summarize *the path of urine as it is excreted from the body.*

Reabsorption and the formation of urine

The filtrate collected in the Bowman's capsule flows through the renal tubule, which consists of the convoluted tubule, the loop of Henle, and the collecting tubule, as illustrated in **Figure 18**.

Much of the lost water and useful substances, such as glucose and minerals, are reabsorbed into the capillaries surrounding the renal tubule. This process is called reabsorption. At the same time, excess fluids and toxic substances in the capillaries are passed to the collecting tubules. This waste product is called urine. Urine leaves the kidney through ducts called the ureters (YOO ruh turz), as shown in **Figure 18**. Urine is then stored in the urinary bladder and exits the body through the urethra.

The kidneys filter about 180 L of blood each day in adults but produce only about 1.5 L of urine. The processes of filtration and reabsorption from the blood require large amounts of energy. Although kidneys account for only one percent of body weight, they use 20 to 25 percent of the body's oxygen intake for their internal energy requirements.

CHEMISTRY Connection The kidneys can help maintain a normal pH in the blood by adjusting the acid-base balance. Recall that low pH results when there is an abundance of H^+. When the blood pH is too low, the kidneys can increase pH levels in the body by excreting hydrogen (H^+) ions and ammonia into the renal tubules. The kidneys can decrease pH levels by reabsorbing buffers such as bicarbonate (HCO_3^-) and sodium (Na^+) ions. Because biological processes normally require pH between 6.5 and 7.5, the kidneys help to maintain homeostasis by keeping pH levels within the normal range.

Get It?
Describe the process of reabsorption.

Kidney Disorders

Sometimes kidney function can be inhibited or impaired by infections or disorders. When kidney function is impaired, the body cannot rid itself of wastes and homeostasis might be disrupted.

Infections

Symptoms of a kidney infection include fever, chills, and mid- to low-back pain. Kidney infections often start as urinary bladder infections that spread to the kidneys. Obstructions in the kidneys also can cause an infection. If the infection is not treated, the kidneys can become scarred and their function might be permanently impaired. Antibiotics usually are effective in treating bacterial infections.

STEM CAREER Connection

Nephrology Nurse

Do you want a career that gives you the opportunity to help people who are seriously ill? Nephrology nurses are registered nurses who care for patients of all ages who have kidney-related health conditions, such as high blood pressure, diabetes, infections, birth defects, and substance abuse. These highly skilled nurses require advanced education and training.

CCC CROSSCUTTING CONCEPTS

Stability and Change Make a graphic organizer that summarizes how the kidneys help maintain homeostasis and a normal pH in the blood. Use specific information from the text.

Nephritis

Another common kidney problem is nephritis (nih FRIH tus), which often is caused by inflammation or painful swelling of some of the glomeruli, as listed in **Table 3**. This occurs for many reasons, such as when large particles in the bloodstream become lodged in some of the glomeruli. Symptoms of this condition include blood in the urine, swelling of body tissues, and protein in the urine. If this condition does not improve on its own, the patient may need a special diet or prescription drugs to treat the infection.

Kidney stones

Kidney stones are another type of kidney disorder, as listed in **Table 3** and shown in **Figure 19**. A kidney stone is a crystallized solid, such as calcium compounds, that forms in the kidney. Small stones can pass out of the body in urine; this can be quite painful. Larger stones often are broken into small pieces by ultrasonic sound waves. The smaller stones then can pass out of the body. In some cases, surgery might be required to remove large stones.

Figure 19 Kidney stones form as minerals, such as calcium, and become solid masses.

Kidneys also can be damaged by other diseases present in the body. Diabetes and high blood pressure are the two most common reasons for reduced kidney function and kidney failure. In addition, kidneys can be damaged by prescription and illegal drug use.

Table 3 Common Excretory Disorders

Excretory Disorder	Brief Description
Nephritis	Inflammation of the glomeruli can lead to inflammation of the entire kidneys. This disorder can lead to kidney failure if it is left untreated.
Kidney stones	Hard deposits form in the kidneys that might pass out of the body in urine. Larger kidney stones can block urine flow or irritate the lining of the urinary tract, leading to possible infection.
Urinary tract blockage	Malformations present at birth can lead to blockage of the normal flow of urine. If it is untreated, this blockage can lead to permanent damage of the kidneys.
Polycystic kidney disease	This is a genetic disorder distinguished by the growth of many fluid-filled cysts in the kidneys. This disorder can reduce kidney function and lead to kidney failure.
Kidney cancer	Uncontrolled cell growth often begins in the cells that line the tubules within the kidneys. This can lead to blood in the urine or a mass in the kidneys, or it can affect other organs as the cancer spreads, which can lead to death.

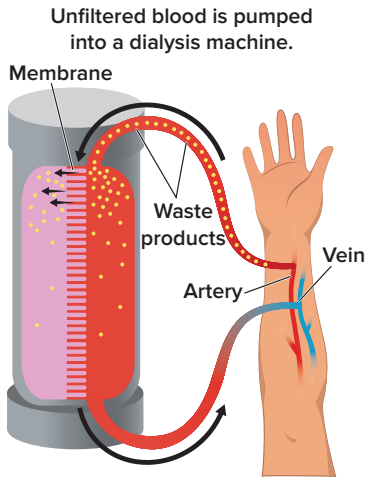

Figure 20 Dialysis is used to filter wastes and toxins from a patient's blood.

Kidney Treatments

Modern medicine offers two possible treatments for reduced kidney function or complete kidney failure.

Dialysis

Dialysis (di AH luh sus) is a procedure in which an artificial kidney machine filters out wastes and toxins from a patient's blood. One type of dialysis is illustrated in **Figure 20**. Blood is passed through a machine that temporarily filters and cleanses the blood. The filtered blood is then returned to the patient's body. The procedure lasts about three to four hours and requires three sessions per week.

Kidney transplant

A kidney transplant is the surgical placement of a healthy kidney from another person, called a donor, into the patient's body. Kidney transplants have shown increasing success in recent years. The major complication of a transplant is rejection of the donated organ. Rejection is prevented with medications such as steroids. Many transplant patients also need blood-pressure medication and other drugs to prevent infection.

Check Your Progress

Summary

- The kidneys are the main excretory organs in the body.
- Nephrons are independent filtration units in the kidneys.
- Water and important substances are reabsorbed into the blood after filtration.
- The kidneys produce a waste product called urine.

Demonstrate Understanding

1. **Explain** how the kidneys help maintain homeostasis.
2. **Diagram** the excretion of waste from the Bowman's capsule to the urethra.
3. **Compare and contrast** filtration and reabsorption in a nephron.
4. **Explain** how kidney disorders may result from genetic or environmental factors and how the disorder can affect an individual.

Explain Your Thinking

5. **Hypothesize** why kidney failure without dialysis can result in death.
6. **MATH Connection** Calculate the average amount of urine that the body produces in a week.

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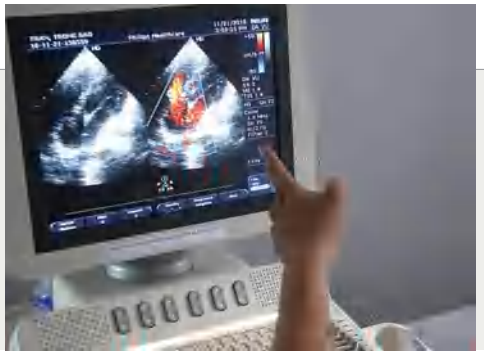
SCIENCE & TECHNOLOGY

Matters of the Heart

Blood pressure and flow are two components of hemodynamics—the forces acting within the circulatory system as the heart pumps blood. By building models, physicians and scientists are understanding the relationship between hemodynamics and the physiology of the circulatory system.



Physicians use doppler echocardiograms like this one to observe blood flow through the heart of a patient.

Researchers are investigating the influence of hemodynamics on fetal development, cardiovascular disease progression, and cardiovascular device function—such as stents and replacement heart valves. A variety of models, from incubator-sized physical models of circulatory systems to elegant computational models, are used to understand how hemodynamics impact specific components of the system.

Hemodynamics is particularly important for understanding heart valve disease and for developing replacement valves. The heart's four valves operate based on hemodynamics. The changing pressures that occur with each heartbeat cause the valves to open and close, keeping oxygenated blood separate from deoxygenated blood. The doppler echocardiogram in the photo shows the pattern of blood flow through the heart.

When a heart valve needs to be replaced, surgeons typically use either mechanical valves or biologic valves. Mechanical valves do not contain any tissue and require the recipient to take medicine to prevent blood clots.

Biologic valves are constructed from animal tissue, typically from a sheep or a cow. Biologic valves often wear out and need to be replaced more than once. In children who need replacement heart valves, a biologic valve might only last a matter of months.

To design better replacement valves for all patients, researchers are looking to modeling to understand the forces acting on the valves. By using an incubator-sized model, researchers can test a newly designed replacement valve without putting it in a patient. They can adjust the fluid properties and pressures based on different parameters, and they can use the resulting data to refine the design of the replacement valve.

Other researchers use data from physical models and from patients to build computational models that help scientists understand the disease process in a specific patient.

COMMUNICATE SCIENTIFIC INFORMATION

Research heart valve replacement surgery. Write a paper summarizing the different treatment options.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 CIRCULATORY SYSTEM

- Blood vessels transport important substances throughout the body.
- The top half of the heart is made up of two atria, and the bottom half is made up of two ventricles.
- The heart pumps deoxygenated blood to the lungs, and it pumps oxygenated blood to the body.
- Blood is made up of plasma, red blood cells, white blood cells, and platelets.
- Blood is classified by the following four blood types: A, B, AB, and O.

- artery
- capillary
- vein
- valve
- heart
- pacemaker
- plasma
- red blood cell
- platelet
- white blood cell
- atherosclerosis

Lesson 2 RESPIRATORY SYSTEM

- Alveoli in the lungs are the sites of gas exchange between the respiratory and circulatory systems.
- The pathway of air starts with the mouth or nose and ends at the alveoli located in the lungs.
- Inhalation and exhalation are the processes of taking in and expelling air.
- Respiratory disorders can inhibit respiration.

- breathing
- external respiration
- internal respiration
- trachea
- bronchus
- lung
- alveolus

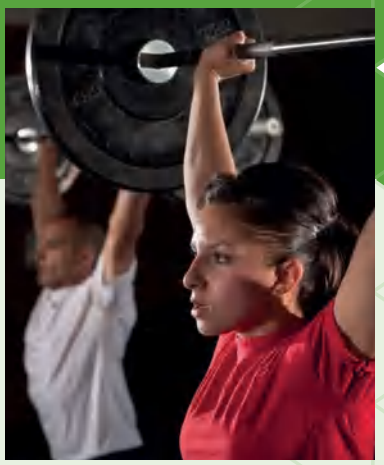
Lesson 3 EXCRETORY SYSTEM

- The kidneys are the main excretory organs in the body.
- Nephrons are independent filtration units in the kidneys.
- Water and important substances are reabsorbed into the blood after filtration.
- The kidneys produce a waste product called urine.

- kidney
- urea

THREE-DIMENSIONAL THINKING

Module Wrap-Up



REVISIT THE PHENOMENON

What is the woman's body doing in response to lifting? Why?

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 do extreme conditions affect the average daily loss of water in the human body?

The body obtains water by absorbing it through the digestive tract. The body loses water primarily by excreting it in urine from the kidneys, through sweat, and through the lungs.

Data and Observations The table shows data collected for normal temperatures, for high temperatures, and during rigorous exercise.

CER Analyze and Interpret Data

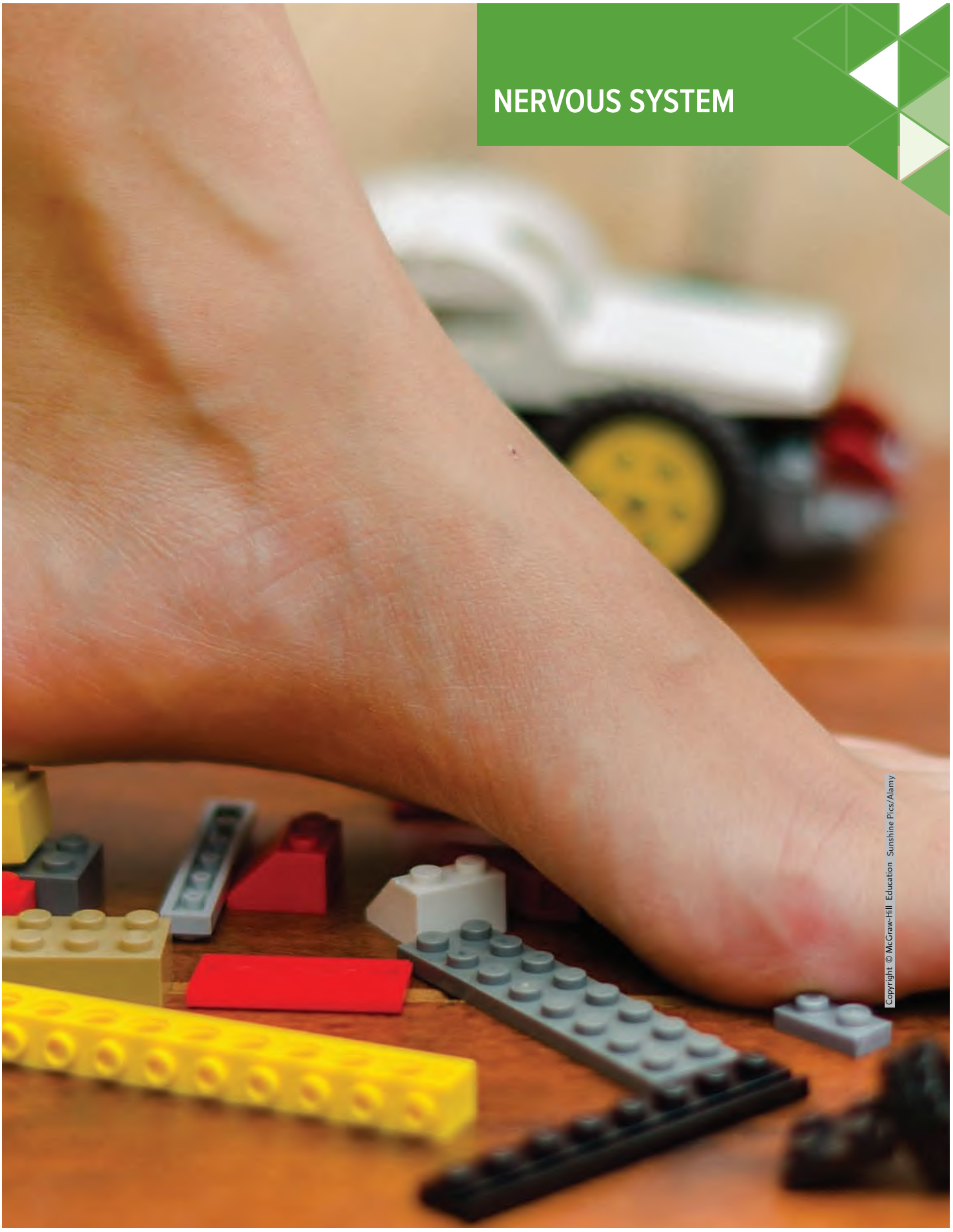
1. **Claim, Evidence** Identify what the major source of water loss is during normal temperatures.
2. **Reasoning** Hypothesize why more water is lost in sweat during rigorous exercise than in urine.
3. **Calculate** the percent of water loss for each of the three conditions.

Average Daily Water Loss in Humans (in mL)

Source	Normal Temperatures	High Temperatures	Rigorous Exercise
Kidneys	1500	1400	750
Skin	450	1800	5000
Lungs	450	350	650

*Data obtained from: Beers, M. 2003. *The Merck Manual of Medical Information, Second Edition* West Point, PA.: Merck & Co. Inc.

NERVOUS SYSTEM



NERVOUS SYSTEM

ENCOUNTER THE PHENOMENON

If you step on several toy blocks, it's going to hurt. Why is this response a good thing?

SEP Ask Questions

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

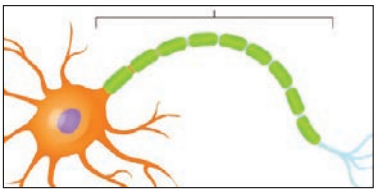
CER Claim, Evidence, Reasoning

Make your Claim Use your CER chart to make a claim about why a response when stepping on toy blocks is a good thing. Explain your reasoning.

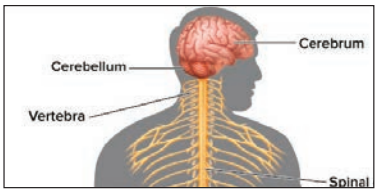
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

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 Nervous System: How Nerves Work



LESSON 2: Explore & Explain: Organization of the Nervous System

LESSON 1

STRUCTURE OF THE NERVOUS SYSTEM

FOCUS QUESTION

What are the structures and functions of a neuron?

Neurons

When you stub your toe, you know right away what happened. How does your brain get the message so quickly? Electricity and chemistry are both involved in getting messages to your brain. **Neurons** are specialized cells that help you gather information about your environment, interpret the information, and react to it. Neurons make up an enormous communication network in your body called the nervous system.

Figure 1 shows that a neuron consists of three main regions: the dendrites, a cell body, and an axon. **Dendrites** receive signals called impulses from other neurons and conduct the impulses to the cell body. Each neuron contains several dendrites. The nucleus of the neuron and many of the cell organelles are found in the **cell body.** Lastly, an **axon** carries the nerve impulse from the cell body to other neurons and muscles.

Get It?

Relate dendrites, axons, and cell bodies.

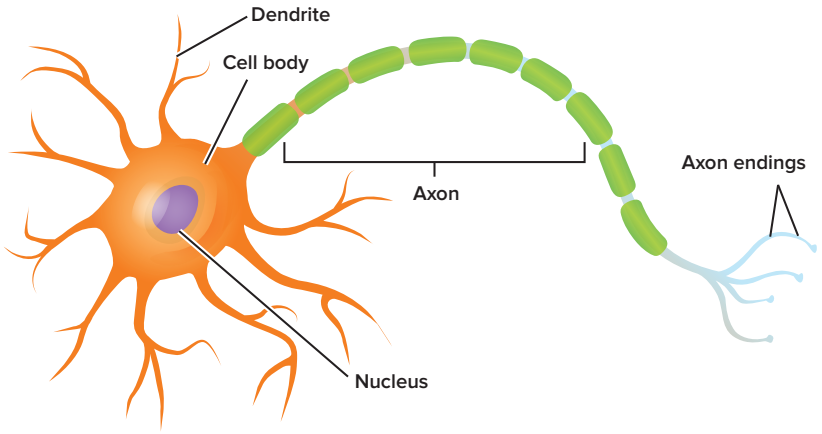


Figure 1 There are three main parts of a neuron: the dendrites, a cell body, and an axon. Neurons are highly specialized cells that are organized to form complex networks.

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 do neural pathways develop and become more efficient?
Plan and carry out an investigation to determine the effect learning strategies have on a neural circuit.

Quick Investigation: Investigate the Blink Reflex
Carry out an investigation to determine the effect stimuli have on the blink reflex.

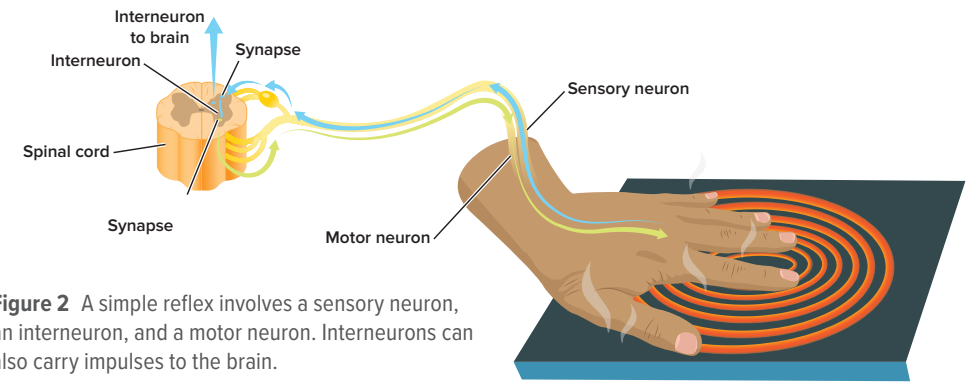


Figure 2 A simple reflex involves a sensory neuron, an interneuron, and a motor neuron. Interneurons can also carry impulses to the brain.

Explain *how a reflex might be completed before the brain interprets the event.*

There are three kinds of neurons: sensory neurons, interneurons, and motor neurons. Sensory neurons send impulses from receptors in the skin and sense organs to the brain and spinal cord. Sensory neurons signal interneurons, which are found in the spinal cord and brain. Interneurons carry the impulse to motor neurons, which carry impulses away from the brain and spinal cord to a gland or muscle, which results in a response. Refer to **Figure 2** to follow the path of an impulse for a simple involuntary reflex. The nerve impulse completes what is called a reflex arc. A **reflex arc** is a nerve pathway that consists of a sensory neuron, an interneuron, and a motor neuron. Notice that the brain is not involved. A reflex arc is a basic structure of the nervous system.

A Nerve Impulse

PHYSICS Connection A nerve impulse is an electrical charge traveling the length of a neuron. An impulse results from a stimulus, such as a touch or a loud bang, which causes a person to react.

A neuron at rest

The neuron in **Figure 3** is at rest, which means it is not conducting an impulse. Notice that there are more sodium ions (Na^+) outside the cell than inside the cell. The reverse is true for potassium ions (K^+)—there are more potassium ions inside the cell than outside the cell.

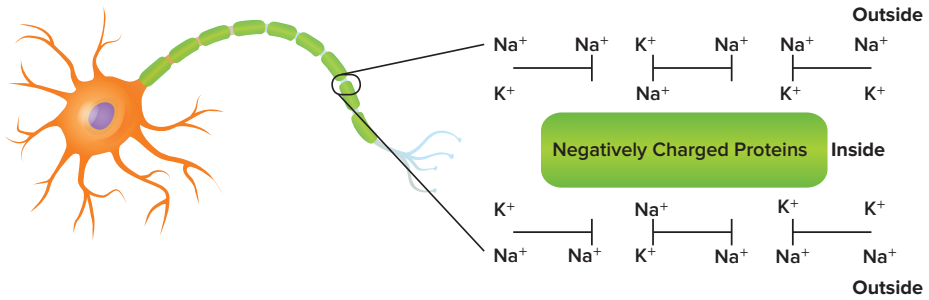


Figure 3 The distribution of Na^+ and K^+ ions, and the presence of negatively charged protein molecules in the cytoplasm, keep the inside of the cell more negatively charged than the outside when a neuron is at rest.

Recall that ions tend to diffuse across the plasma membrane from an area of high concentration of ions to an area of low concentration of ions. Proteins found in the plasma membrane work to counteract the diffusion of the sodium ions and potassium ions. These proteins, called the sodium-potassium pump, actively transport sodium ions out of the cell and potassium ions into the cell.

For every two potassium ions pumped into a neuron, three sodium ions are pumped out. This maintains an unequal distribution of positively charged ions, resulting in a positive charge outside the neuron and a negatively charged cytoplasm inside the neuron.

An action potential

Another name for a nerve impulse is an **action potential.** The minimum stimulus to cause an action potential to be produced is a **threshold.** However, a stronger stimulus does not generate a stronger action potential. Action potentials are described as being "all or nothing," meaning that a nerve impulse is either strong enough to travel along the neuron or it is not strong enough.

When a stimulus reaches the threshold, channels in the plasma membrane open. Sodium ions rapidly move into the cytoplasm of the neuron through these channels, causing a temporary reversal in electrical charges. The inside of the cell then has a positive charge, which causes other channels to open. Potassium ions leave the cell through these channels, restoring a positive charge outside the cell. **Figure 4** shows that this change in charge moves like a wave along the length of the axon.

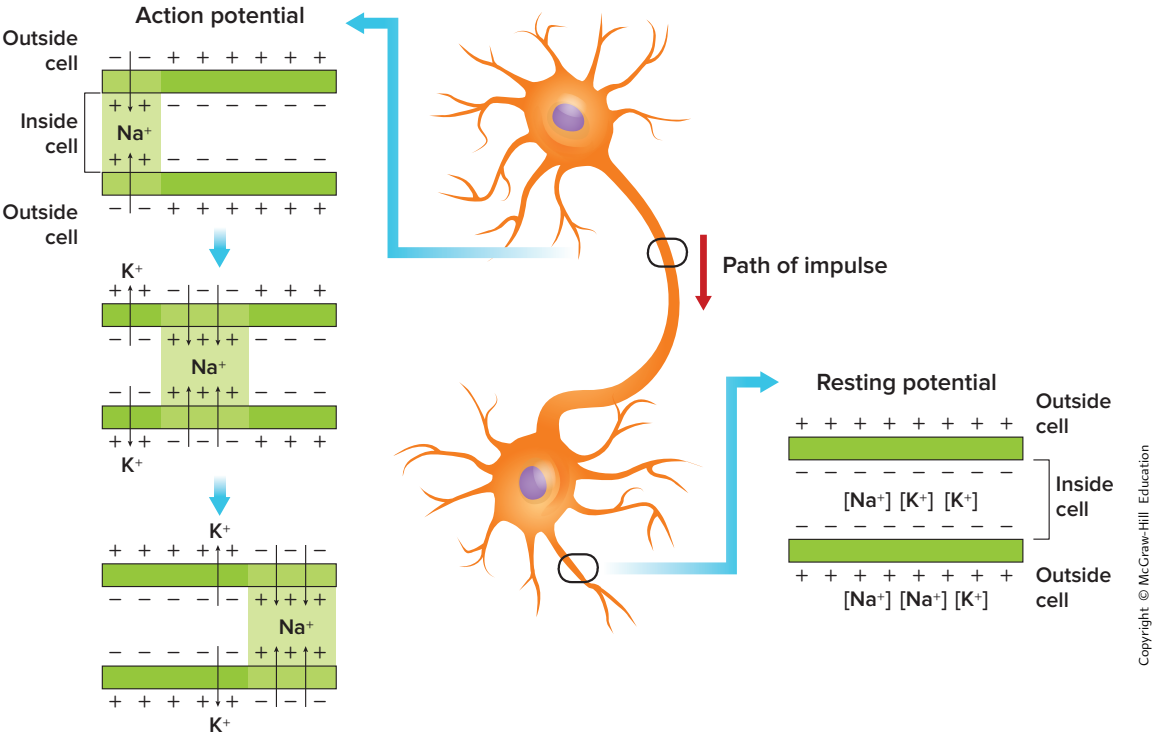


Figure 4 Follow as an action potential moves along an axon from left to right. Notice what happens to the Na^+ and K^+ and how this changes the relative electrical charges inside and outside the neuron.

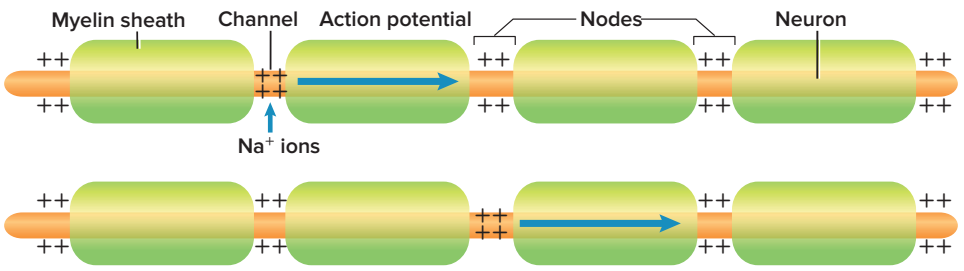


Figure 5 A nerve impulse moves from node to node along myelinated axons.

Explain *what happens at a node when an impulse moves along a myelinated axon.*

Speed of an action potential

The speed of an action potential varies. Many axons have a covering of a lipid called myelin, which forms an insulating layer, called a sheath, around the axon. The myelin sheath has many gaps, called **nodes,** along the length of the axon, as shown in **Figure 5**. Sodium ions and potassium ions cannot diffuse through myelin, but they can reach the plasma membrane at these nodes. This allows the action potential to jump from node to node, greatly increasing the speed of the impulse as it travels the length of the axon. For example, an axon that is not covered with myelin may conduct an impulse at a speed of only 10 m/s. An axon that is covered with myelin can conduct impulses at speeds of up to 150 m/s.

In the human body, there are neurons that have myelin, and neurons that do not have myelin. Neurons with myelin carry impulses that are associated with sharp pain; neurons that lack myelin carry impulses associated with dull, throbbing pain. The action potentials in these neurons travel much more slowly than they do in neurons with myelin. If you were to accidentally cut your finger on the cactus spines shown in **Figure 6,** which kind of neurons would be involved?

Figure 6 Pain receptors in the skin would send impulses to the brain if a person's finger were to be cut by the sharp spines on this cactus.

Get It?

Explain the relationship of a threshold to an action potential.

SCIENCE USAGE v. COMMON USAGE

Channel

Science usage: a path along which information in the form of ions or molecules passes

Nerve impulses move as channels open in the plasma membrane.

Common usage: the deeper part of a river, harbor, or strait

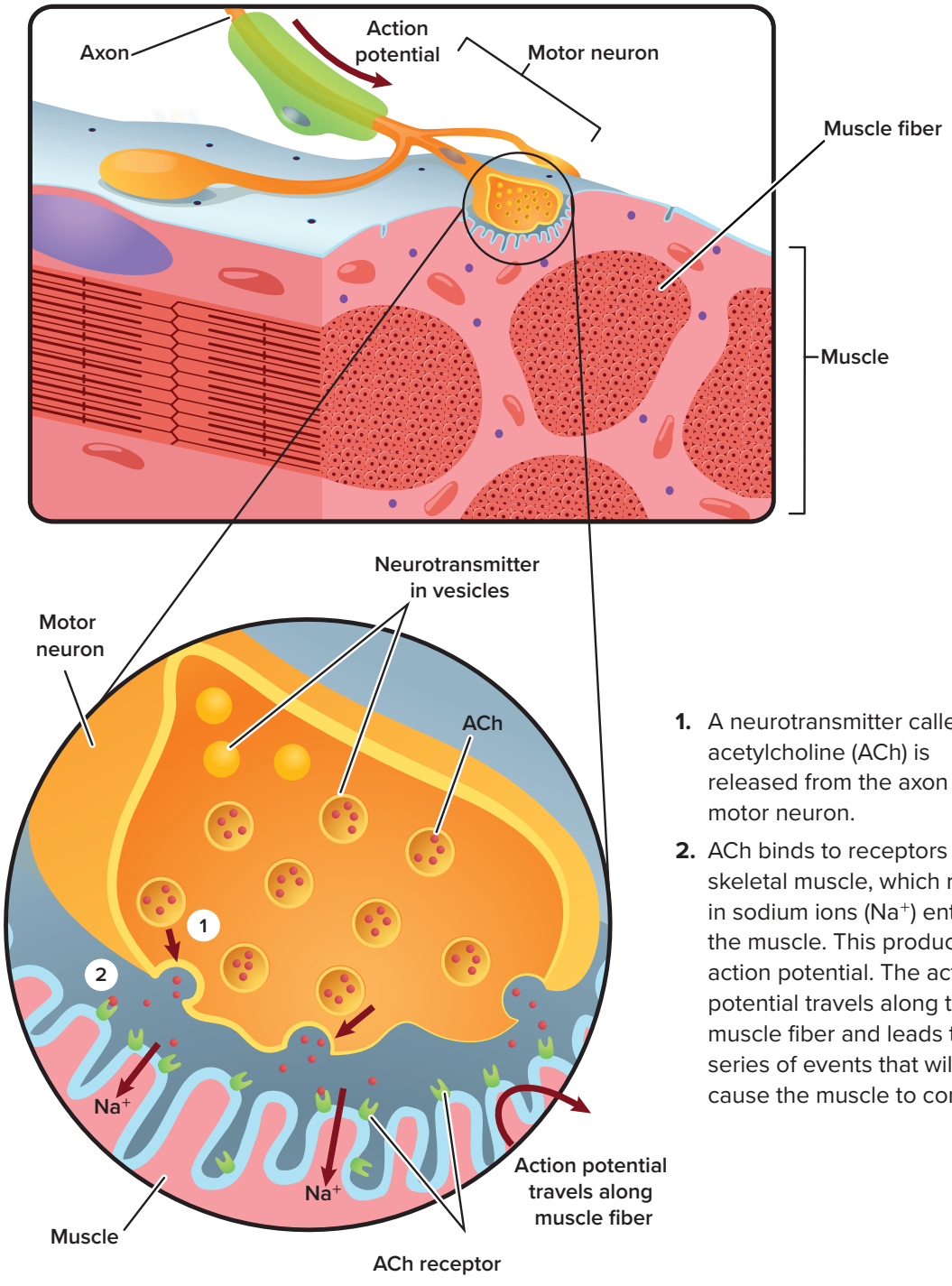
Large ships move through a harbor channel.

CCC CROSSCUTTING CONCEPTS

Systems and System Models Study **Figure 4** and **Figure 5.** Using evidence from these two figures, write an analogy that helps to explain how the parts of a nerve work together to conduct an impulse.

Figure 7 Visualizing An Action Potential

To cause the voluntary contraction of a muscle, a signal from the brain creates an action potential in a motor neuron. This action potential travels along the motor neuron, which leads to the release of a neurotransmitter that signals the fibers of the muscle to contract.



1. A neurotransmitter called acetylcholine (ACh) is released from the axon of a motor neuron.
2. ACh binds to receptors on a skeletal muscle, which results in sodium ions (Na^+) entering the muscle. This produces an action potential. The action potential travels along the muscle fiber and leads to a series of events that will cause the muscle to contract.

The synapse

A small gap exists between the axon of one neuron and the dendrite of another neuron. This gap is called a **synapse** (SIH naps). When an action potential reaches the end of an axon, small sacs called vesicles carrying neurotransmitters fuse with the plasma membrane and release a neurotransmitter by exocytosis. When a motor neuron synapses with a muscle cell, as illustrated in **Figure 7** on the last page, the released neurotransmitter crosses the synapse and causes a muscle to contract.

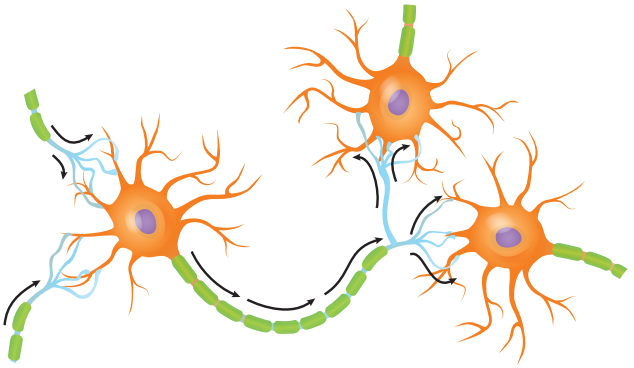


Figure 8 A single neuron can have multiple connections with other neurons.

CHEMISTRY Connection A **neurotransmitter** is a chemical that diffuses across a synapse and binds to receptors on the dendrite of a neighboring neuron. This causes channels to open on the neighboring cell and creates a new action potential. Once a neurotransmitter has been released into a synapse, it does not remain there for long. Depending on the neurotransmitter, it might simply diffuse away from the synapse, or enzymes might break it down. Some neurotransmitters are taken up by the transport proteins in the membane of the neuron and used again. **Figure 8** shows that a single neuron can communicate with many other neurons.

Check Your Progress

Summary

- There are three major parts of a neuron.
- There are three basic types of neurons.
- A nerve impulse is an electric charge and is called an action potential.
- Neurons use chemicals and electricity to relay impulses.

Demonstrate Understanding

1. **Relate** the structure of a neuron to its function.
2. **Describe** how the structures of the nervous system are organized in a hierarchy.
3. **Infer** why energy is necessary to counteract the diffusion of Na^+ and K^+ ions across the plasma membrane of a neuron.

Explain Your Thinking

4. **Plan** an experiment that neurobiologists could use to show that an action potential travels faster along a myelinated axon than along a nonmyelinated axon.
5. **MATH Connection** The sciatic nerve extends from the lower spinal cord to the foot. If a person's sciatic nerve is 0.914 m in length and the speed of an action potential is 107 m/s, how long will it take for a nerve impulse to travel the full distance of this nerve?

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

LESSON 2

ORGANIZATION OF THE NERVOUS SYSTEM

FOCUS QUESTION

What are the major differences in the divisions of the nervous system?

The Central Nervous System

The nervous system consists of two major divisions. The interneurons of the brain and the spinal cord make up the **central nervous system** (CNS). The **peripheral nervous system** (PNS) consists of the sensory neurons and motor neurons that carry information to and from the CNS.

The function of the CNS is the coordination of all the body's activities. It relays messages, processes information, and analyzes responses. When sensory neurons carry information about the environment to the spinal cord, interneurons might respond via a reflex arc, or they might relay this information to the brain. Some brain interneurons send a message by way of the spinal cord to motor neurons, and the body responds. Other neurons in the brain might store the information.

Get It?

Describe the function of the central nervous system.

The brain

Over 100 billion neurons are found in the brain. Because the brain maintains homeostasis and is involved with almost all of the body's activities, it is sometimes called the control center of the body. Refer to **Figure 9** on the next page to learn about important events that have led to understanding of the functions of the brain. For example, four thousand years ago surgeons drilled holes in people's skulls in an effort to reduce pressure on the brain after a head injury or to release "bad humors" from the heads of people who had a mental illness. Fast forward to 1981, and the first mediciation used to treat depression is available with a presciption. The noninvasive brain surgery first performed in 2009 has been used to treat patients with pain or uncontrollable tremors. Approximately 1,000 beams of ultrasound pass through the skull and are focused on a specific area of tissue.

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 Cross Cutting Concepts**

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

Revisit the Encounter the Phenomenon Question

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

Figure 9

Brainstorm

For thousands of years, scientists have studied the brain and investigated ways to treat neurological diseases.

1 **2000 B.C.** Ancient surgeons use bronze tools to drill holes in the skull.

2 **300 B.C.** The first known human dissection is performed.

3 **1885** Knee-jerk response becomes one of the principle elements of a neurological exam after the absence of a knee-jerk response is described in syphilis patients.

4 **1901** Auguste D. age 51, has the first diagnosed case of Alzheimer's disease.

5 **1963** The theory of action potential, which explains the chemical processes of sending messages in the body, is described.

6 **1981** Fluoxetine, the first anti-depressant drug, is released.

7 **2005** Researchers create functioning brain cells from adult stem cells in mice.

8 **2009** Noninvasive brain surgery using ultrasound is successfully performed on nine people.

Refer to **Figure 10**. The **cerebrum** (suh REE brum) is the largest part of the brain and is divided into two halves called hemispheres. The two hemispheres are not independent of each other; they are connected by a bundle of nerves. The cerebrum carries out thought processes involved with learning, memory, language, speech, voluntary body movements, and sensory perception. Most of these higher thought processes occur near the surface of the brain. The folds and grooves on the surface of the cerebrum, as shown in **Figure 10**, increase its surface area and allow more complicated thought processes.

Get It?

Explain the importance of the folds and grooves on the surface of the cerebrum.

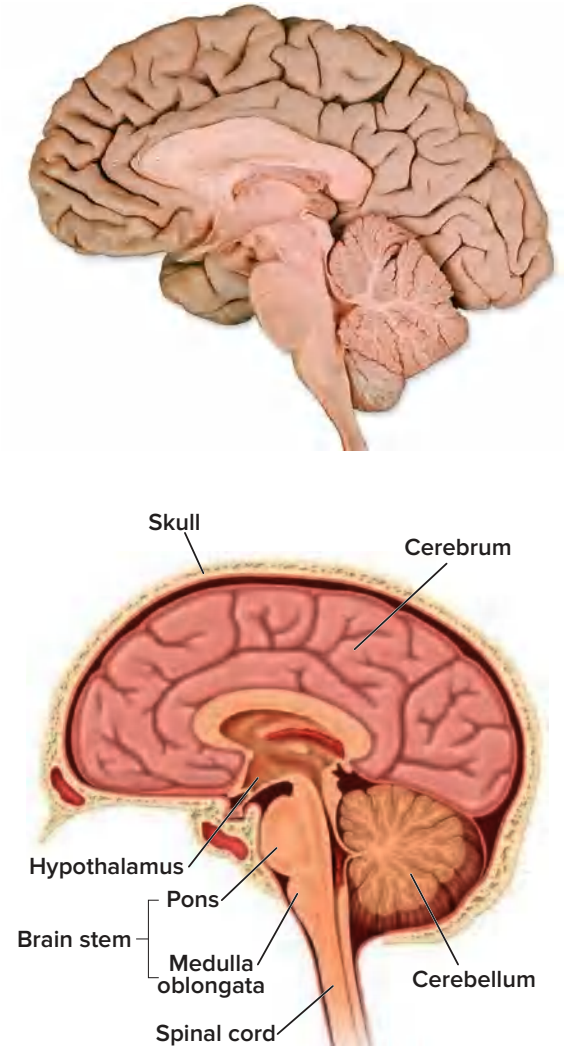


Figure 10 **Top:** A photograph of a human brain shows distinct sections. **Bottom:** The major sections of the brain are the cerebrum, the cerebellum, and the brain stem.

Describe *the position of the cerebrum in relation to the cerebellum.*

The cerebellum controls balance, posture, and coordination, and is located at the back of the brain. The cerebellum is responsible for the smooth and coordinated movement of skeletal muscles and is also involved with motor skills, such as playing the piano or riding a bike.

The brain stem connects the brain to the spinal cord and is made up of two regions called the medulla oblongata and the pons. The **medulla oblongata** relays signals between the brain and the spinal cord. It also helps control breathing rate, heart rate, and blood pressure. The **pons** relays signals between the cerebrum and the cerebellum. The pons also helps control the rate of breathing. Have you ever felt a gagging sensation when your doctor put a tongue depressor in your mouth? The medulla oblongata contains the interneurons responsible for the swallowing, gagging, vomiting, coughing, and sneezing reflexes.

Located between the brain stem and the cerebrum, the hypothalamus is essential for maintaining homeostasis. The **hypothalamus** (hi poh THA luh mus) regulates body temperature, thirst, appetite, and water balance. It also partially regulates blood pressure, sleep, aggression, fear, and sexual behavior. It is about the size of a fingernail and performs more functions than any other brain region of comparable size.

The spinal cord

The spinal cord is a nerve column that extends from the brain to the lower back. It is protected by the vertebrae. Spinal nerves extend from the spinal cord to parts of the body and connect them to the central nervous system. Reflexes are processed in the spinal cord.

Get It?

Explain the importance of the central nervous system in the human body.

The Peripheral Nervous System

When you hear the word *nerve*, you might initially think of a neuron. However, a nerve is a bundle of axons. Many nerves contain both sensory and motor neurons. For example, there are 12 cranial nerves that lead to and from the brain and 31 spinal nerves (and their branches) that lead to and from the spinal cord, as shown in **Figure 11**. You could think of nerves as two-way streets. Information travels to and from the brain through these sensory and motor neurons.

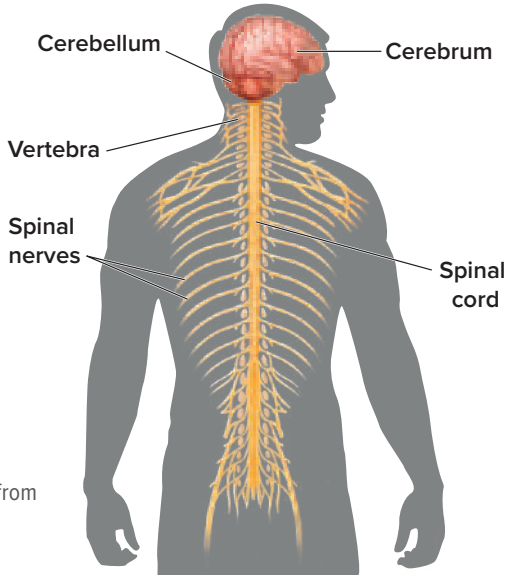


Figure 11 Thirty-one pairs of spinal nerves extend from the spinal cord.

Differentiate *neurons and nerves.*

Refer to **Figure 12** as you read about the peripheral nervous system. This system includes all neurons that are not part of the central nervous system, including sensory neurons and motor neurons. Neurons in the peripheral nervous system can be classified further as being either part of the somatic nervous system or part of the autonomic nervous system.

The somatic nervous system

Nerves in the **somatic nervous system** relay information from external sensory receptors to the central nervous system. Somatic motor nerves relay information from the central nervous system to skeletal muscles. Usually, this is voluntary. However, not all reactions of the central nervous system are voluntary. Some responses are the result of a reflex, which is a fast response to a change in the environment. Reflexes do not require conscious thought and are involuntary. Most signals in reflexes go only to the spinal cord and not to the brain. Remember the example of someone putting their hand near a hot stove burner? Refer to **Figure 2** in Lesson 1, and note that the illustrated reflex is part of the somatic nervous system.

The autonomic nervous system

Remember the last time you had a scary dream? You might have awakened and realized that your heart was pounding. This type of reaction is the result of the action of the autonomic nervous system. The **autonomic nervous system** carries impulses from the central nervous system to the heart and other internal organs. The body responds involuntarily, not under conscious control. The autonomic nervous system is important in two different kinds of situations. When you have a nightmare or find yourself in a scary situation, your body responds with what is known as a fight-or-flight response. When everything is calm, your body rests and digests.

Get It?

Explain why the nervous system is essential to the human body.

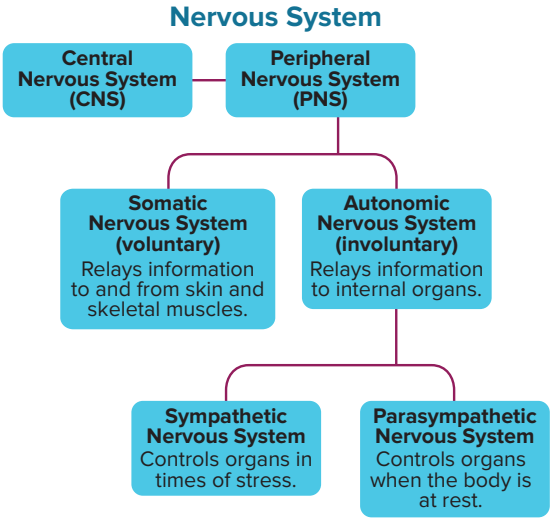


Figure 12 Each division of the nervous system functions in the control of the body and the communication within the body.

Table 1 The Autonomic Nervous System

Structure	Sympathetic Stimulation	Parasympathetic Stimulation
Iris (eye muscle)	Pupil dilation	Pupil constriction
Heart	Heart rate and force increased	Heart rate and force decreased
Lung	Bronchial muscle relaxed	Bronchial muscle contracted
Small Intestine	Muscle contractions reduced	Digestion increased

HEALTH Connection There are two branches of the autonomic nervous system, and they act together. The **sympathetic nervous system** is most active in times of emergency or stress, when the heart rate and breathing rate increase. The **parasympathetic nervous system** is most active when the body is relaxed. It counterbalances the effects of the sympathetic system and restores the body to a resting state after a stressful experience. **Table 1** compares and contrasts the two systems. Both the sympathetic and parasympathetic systems relay impulses to the same organs, but the overall response depends on the intensities of the opposing signals.

Check Your Progress

Summary

- The nervous system has two major divisions: the central nervous system and the peripheral nervous system.
- The brain and spinal cord make up the central nervous system.
- The somatic nervous system and the autonomic nervous system make up the peripheral nervous system.
- The sympathetic nervous system and the parasympathetic nervous system are branches of the autonomic nervous system.

Demonstrate Understanding

1. **Compare** the structures of the central nervous system with the structures of the peripheral nervous system, and explain their relationships.
2. **Assess** the similarities and differences between the somatic nervous system and the autonomic nervous system.
3. **Explain** Which part of the nervous system is involved in a fight-or-flight response? Why is such a response important?

Explain Your Thinking

4. **Hypothesize** what types of tests a researcher could perform to check whether different sections of the brain were functioning.
5. **Create** a model that demonstrates how information flows between the peripheral and central nervous systems.
6. **WRITING Connection** Write a short story that describes a situation involving the heart when the sympathetic and parasympathetic nervous systems work together to maintain homeostasis.

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LESSON 3

THE SENSES

FOCUS QUESTION

What are the different sensory structures and what are each of them able to detect?

Taste and Smell

Specialized neurons in your body called sensory receptors enable you to taste, smell, hear, see, and touch, and to detect motion and temperature.

The senses of taste and smell are stimulated by chemicals and often function together. Specialized receptors located high in the nose respond to chemicals in the air and send the information to the olfactory bulb in the brain. **Taste buds** are areas of specialized chemical receptors on the tongue that detect the tastes of sweet, sour, salty, and bitter. These receptors detect the different combinations of chemicals in food and send this information to another part of the brain.

The receptors associated with taste and smell are shown in **Figure 13**. Signals from these receptors work together to create a combined effect in the brain. Try eating while holding your nose. You will find that your food loses much of its flavor.

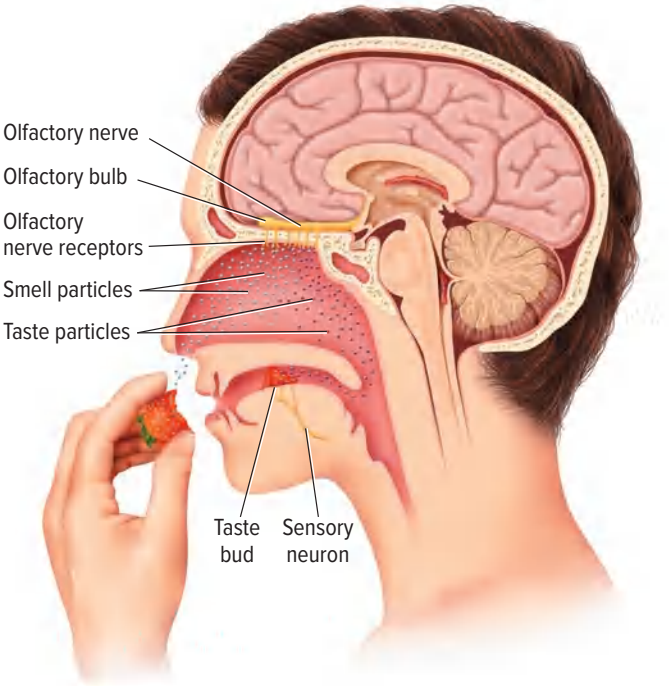

Figure 13 The receptors of taste and smell function together and are stimulated in similar ways. Food is often smelled as it is tasted.

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 Adaptations to Darkness

Carry out an investigation to determine the structures in the eye that adapt to low light.

Review the News

Obtain information from a current news story about human senses. Evaluate your source and communicate your findings to your class.

Sight

Figure 14 shows the path of light as it travels through the eye. Light first enters the eye through a transparent, yet durable, layer of cells called the cornea. The cornea helps to focus the light through an opening called the pupil. The size of the pupil is regulated by muscles in the iris—the colored part of the eye. Behind the iris is the **lens,** which inverts the image and projects it onto the retina. The image travels through the vitreous humor, which is a colorless, gelatinlike liquid between the lens and the retina. The **retina** contains numerous receptor cells called rods and cones. **Rods** are light-sensitive cells that are excited by low levels of light. **Cones** function in bright light and provide information about color to the brain. These receptors send action potentials to the brain via the neurons in the optic nerve. The brain then interprets the specific combination of signals received from the retina and forms a visual image.

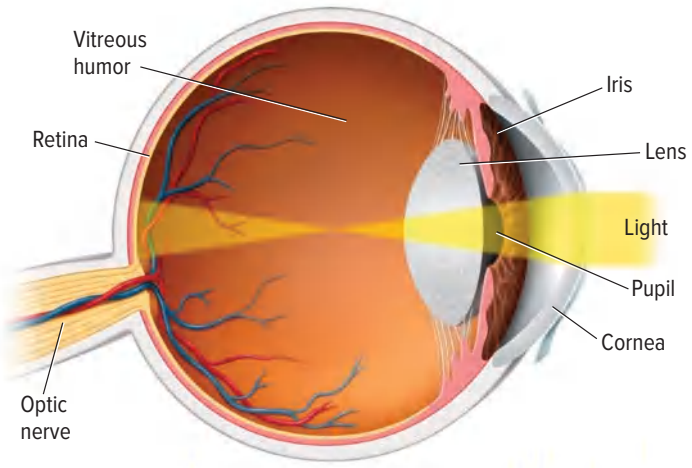

Figure 14 Light travels through the cornea and the pupil to the lens, which focuses the image on the retina. Rods and cones in the retina send information to the brain through the optic nerve.

Hearing and Balance

Hearing and balance are the two major functions of the ear. From a soft sound, such as whispering, to a loud sound, such as a crowd cheering at a sporting event, specialized receptors in the ear can detect both the volume and the highness and lowness of sounds. How can you stand on one foot without falling over? Canals in the inner ear are responsible for your sense of balance, or equilibrium. Receptors in the inner ear send messages to your brain about the position of your body and help you balance on one foot, even when your eyes are closed.

CCC CROSSCUTTING CONCEPTS

Systems and System Models Goggles and safety glasses are important pieces of lab equipment. Using evidence and terms from the model shown in **Figure 14**, construct an explanation about why it is important to protect the lens of the eye.

ACADEMIC VOCABULARY

Interpret

to explain or tell the meaning of

Our senses help us interpret our environment.

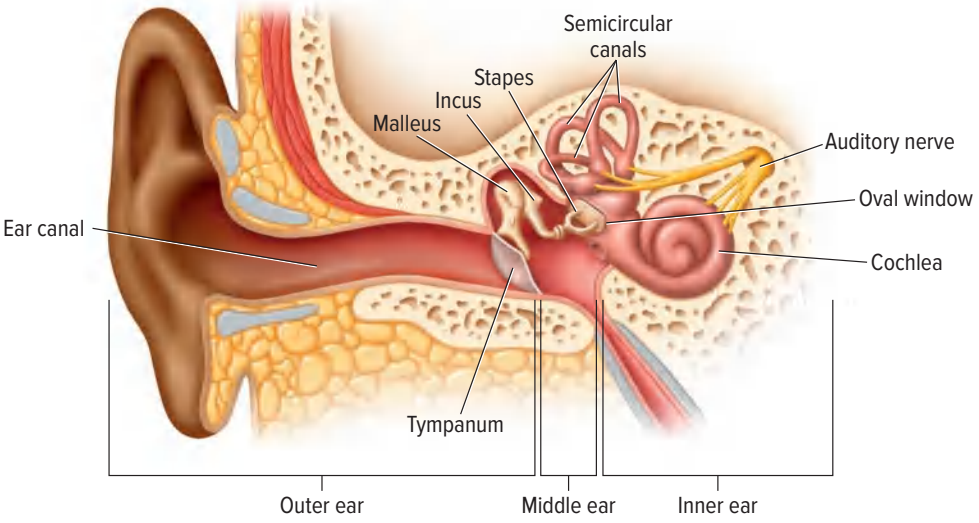

Figure 15 Sound waves cause the tympanum to vibrate, and the vibrations travel through the bones of the middle ear to the cochlea. Hair cells in the cochlea generate nerve impulses, which are sent to the brain through the auditory nerve.

Hearing

Vibrations called sound waves cause particles in the air to vibrate. **Figure 15** illustrates the path of sound waves as they travel through the ear.

PHYSICS Connection Sound waves enter the auditory, or ear, canal and cause a membrane, called the eardrum or tympanum, at the end of the ear canal to vibrate. These vibrations travel through three bones in the middle ear: the malleus (also called the hammer), the incus (anvil), and the stapes (stirrup). As the stapes vibrates, it causes the oval window, a membrane that separates the middle ear from the inner ear, to move back and forth. In the inner ear, a snail-shaped structure called the **cochlea** (KOH klee uh) is filled with fluid and lined with tiny hair cells. Vibrations cause the fluid inside the cochlea to move like a wave against the hair cells. The hairs cells respond by generating nerve impulses in the auditory nerve and transmitting them to the brain.

Get It?

Summarize how each sense organ detects changes in the environment.

Balance

The inner ear also contains organs for balance, including three semicircular canals. **Semicircular canals** transmit information about body position and balance to the brain. The three canals are positioned at right angles to one another, and they are fluid-filled and lined with hair cells. When the position of your head changes, fluid within the semicircular canals moves. This causes the hair cells to bend, which in turn sends nerve impulses to the brain. The brain then is able to determine your position and whether your body is still or in motion.

Touch

Many types of sensory receptors that respond to temperature, pressure, and pain are found in the epidermis and dermis layers of the skin. **Figure 16** illustrates the different types of receptors—some that respond to light touches and others that respond to heavy pressure. Notice that receptors that respond to light touches are just below the surface of the skin. Receptors that respond to deep pressure or vibrations are further below the skin's surface. Other receptors in the skin send signals when hair is moved.

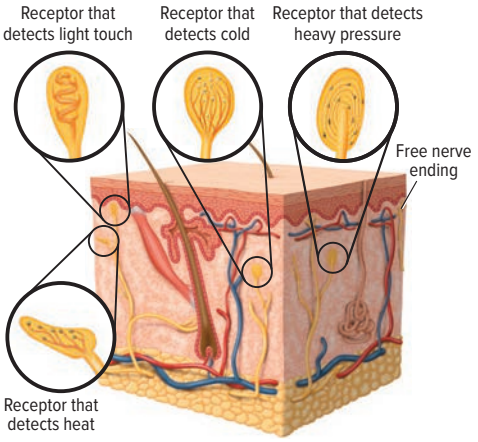

Figure 16 Many types of receptors are found in the skin. A person can tell if an object is hot or cold, sharp or smooth.

Distribution of receptors is not uniform in all areas of the body. The tips of the fingers have many receptors that detect light touch. The soles of the feet have many receptors that respond to heavy pressure. Pain receptors are simple, consisting of free nerve endings that are found in all tissues of the body except the brain. Pain receptors respond to external stimili, such as extreme hot or cold temperatures, as well as to internal stimuli, such as chemicals released by injured cells, making the area more sensitive to painful stimulation. The brain constantly receives signals from these receptors and responds appropriately.

Check Your Progress

Summary

- The senses of taste and smell work together.
- The eye has two types of receptors.
- The ear is involved in both hearing and balance.
- The skin has many types of sensory receptors.

Demonstrate Understanding

1. **Diagram** the route of a sound wave from the auditory canal until it causes a nerve impulse to be generated.
2. **Predict** what might be the result if the cornea was damaged.
3. **Analyze** the importance of the kind of receptors found in the fingers.
4. **Explain** why it might be difficult to taste when you have a cold and your nasal passages are clogged.

Explain Your Thinking

5. **Construct** an experiment to test the idea that certain areas of the tongue are taste-specific.
6. **Develop** a hypothesis as to why people who have lost their sense of sight still experience sight occasionally. People who once could hear occasionally experience sound. Why might these phenomena occur?

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LESSON 4

EFFECTS OF DRUGS

FOCUS QUESTION

How can drugs affect the nervous system?

How Drugs Work

A **drug** is a substance, natural or artificial, that alters the function of the body. There are many types of drugs, some of which are illustrated in **Table 2**. Drugs range from prescriptions such as antibiotics, which fight bacterial infections, to over-the-counter pain relievers. There are also illegal drugs, such as cocaine and heroin, which can cause addiction and death. Common substances such as caffeine, nicotine, and alcohol are also drugs. Drugs affect a person's body in many different ways. Drugs that affect the nervous system work in one or more of the following ways:

- A drug can cause an increase in the amount of a neurotransmitter that is released into a synapse.
- A drug can block a receptor site on a dendrite, preventing a neurotransmitter from binding.
- A drug can prevent a neurotransmitter from leaving a synapse.
- A drug can imitate a neurotransmitter.

Table 2 Some Common Drugs

Alcohol	Caffeine	Prescription Drugs	Over-the-Counter Drugs	Tobacco
				
beer, wine	coffee, tea, soda, chocolate	antibiotics, pain medications	aspirin, cold medications	cigarettes, cigars

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 Cross Cutting 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 effects of drugs on the human body. Evaluate your source and communicate your findings to your class.

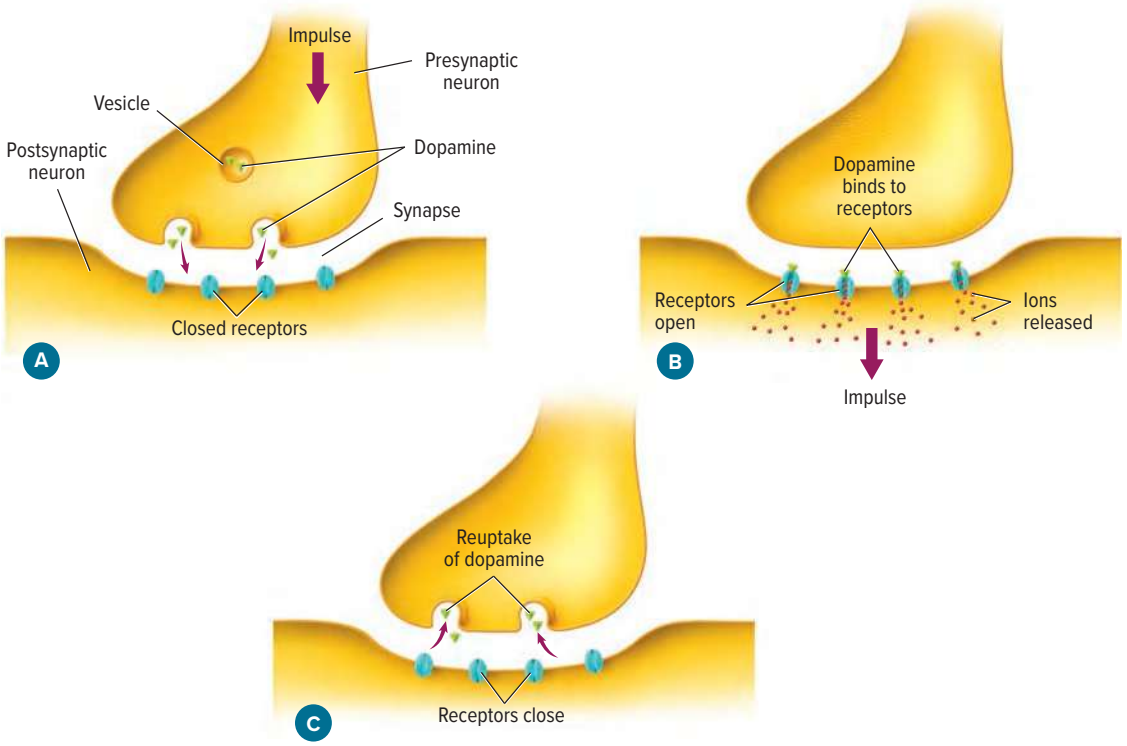

Figure 17 Dopamine crosses the gap from one neuron and binds to receiver sites, or receptors, on the membrane of another neuron. This occurs at a synapse.

Many drugs that affect the nervous system influence the level of a neurotransmitter called dopamine. **Dopamine** (DOH puh meen) is a neurotransmitter found in the brain that is involved with the control of body movements and other functions. Dopamine also is strongly involved with feelings of pleasure or reward. Dopamine normally is removed from a synapse by being reabsorbed by the neuron that released it, as illustrated in **Figure 17**.

Classes of Commonly Abused Drugs

Drug abuse does not necessarily involve the use of illegal drugs. Any use of a drug for reasons other than legitimate medical purposes, whether deliberate or unintentional, can be considered abuse of that drug.

Stimulants

Drugs that increase alertness and physical activity are **stimulants.** **Figure 18** on the next page indicates some common stimulants.

Nicotine Nicotine in cigarette and cigar smoke increases the amount of dopamine released into a synapse. Nicotine also constricts blood vessels, raising blood pressure and causing the heart to work harder than normal. Cigarette smoking has been linked to about 90 percent of all lung cancer cases.

Caffeine The most commonly used, and often abused, stimulant is caffeine. Caffeine is found in coffee, tea, some soft drinks, and even some foods such as chocolate. Examples of these are shown in **Figure 18**. Caffeine works by binding to adenosine receptors on neurons in the brain. Adenosine slows down neural activity, causing drowsiness. When caffeine binds to these receptors, it has the opposite effect. It makes users feel awake and alert. Caffeine also temporarily raises epinephrine (adrenaline) levels in the body, giving a quick burst of energy that soon wears off.

Depressants

Drugs that tend to slow down the central nervous system are **depressants.** These drugs can lower blood pressure, interrupt breathing, and slow the heart rate. Depressants can relieve anxiety, but they also can cause the noticeable effect of sedation.

Alcohol Alcohol is a depressant. It affects the central nervous system and is one of the most widely abused drugs in the world today. It is produced by the fermentation of grains and fruits. Alcohol is known to affect at least four different neurotransmitters, resulting in a feeling of relaxation and sluggishness. Short-term alcohol use impairs judgment, coordination, and reaction time. Long-term effects of alcohol abuse include a reduction in brain mass, liver damage, stomach and intestinal ulcers, and high blood pressure. Consumption of alcohol during pregnancy is the cause of fetal alcohol syndrome, which can result in damage to a baby's brain and nervous system.

Inhalants Inhalants are chemical fumes that have an influence on the nervous system. Exposure to inhalants might be accidental as a result of poor ventilation. Inhalants generally work by acting as a depressant on the central nervous system. Inhalants might produce a short-term effect of intoxication, as well as nausea and vomiting. Death can occur. Long-term exposure to inhalants can cause memory loss, hearing loss, vision problems, peripheral nerve damage, and brain damage.

Figure 18 There are many common stimulant drugs, such as coffee, tea, cocoa, and chocolate.

STEM CAREER Connection

Addiction Counselor

Addiction counselors work with patients that are addicted to drugs like opioids and alcohol and their familes. They teach clients how the brain responds to addictive substances, and provide them with the support needed to combat their addiction.

WORD ORIGINS

dopamine

dopa– refers to an amino acid

–amine refers to a derivative of ammonia

Illegal drugs Amphetamines and cocaine both increase dopamine levels, and both prevent dopamine from being reabsorbed, so it remains in the synapses. This ultimately increases the levels of dopamine in the brain, which results in a feeling of pleasure and well-being.

The use of cocaine and amphetamines has short-term and long-term effects. Cocaine abuse might result in disturbances in heart rhythm, heart attacks, chest pain, respiratory failure, strokes, seizures, headaches, abdominal pain, and nausea. Abuse of amphetamines might result in rapid heart rate, irregular heartbeat, increased blood pressure, and irreversible, stroke-producing damage to small blood vessels in the brain. Elevated body temperature, called hyperthermia, and convulsions can result from an amphetamine or cocaine overdose, and if not treated immediately, this can result in death. Abusers also can experience episodes of violent behavior, paranoia, anxiety, confusion, and insomnia. It can take a year or longer for users of methamphetamine—the strongest type of amphetamine—to recover after quitting the drug.

Marijuana is the most-used illegal drug in the United States. The active chemical in marijuana is tetrahydrocannabinol, or THC. Smoking marijuana quickly gets THC into the bloodstream, where it is carried to the brain. THC binds to receptors on neurons in the brain, which produces the effect of intense pleasure. These receptors are found on neurons associated with many body activities. Short-term effects of marijuana use include problems with memory and learning, loss of coordination, increased heart rate, anxiety, paranoia, and panic attacks. Long-term smoking of marijuana might also cause lung cancer.

Get It?
Explain the function of a neurotransmitter.

Tolerance and Addiction

Tolerance occurs when a person needs more and more of the same drug to get the same effect. The dosage needs to increase because the body becomes less responsive to the drug. Drug tolerance can lead to addiction.

Addiction

The psychological and physiological dependence on a drug is **addiction.** Current research suggests that the neurotransmitter dopamine is involved with most types of physiological addiction. Recall that dopamine normally is removed from a synapse as it is reabsorbed by the neuron that released it. However, certain drugs prevent that reabsorption, which results in an increase of dopamine in the brain. A person addicted to drugs derives pleasure from increased levels of dopamine and builds up a tolerance to the drug. As a result, the person takes more of the drug. When people who are addicted try to quit, the levels of dopamine decrease, making it difficult to resist going back to the drug.

Addictions can also be psychological. An individual with a psychological dependence on a drug such as marijuana has a strong desire to use the drug for emotional reasons. Both physiological and psychological dependence can affect emotional and physical health. Both types are strong, making it difficult to quit a drug.

Treatment

People who are either psychologically or physiologically dependent on a drug experience serious withdrawal symptoms without it. It is very difficult for dependent users to quit on their own. They might be able to quit for short periods of time, but they are likely to use the drug again. Medical supervision is necessary when people who are psychologically and physiologically dependent on a drug try to quit.

The best way to avoid an addiction is never to use drugs in the first place, even when pressured to use them. Encourage people who abuse drugs to seek treatment for drug dependency. Physicians, nurses, counselors, clergy, and social workers are trained to direct people to the resources they need to get help, as illustrated in **Figure 19**.

Figure 19 Counseling often is necessary to break addiction.

Get It?

Explain the best way to avoid addiction.

Check Your Progress

Summary

- Drugs can affect the nervous system in four ways.
- Common substances such as caffeine and alcohol are considered drugs.
- Many addictive drugs increase levels of dopamine.
- Drug abuse has many negative consequences.
- A person can become psychologically and physiologically addicted to drugs.

Demonstrate Understanding

1. **Describe** four ways that drugs can influence the nervous system.
2. **Compare** the actions of cocaine, amphetamines, and nicotine on the nervous system.
3. **Explain** why the effects of stimulants and depressants do not necessarily counteract each other.
4. **Infer** why students who abuse amphetamines are likely to experience failing grades.
5. **Discuss** how, on a cellular level, a person can become addicted to a drug.

Explain Your Thinking

6. **Design an experiment** Drugs affect people in different ways and at different rates. How would you design an experiment to determine the rate at which a drug reaches different body tissues?

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ENGINEERING & TECHNOLOGY

Lending a (Virtual) Hand

People have long wondered if it is possible to develop computers that have artificial intelligence (AI). "Superintelligent' machines that can truly think for themselves—usually in the form of robots that look like humans—have been the focus of many science fiction novels and movies. We may not yet have androids that can walk the dog for us, but today's limited AI has many uses, including functioning as assistants for older adults and for people who have disabilities.

Virtual assistants can perform tasks for people who have disabilities.

Machine learning and deep learning

In recent years, scientists and engineers have developed what is known as "machine learning" (ML). Computers with this type of AI have software that uses algorithms to "learn" the likes and dislikes of users and to make predictions about what those people want or need. "Deep learning" (DL) improves on machine learning by delving deeply into pattern recognition. It is used in image and voice recognition applications.

Virtual assistant (VA) applications use ML and DL. Some VAs can be operated with voice only, and so they are helpful to people who have mobility issues and to people who are visually impaired. VAs can be used to order groceries, set a thermostat, pay bills, and operate appliances, among many other tasks. Image recognition applications are useful for people who are visually impaired. For example, there are now smartphones enabled with image and voice recognition with interfaces that can be operated with just a person's voice or touch.

Image and voice recognition are also used in applications for people who are hearing impaired. One application captures the motions of a person using American Sign Language (ASL) and translates them into both text and speech for a hearing person. It also translates the hearing person's spoken words into text.

In the future, limited AI will likely provide even more assistance for people who are disabled.

COMMUNICATE SCIENTIFIC INFORMATION

Research AI applications that use image and voice recognition. Choose one and create a presentation that explains how it works and how it can assist people with disabilities.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 STRUCTURE OF THE NERVOUS SYSTEM

- There are three major parts of a neuron.
- There are three basic types of neurons.
- A nerve impulse is an electric charge and is called an action potential.
- Neurons use chemicals and electricity to relay impulses.

- neuron
- dendrite
- cell body
- axon
- reflex arc
- action potential
- threshold
- node
- synapse
- neurotransmitter

Lesson 2 ORGANIZATION OF THE NERVOUS SYSTEM

- The nervous system has two major divisions: the central nervous system and the peripheral nervous system.
- The brain and spinal cord make up the central nervous system.
- The somatic nervous system and the autonomic nervous system make up the peripheral nervous system.
- The sympathetic nervous system and the parasympathetic nervous system are branches of the autonomic nervous system.

- central nervous system
- peripheral nervous system
- cerebrum
- medulla oblongata
- pons
- hypothalamus
- somatic nervous system
- autonomic nervous system
- sympathetic nervous system
- parasympathetic nervous system

Lesson 3 THE SENSES

- The senses of taste and smell work together.
- The eye has two types of receptors.
- The ear is involved in both hearing and balance.
- The skin has many types of sensory receptors.

- taste bud
- lens
- retina
- rod
- cone
- cochlea
- semicircular canal

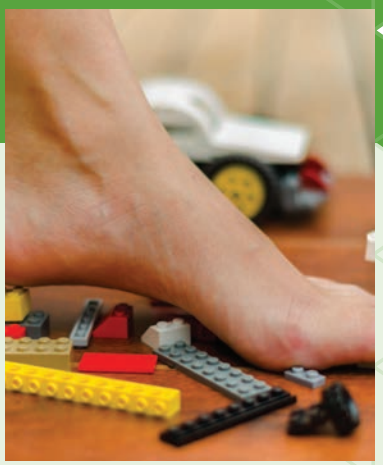
Lesson 4 EFFECTS OF DRUGS

- Drugs can affect the nervous system in four ways.
- Common substances such as caffeine and alcohol are considered drugs.
- Many addictive drugs increase levels of dopamine.
- Drug abuse has many negative consequences.
- A person can become psychologically and physiologically addicted to drugs.

- drug
- dopamine
- stimulant
- depressant
- tolerance
- addiction

THREE-DIMENSIONAL THINKING

Module Wrap-Up



REVISIT THE PHENOMENON

If you step on several toy blocks, it's going to hurt. Why is this response a good thing?

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

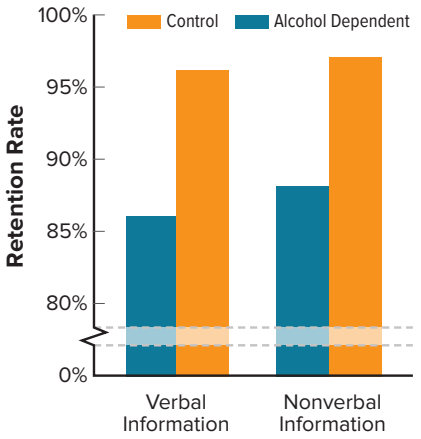
Can the effects of alcohol use be observed?

Two groups of students, ages 15–16, were given memory tasks to perform. Group 1 included individuals that were dependent on alcohol. Group 2 were nondrinkers, the control. The images indicate typical results of comparing students from each group. The graph shows the difference in retention rate between the two groups when processing verbal information and nonverbal information.

CER Analyze and Interpret Data

1. **Claim, Evidence** Describe the difference in retention rate in both testing categories between people who are dependent on alcohol and nondrinkers.
2. **Reasoning** Analyze what long-term consequences might result from drinking as a teen. Base your answer on these results.

Effects of Alcohol Dependence on Memory Retention



*Data obtained from: Brown, S.A., et al. 2000. Neurocognitive functioning of adolescents: effects of protracted alcohol use. *Alcoholism: Clinical and Experimental Research*. 24:164–171.

Credits

1. Module 9 Cellular Reproduction And Sexual Reproduction: *Chapter from Inspire Biology 9-12 Student Edition by McGraw-Hill, 2020* 2
2. Module 10 Introduction To Genetics And Patterns Of Inheritance: *Chapter from Inspire Biology 9-12 Student Edition by McGraw-Hill, 2020* 32
3. Module 11 Molecular Genetics: *Chapter from Inspire Biology 9-12 Student Edition by McGraw-Hill, 2020* 68
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