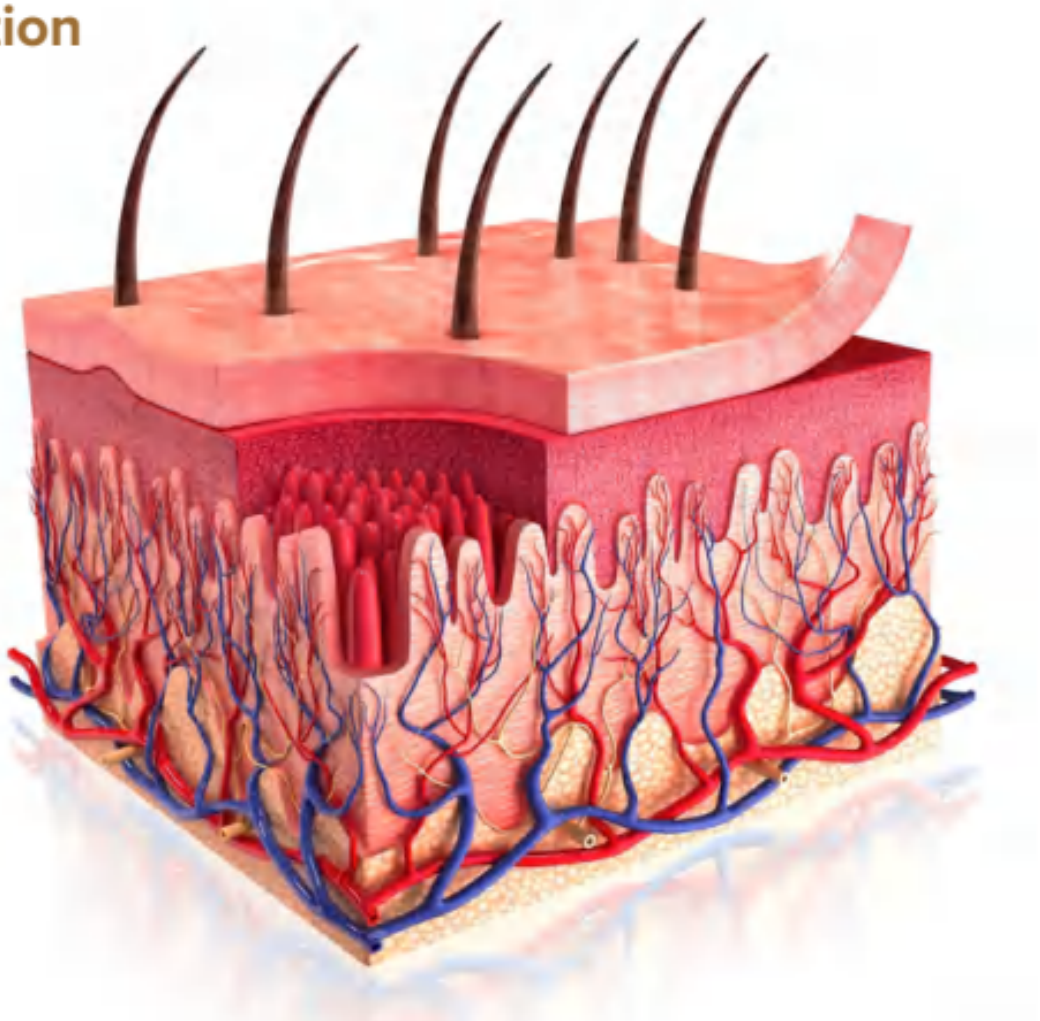
UNITED ARAB EMIRATES
MINISTRY OF EDUCATION

2023-2024

Inspire Biology

UAE Edition
Grade 10 General
Student Edition



Mc Graw Hill

Inspire Biology, Student Edition

UAE Edition Grade 10 2022-23

create.mheducation.com

ISBN-13: 9781307729900

ISBN-10: 1307729908

Contents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CHEMISTRY IN BIOLOGY

ENCOUNTER THE PHENOMENON

What is wrong with the water?

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 how oxygen drives life on Earth. Explain your reasoning.

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

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

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

LESSON 2: Explore & Explain: Chemical Reactions

LESSON 4: Explore & Explain: Macromolecules

LESSON 1

MATTER

FOCUS QUESTION

What makes up everything around us?

Atoms

Chemistry is the study of matter, its composition, and properties. Matter is anything that has mass and takes up space. All of the organisms that you study in biology are made up of matter. **Atoms** are the building blocks of matter.

The structure of an atom

An atom is so small that billions of them could fit on the head of a pin. Yet, atoms are made up of even smaller particles called neutrons, protons, and electrons, as shown in **Figure 1.** Neutrons and protons are located at the center of the atom, called the **nucleus.** **Protons** are positively charged particles (p^+), and **neutrons** are particles that have no charge (n^0). **Electrons** are negatively charged particles (e^-) found outside the nucleus. Electrons constantly move around an atom's nucleus in energy levels. The structure of an atom results from the attraction between protons and electrons. Atoms contain an equal number of protons and electrons, so the overall charge of an atom is zero.

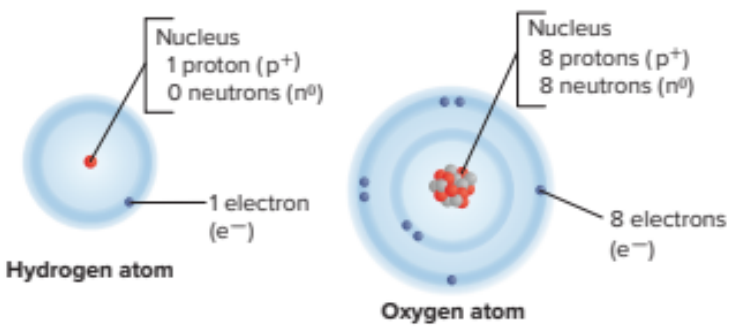

Figure 1 Hydrogen has only one proton and one electron. Oxygen has eight protons, eight neutrons, and eight electrons. The electrons move around the nucleus in two energy levels (shown as the darker shaded rings).

Infer *the number of protons in an aluminum atom, which has 13 electrons.*

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.

Revisit the Encounter the Phenomenon Question

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

Identify Cross Cutting Concepts

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

HISTORY Connection In the fifth century B.C., Greek philosophers Leucippus and Democritus first proposed the idea that all matter is made up of tiny, indivisible particles. It wasn't until the 1800s that scientists began to collect experimental evidence to support the existence of atoms. As technology improved over the next two centuries, scientists proved not only that atoms exist but also that they are made up of even smaller particles.

Elements

An **element** is a pure substance that cannot be broken down into other substances by physical or chemical means. Elements are made of only one type of atom. There are over 100 known elements, 92 of which occur naturally. As shown in **Figure 2**, elements found in living organisms also are found in Earth's crust.

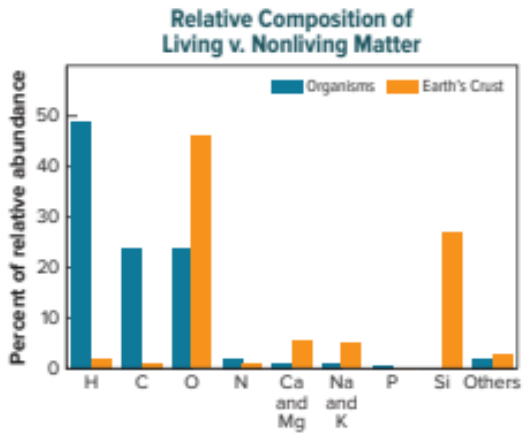

Figure 2 The elements in Earth's crust and living organisms vary in their abundance. Living things are composed primarily of three elements: carbon, hydrogen, and oxygen.

Interpret *What is the most abundant element in living things?*

Scientists have collected a large amount of information about the elements, such as the number of protons and electrons each element has and the atomic mass of each element. They are also continually discovering new elements. In **Figure 2**, the symbols of different elements are used to label the bars of the graph. For example, H is the chemical symbol for hydrogen, C is the chemical symbol for carbon, and O is the chemical symbol for oxygen. Elements are combined in different ways to form the products and compounds that make up everything on Earth.

WORD ORIGINS

atom

Comes from the Greek word *atomos*, meaning *not divisible*.

CCC CROSSCUTTING CONCEPTS

Energy and Matter The element carbon is sometimes called "the stuff of life." Using evidence from **Figure 2**, write a paragraph that supports this statement.

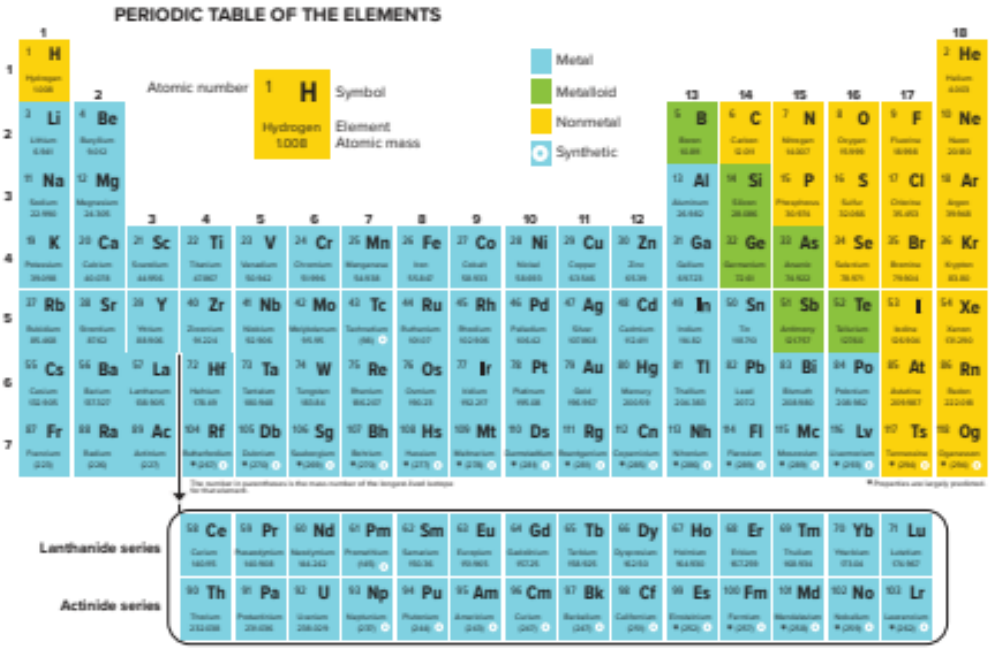

Figure 3 The periodic table of the elements organizes all of the known elements. Examine the biologists' guide to the periodic table inside the back cover.

The periodic table of the elements

The periodic table, shown in **Figure 3**, is organized into horizontal rows, called periods, and vertical columns, called groups. Each individual block represents an element. The atomic mass, atomic number, and symbol of each element are shown in its block.

The table is called the periodic table because elements in the same group have similar chemical and physical properties. This organization even allows scientists to predict the properties of elements that have not yet been discovered or isolated.

Get It?

Identify three pieces of information about an element you can find in its individual block in the periodic table.

ACADEMIC VOCABULARY

isolated
separated from other substances
An element is isolated when it is separated from other substances.

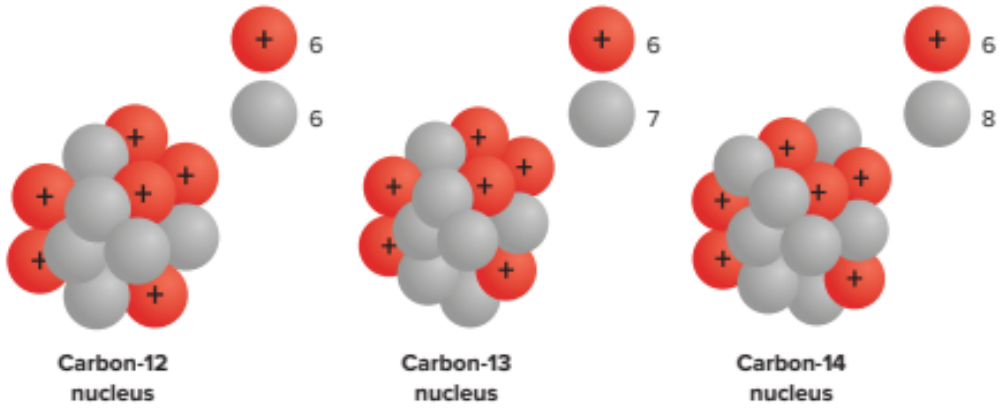

Figure 4 Carbon-12 and carbon-13 occur naturally in living and nonliving things. All living things also contain a small amount of carbon-14.

Compare *the similarities and differences of isotopes.*

Isotopes

Although atoms of the same element have the same number of protons and electrons, atoms of an element can have different numbers of neutrons, as shown in **Figure 4**. Atoms of the same element that have different numbers of neutrons are called **isotopes.** Isotopes of an element are identified by adding the number of protons and neutrons in the nucleus. For example, the most abundant form of carbon, carbon-12, has six protons and six neutrons in its nucleus. One carbon isotope—carbon-14—has six protons and eight neutrons. Isotopes of elements have the same chemical characteristics.

Radioactive isotopes

Changing the number of neutrons in an atom does not change the overall charge of the atom. However, changing the number of neutrons can affect the stability of the nucleus, in some cases causing the nucleus to decay, or break apart. When a nucleus breaks apart, it gives off radiation that can be detected. Isotopes that give off radiation are called radioactive isotopes.

Radioactive isotopes can have practical applications. For example, carbon-14 is a radioactive isotope that is found in all living things. Scientists know the half-life, or the amount of time it takes for half of carbon-14 to decay, so they can calculate the age of an object by finding how much carbon-14 remains in the sample. Other radioactive isotopes have medical uses, as shown in **Figure 5**.

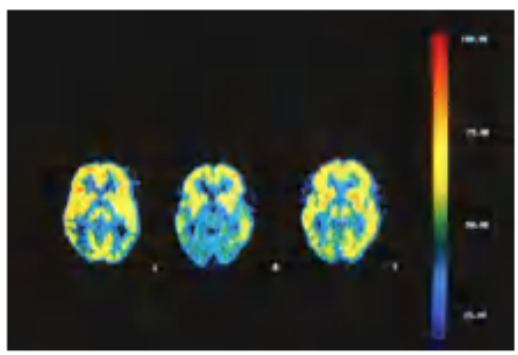

Figure 5 Radioactive isotopes are used to help doctors diagnose disease, and locate and treat certain types of cancer.

Figure 6 You and your world are made of compounds. **Left:** Brilliant fireworks displays depend on compounds. **Right:** Table salt is the compound NaCl.

Compounds

Elements can combine to form more complex substances. A **compound** is a pure substance formed when two or more different elements combine. There are millions of known compounds. **Figure 6** shows two examples. Each compound has a chemical formula made up of the chemical symbols from the periodic table. You might know that water is the compound H_2O. Sodium chloride (NaCl) is the compound commonly called table salt. The fuel people use in cars is a mixture of hydrocarbon compounds. Hydrocarbons have only hydrogen and carbon atoms.

Compounds have several unique characteristics. First, compounds are always formed from a specific combination of elements in a fixed ratio. Water always is formed in a ratio of two hydrogen atoms and one oxygen atom, and each water molecule has the same structure. Second, compounds are chemically and physically different from the elements that comprise them. Another characteristic of compounds is that they cannot be broken down into simpler compounds or elements by physical means, such as tearing or crushing. Compounds, however, can be broken down by chemical means into simpler compounds or into their original elements. For example, you cannot pass water through a filter and separate the hydrogen from the oxygen, but a process called electrolysis, illustrated in **Figure 7**, can break water down into hydrogen gas and oxygen gas.

Figure 7 Electrolysis of water produces hydrogen gas that can be used for hydrogen fuel cells.

Explain *why water is classified as a compound.*

Chemical Bonds

Compounds such as water are formed when two or more substances combine. The force that holds the substances together is called a chemical bond. Think back to the protons, neutrons, and electrons that make up an atom. The electrons are involved directly in forming chemical bonds. Electrons travel around the nucleus of an atom in areas called energy levels, as illustrated in **Figure 8**. Each energy level has a specific number of electrons that it can hold at any time. The first energy level, which is the level closest to the nucleus, can hold up to two electrons. The second energy level can hold up to eight electrons.

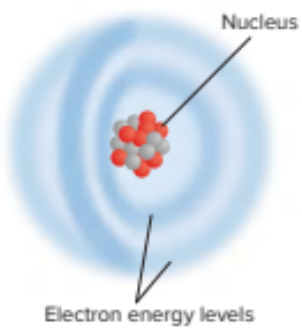

Figure 8 Electrons move constantly within the energy levels surrounding the nucleus.

A partially-filled energy level is not as stable as an energy level that is empty or completely filled. Atoms become more stable by losing electrons or attracting electrons from other atoms. This results in the formation of chemical bonds between atoms. It is the forming of chemical bonds that stores energy and the breaking of chemical bonds that provides energy for processes such as growth, development, adaptation, and reproduction in living things. There are two main types of chemical bonds—ionic bonds and covalent bonds.

Ionic bonds

Recall that atoms are neutral; they do not have an electric charge. Also recall that an atom is most stable when the outermost energy level is either empty or completely filled. Some atoms tend to give up (donate) or obtain (accept) electrons to empty or fill the outer energy level to be stable.

An atom that has lost or gained one or more electrons becomes an **ion** and carries an electric charge. For example, sodium has one electron in its outermost energy level. Sodium can become more stable if it gives up this one electron, leaving its outer energy level empty. When it gives away this one negative charge, the neutral sodium atom becomes a positively charged sodium ion (Na^+). Similarly, chlorine has seven electrons in its outer energy level. It can accept an electron. When a neutral chlorine atom accepts an electron from a donor atom, such as sodium, the chlorine atom becomes a negatively charged ion (Cl^-).

An **ionic bond** is an electrical attraction between two oppositely charged atoms or groups of atoms called ions. **Figure 9** shows how an ionic bond forms as a result of the electrical attraction between Na^+ and Cl^- to produce NaCl (sodium chloride). Substances formed by ionic bonds are called ionic compounds.

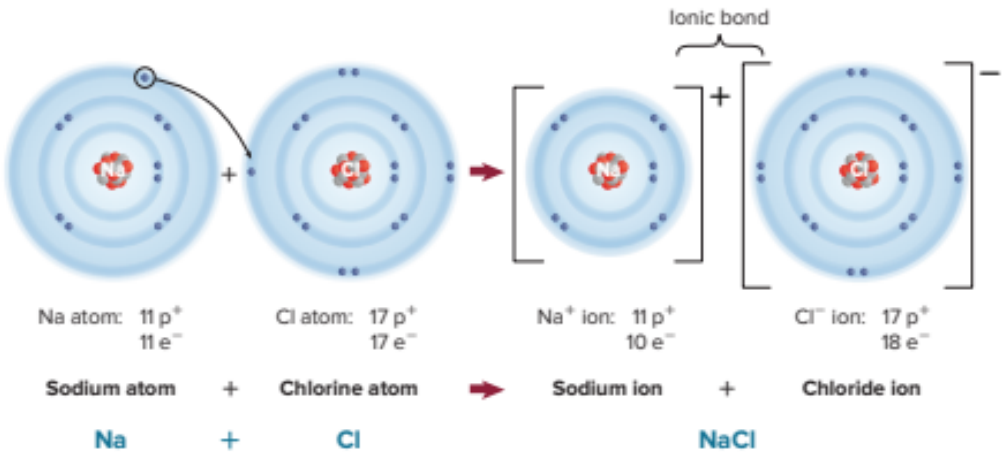

Figure 9 To form ions, sodium donates an electron, and chlorine gains an electron. An ionic bond forms when the oppositely charged ions come close together.

Ions in living things include sodium, potassium, calcium, chloride, and carbonate ions. They help maintain homeostasis as they travel in and out of cells. In addition, ions help transmit signals among cells that allow you to see, taste, hear, feel, and smell.

Some atoms tend to donate or accept electrons more easily than other atoms do. Look at the periodic table of elements at the back of the book. The elements identified as metals tend to donate electrons, and the elements identified as nonmetals tend to accept electrons. The resulting ionic compounds have some unique characteristics. For example, most dissolve in water. When dissolved in solution, ionic compounds break down into ions, and these ions can carry an electric current. Most ionic compounds, such as sodium chloride (table salt), are crystalline at room temperature. Ionic compounds generally have higher melting points than do molecular compounds formed by covalent bonds, which are described on the next page.

EARTH SCIENCE Connection Although most ionic compounds are solid at room temperature, some ionic compounds are liquid at room temperature. Ionic liquids are made up of positively and negatively charged ions. They have important potential in real-world applications as safe and environmentally friendly solvents that can possibly replace other harmful solvents. The key characteristic of ionic liquid solvents is that they typically do not evaporate and release chemicals into the atmosphere. Most ionic liquids are safe to handle and store, and they can be recycled after use. For these reasons, ionic liquids are attractive to industries that are dedicated to environmental responsibility.

Get It?
Compare ionic solids and liquids.

Covalent bonds

When you were younger, you probably learned to share. If you had a book that your friend wanted to read as well, you could enjoy the story together. In this way, you both benefited from the book. Similarly, one type of chemical bond forms when atoms share electrons in their outer energy levels.

The chemical bond that forms when electrons are shared is called a **covalent bond.** **Figure 10** illustrates the covalent bonds between oxygen and hydrogen that form water. Each hydrogen (H) atom has one electron in its outermost energy level, and oxygen (O) has six. Because the outermost energy level of oxygen is the second level, which can hold up to eight electrons, oxygen has a strong tendency to fill the energy level by sharing the electrons from the two nearby hydrogen atoms. Hydrogen does not completely give up the electrons; it also has a strong tendency to share electrons with oxygen to fill its outermost energy level. Two covalent bonds form, which creates water, shown in **Figure 11**.

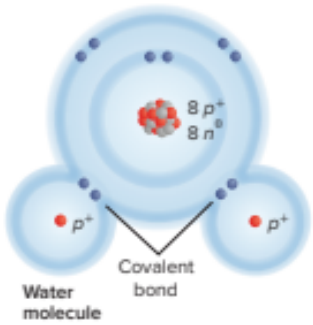

Figure 10 In water (H_2O), two hydrogen atoms each share one electron with one oxygen atom. Because the oxygen atom needs two electrons to fill its outer energy level, it forms two covalent bonds, one with each hydrogen atom.

Figure 11 Many compounds in living things, such as water, are held together by covalent bonds.

Infer *Why is it important for people who study biology to understand characteristics of covalent bonds?*

Most compounds in living organisms have covalent bonds holding them together. Water and other substances with covalent bonds are called molecules. A **molecule** is a compound in which the atoms are held together by covalent bonds. Depending on the number of pairs of electrons that are shared, covalent bonds can be single, double, or triple, as shown in **Figure 12.**

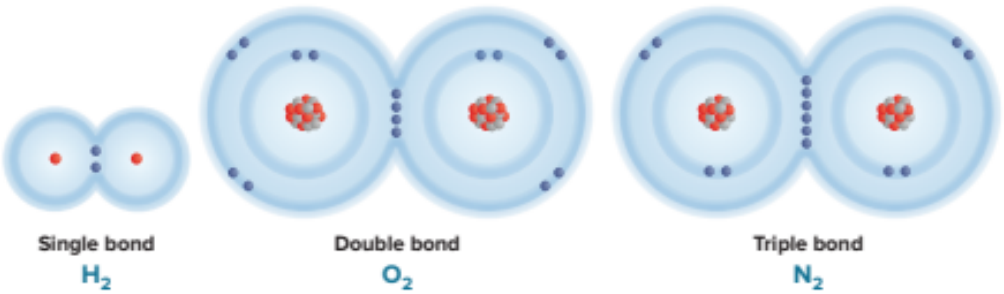

Figure 12 A single bond has one pair of shared electrons, a double bond has two pairs, and a triple bond has three pairs.

Compare and contrast *the different types of covalent bonds.*

Check Your Progress

Summary

- Elements are pure substances made up of only one kind of atom.
- Isotopes are forms of the same element that have a different number of neutrons.
- Compounds are substances with unique properties that are formed when elements combine.
- Elements can form covalent and ionic bonds.

Demonstrate Understanding

1. **Diagram** Sodium has 11 protons and 11 neutrons in its nucleus. Draw a sodium atom. Be sure to label the particles.
2. **Explain** Is carbon monoxide (CO) an atom or is it not? Why or why not?
3. **Explain** Are all compounds molecules? Why or why not?
4. **Compare** ionic bonds and covalent bonds.

Explain Your Thinking

5. **Explain** how the number of electrons in an energy level affects bond formation.
6. **MATH Connection** Beryllium has four protons in its nucleus. How many neutrons are in beryllium-9? Explain how you calculated your answer.

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LESSON 2

CHEMICAL REACTIONS

FOCUS QUESTION

How do enzymes facilitate life?

Reactants and Products

A car with shining chrome is appealing to many drivers. However, the car might get rusty over time. Rust is a result of a chemical change called a chemical reaction. A **chemical reaction** is the process by which atoms or groups of atoms in substances are reorganized into different substances. Chemical bonds are broken and formed during chemical reactions. The rust on the train in **Figure 13** is a compound called iron oxide (Fe_2O_3) formed when oxygen (O_2) in the air reacted with iron (Fe). Clues that a chemical reaction has taken place include production of heat or light, and the formation of a new gas, liquid, or solid.

Substances can undergo changes that do not involve chemical reactions. For example, the water in **Figure 13** is undergoing a physical change. A physical change alters a substance's appearance but not its composition.

Figure 13 After a chemical change, such as rusting, a new substance is formed. During a physical change, such as water boiling, the chemical makeup of the water is not altered.

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 factors affect an enzyme reaction?

Plan and carry out an investigation to determine the cause and effect of an enzyme reaction.

Virtual Investigation: Model Ecosystems

Use a model to determine the effects of substrate concentration and pH on the rate of an enzyme-controlled reaction.

Chemical equations

When scientists write chemical reactions, they express each component of the reaction in a chemical equation. In written chemical equations, chemical formulas describe the substances in the reaction with arrows indicating the process of change.

Reactants and products A chemical equation shows the **reactants,** the starting substances, on the left side of the arrow. The **products,** the substances formed during the reaction, are on the right side of the arrow. The arrow can be read as "yields" or "react to form."

Reactants → Products

The following chemical equation can be written to describe the reaction that provides your body with energy. In this reaction, glucose and oxygen react to form carbon dioxide and water.

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

Glucose and oxygen react to form carbon dioxide and water.

Balanced equations In chemical reactions, matter cannot be created or destroyed. This principle is called the law of conservation of mass. Accordingly, all chemical equations must show this balance of mass. This means that the number of atoms of each element on the reactant side must equal the number of atoms of the same element on the product side. Coefficients are used to make the number of atoms on each side of the arrow equal.

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

Multiply the coefficient by the subscript for each element. You can see in this example that there are six carbon atoms, twelve hydrogen atoms, and eighteen oxygen atoms on each side of the arrow. The equation confirms that the number of atoms on each side is equal, and therefore the equation is balanced.

Get It?

Explain why chemical equations must be balanced.

ACADEMIC VOCABULARY

coefficient
in a chemical equation, the number written in front of a reactant or a product *The number 6 in $6Fe_2O_3$ is a coefficient.*

Energy of Reactions

PHYSICS Connection A sugar cookie is made with flour, sugar, and other ingredients mixed together. However, the ingredients do not change into a cookie until they are baked. Something must start the change from dough to sugar cookie. The key to starting a chemical reaction is energy. For the chemical reactions that transform the dough to a sugar cookie, energy in the form of heat is needed. Similarly, most compounds in living things cannot undergo chemical reactions without an input of energy.

Activation energy

The minimum amount of energy needed for reactants to form products in a chemical reaction is called the **activation energy.** For example, you know that a candle will not burn until you light its wick. The flame provides the activation energy for the reaction that occurs between the substances in the candle wick and the oxygen in the air. In this example, once the reaction begins, no further input of energy is needed, and the candle continues to burn on its own.

Figure 14 shows that for the reactants X and Y to form product XY, energy is required to start the reaction. The peak in the graph represents the activation energy, the amount of energy that must be added to the system to make the reaction occur. Some reactions rarely happen because they have a very high activation energy.

Get It?
Summarize the meaning of the term activation energy.

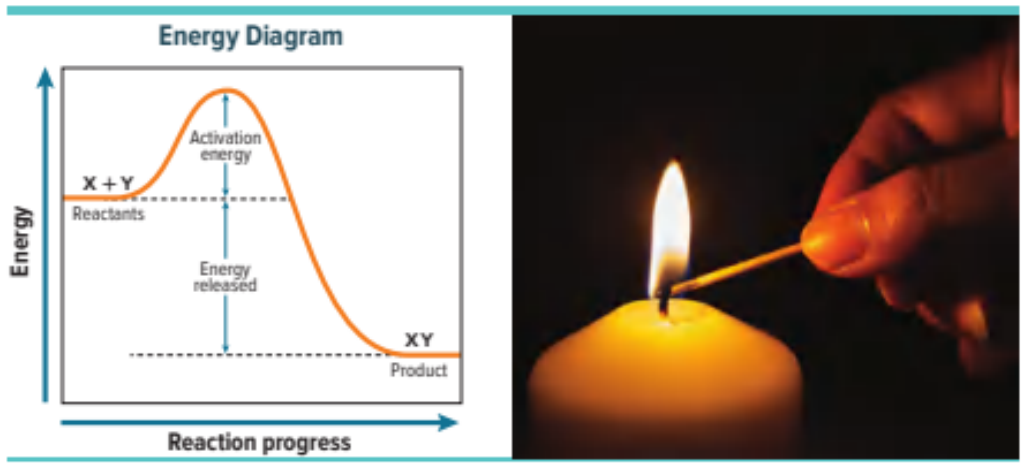

Figure 14 The flame of the match provides activation energy—the amount of energy needed to begin a reaction. The reaction gives off energy in the form of heat and light.

Energy change in chemical reactions

Compare how energy changes during the reactions shown in **Figure 15.** Both reactions require activation energy to get started. However, the reaction in the left graph has lower energy in the product than in the reactants. This reaction is exothermic—it released energy in the form of heat. The reaction shown in the right graph in **Figure 15** is endothermic—it absorbed heat energy. The energy of the products is higher than the energy of the reactant.

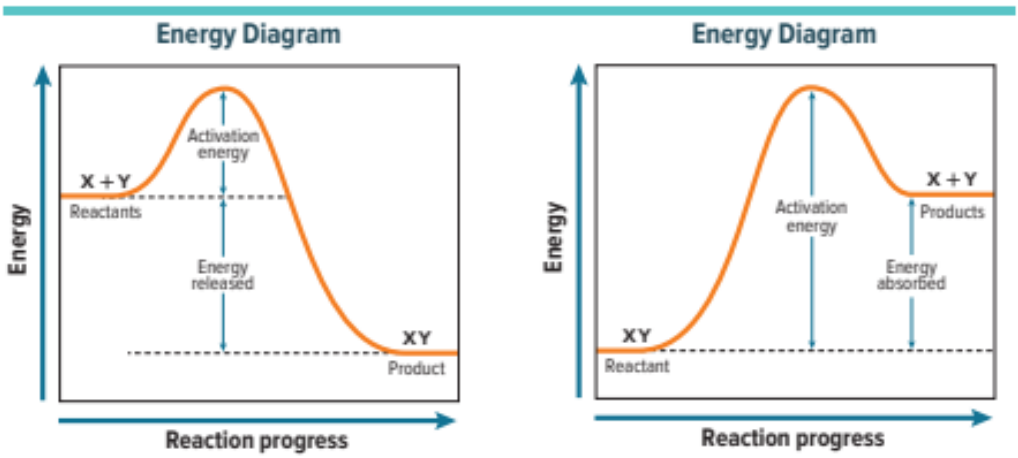

Figure 15 **Left:** In an exothermic reaction, the energy of the products is less than the energy of the reactant. **Right:** In an endothermic reaction, the energy of the products is greater than the energy of the reactant.

Compare *the energy of the products and the reactants in the two graphs.*

In every chemical reaction, there is a change in energy caused by the making and breaking of chemical bonds as reactants form products. Cellular respiration, an exothermic reaction, maintains your body temperature despite ongoing energy transfer from your body to the environment. Endothermic reactions, such as the one shown in **Figure 16**, are also important in living things. Photosynthesis is an example of an endothermic reaction.

Figure 16 An instant cold pack used for first aid gets cold due to an endothermic reaction.

Enzymes

All living things are like chemical factories—driven by chemical reactions. However, these chemical reactions proceed very slowly when carried out in the laboratory because the activation energy is high. To be useful to living organisms, additional substances must be present where the chemical reactions occur to reduce the activation energy and allow the reaction to proceed quickly.

A **catalyst** is a substance that lowers the activation energy needed to start a chemical reaction. Although a catalyst is important in speeding up a chemical reaction, it does not increase how much product is made, and it does not get used up in the reaction. Scientists use many types of catalysts to make reactions occur thousands of times faster than the reaction would be able to occur without the catalyst.

Special proteins called **enzymes** are biological catalysts. The role of enzymes is to lower the activation energy of biochemical reactions. This speeds up the rate of chemical reactions in biological processes. Enzymes are essential to many life processes and are, therefore, essential for life.

Compare the progress of the reactions described in **Figure 17** to see the effect of an enzyme on a chemical reaction. Like all catalysts, the enzyme is not used up by the chemical reaction. Once it has participated in a chemical reaction, the enzyme can be used again.

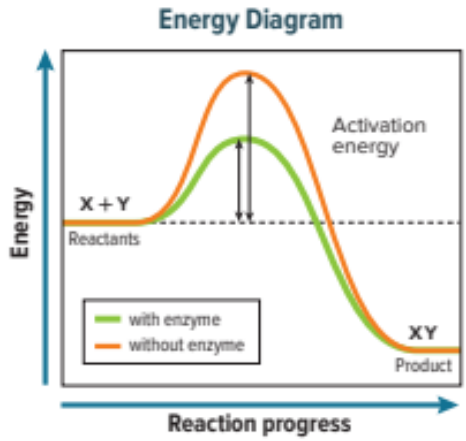

Figure 17 When an enzyme acts as a biological catalyst, the reaction occurs at a rate that is useful to cells.

Compare *the activation energy of the reaction without an enzyme to the activation energy of the reaction with an enzyme.*

An enzyme's name describes what it does. For example, amylase is an important enzyme found in saliva. Digestion of food begins in the mouth when amylase speeds the breakdown of amylose, one of the components of starch.

Other digestive enzymes, such as lipase and protease, also play important roles in the breakdown of food in the human digestive system. Like amylase, most enzymes are specific to one reaction. Lipase breaks down fats in food, and protease breaks down proteins.

Follow the steps shown in **Figure 18** to find out more about how an enzyme works. The reactants that bind to the enzyme are called **substrates.** The specific location where a substrate binds on an enzyme is called the **active site.** The active site and the substrate have complementary shapes. This enables them to interact in a precise manner, similar to the way in which puzzle pieces fit together. As shown in **Figure 18**, the structure of an enzyme is directly related to its function. Only substrates with the same size and shape as the active site will bind to the enzyme.

Once the substrates bind to the active site, the active site changes shape and forms the enzyme-substrate complex. The enzyme-substrate complex helps chemical bonds in the reactants to be broken and new bonds to form—the substrates react to form products. The enzyme then releases the products. The enzyme is then available to bind with more substrates.

Enzymes affect many biological processes. When a person is bitten by a venomous snake, enzymes in the venom break down the membranes of that person's red blood cells. Hard green apples ripen because of the action of enzymes. Photosynthesis and cellular respiration provide energy for the cell with the help of enzymes. Just as worker bees are important for the survival of a beehive, enzymes are the chemical workers in cells.

Get It?
Describe how enzymes affect biochemical reactions.

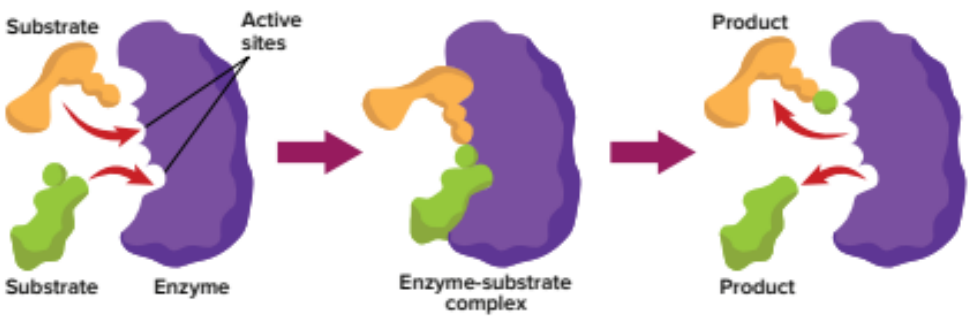

Figure 18 Substrates interact with enzymes at specific places called active sites. Only substrates with a specific shape can bind to the active site of an enzyme. Once the substrates bind, the active site changes shape and forms the enzyme-substrate complex. The substrates react to form products. The products are then released.

ACADEMIC VOCABULARY

specific
precise or particular
Substrates bind at specific locations on enzymes

CCC CROSSCUTTING CONCEPTS

Energy and Matter The law of conservation of energy states that energy can not be created or destroyed during a chemical reaction. Think about what kind of evidence from a scientific experiment would support this idea. Work with a partner or small group to design an experiment that might produce this kind of evidence.

Factors that affect enzyme activity

Factors such as temperature affect enzyme activity. For example, most enzymes in human cells are most active at an optimal temperature close to 37°C. However, enzymes in other organisms, such as bacteria, can be active at other temperatures.

Enzymes are also affected by pH. You'll learn more about pH, which measures acidity, in the next lesson. Different enzymes have different optimal pH levels. For example, the digestive enzymes in your stomach work to help break down food in an acidic environment. Other enzymes work best at other pH levels.

Each type of enzyme has an optimal temperature and pH at which it is most active. The activity of an enzymes decreases as the temperature or pH of the environment moves away from those optimal levels.

Substances called inhibitors can also affect enzyme activity. Some inhibitors bind directly to an enzyme's active site, blocking the binding of the substrates. Other inhibitors bind elsewhere on the enzyme, leaving the active site available. However, they change the shape of the active site, making it impossible for the substrate to bind. Inhibitors can reduce or completely block enzyme activity.

Get It?

Infer Some bacteria live in environments that stay over 100 degrees C. What is one reason they could not survive in the human body?

Check Your Progress

Summary

- Balanced chemical equations must show an equal number of atoms for each element on both sides.
- Activation energy is the energy required to begin a reaction.
- Catalysts are substances that alter chemical reactions.
- Enzymes are biological catalysts that lower the activation energy of biochemical reactions.
- Factors such as pH and temperature affect enzyme activity.

Demonstrate Understanding

1. **Identify** the parts of this chemical reaction: $A + B \rightarrow AB$.
2. **Diagram** the energy changes that can take place in a chemical reaction.
3. **Explain** why the number of atoms of reactants must equal the number of atoms of products formed.
4. **Explain** the role of enzymes in living organisms.

Explain Your Thinking

5. **MATH Connection** For the following chemical reaction, label the reactants and products, and then balance the chemical equation. $\_\_\_H_2O_2 \rightarrow \_\_\_H_2O + \_\_\_O_2$
6. **WRITING Connection** Draw a diagram of a roller coaster and write a paragraph relating the ride to the activation energy of a chemical reaction.

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LESSON 3

WATER AND ITS SOLUTIONS

FOCUS QUESTION

Why do things dissolve in water?

Intermolecular Forces

You have learned that positive ions and negative ions form based on the ability of an atom to attract electrons. If the nucleus of the atom has a weak attraction for the electron, it will donate the electron to an atom with a stronger attraction. Similarly, atoms in a covalent bond do not always attract electrons equally. Some covalent compounds have atoms that hold onto electrons more tightly than the other atoms in the compound. This results in a phenomenon known as polarity.

Polarity is the property of having two opposite poles, or ends. A magnet is an example of an object that has polarity—there is a north pole and a south pole. Molecules that have an unequal distribution of charges are called **polar molecules,** meaning that they have oppositely charged regions. Water is a polar molecule, as shown in **Figure 19**. Notice that it has a slightly negative end and two slightly positive ends.

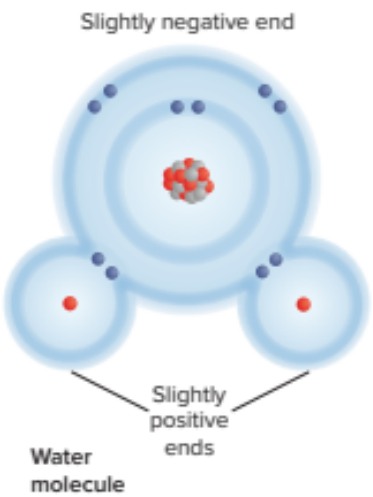


Figure 19 Water molecules have a bent shape, and electrons are not shared equally between hydrogen and oxygen. This results in a molecule with oppositely charged regions.

Summarize *the structure of a water molecule.*

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 much vitamin C are you getting?
Plan and carry out an investigation to determine the proportion of vitamin C in various beverages.

BioLab: What substances or solutions act as buffers?
Plan and carry out an investigation to determine the cause and effect of buffers on living tissue.

Van der Waals forces

You know that magnets have poles and that the poles of magnets exert forces on each other—opposite poles attract one other, while like poles of magnets repel one another. Similarly, when polar molecules are brought close together, they exert forces on each other, too. Regions of opposite charge cause weak electrostatic attractions between molecules. These attractions between the molecules are called **van der Waals forces,** named for Dutch physicist Johannes van der Waals, who first described the phenomenon.

The electrostatic attractions between different molecules are the cause of intermolecular forces. A compound's chemical properties are determined primarily by its chemical structure. Similarly, a compound's physical characteristics, such as its boiling point and melting point, are determined by its intermolecular forces. The strength of the electrostatic attraction depends on the size of the molecule, its shape, and its ability to attract electrons.

Although van der Waals forces are not as strong as covalent and ionic bonds, they play an important role in biological processes. Van der Waals forces are easier to break apart than covalent or ionic bonds, making them ideal for short term interactions. Van der Walls forces act like a molecular "velcro"— unlike a covalent bond, which is more like a molecular "knot." In the example of a gecko, van der Waals forces between the hairlike structures on the gecko's toes and the surface it is climbing allow the animal to climb smooth surfaces.

Figure 20 Scientists have determined that geckos can climb smooth surfaces because of van der Waals forces between the hairlike structures on their toes and the surface they are climbing.

van der Waals forces in water Consider how van der Waals forces work in a common substance—water. The areas of slight positive and negative charges around the water molecule are attracted to the opposite charge of other nearby water molecules. These forces hold the water molecules together.

Without van der Waals forces, water molecules would not form droplets, and droplets would not form a surface of water. The water strider in **Figure 21** takes advantage of this attraction. It is important to understand that van der Waals forces are the attractive forces between the water molecules, not the forces between the atoms that make up water molecules.

Figure 21 Due to the attractive forces between water molecules, the surface of water supports a water strider.

Hydrogen bonds

Earlier, you discovered that water molecules are formed by covalent bonds that link two hydrogen (H) atoms to one oxygen (O) atom. Because electrons are more strongly attracted to the oxygen atom's nucleus, the electrons in the covalent bond with hydrogen are not shared equally. In water, the electrons spend more time near the oxygen atom's nucleus than they do near the hydrogen atoms' nuclei. **Figure 22** shows that there is an unequal distribution of electrons in a water molecule. This, along with the bent shape of water molecules, results in the oxygen end of the molecule having a slightly negative charge and the hydrogen ends of the molecule having a slightly positive charge.

When a polar molecule comes close to the oppositely charged region of another polar molecule, a weak electrostatic attraction results. In water, the electrostatic attraction is called a hydrogen bond. A **hydrogen bond** is a weak interaction involving a hydrogen atom and a fluorine, oxygen, or nitrogen atom from a different molecule. Hydrogen bonding is a strong type of van der Waals force. It is important to remember the difference between covalent bonds, which are the strong chemical bonds within a water molecule, and hydrogen bonds, which are the weaker attractions formed between different water molecules.

Get It?

Explain why understanding the chemistry of water is considered essential to the foundations of biology.

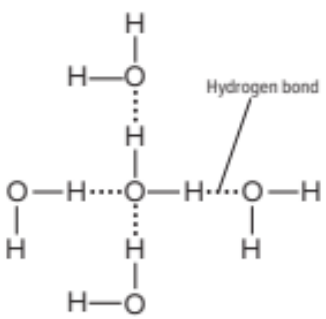


Figure 22 In water, an electrostatic attraction is called a hydrogen bond.

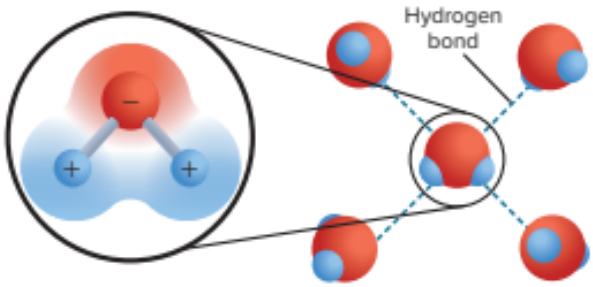
Many of the unique properties of water arise from its ability to form hydrogen bonds. For example, water moderates temperatures on Earth and within living things. Compared to other substances, it takes a large change in energy to change the temperature of water. **Figure 23**, on the next page, shows some of the other special properties of water that contribute to Earth's suitability as an environment for life.

ACADEMIC VOCABULARY

interaction
a reciprocal effect or action
A hydrogen bond is the result of interactions between atoms in different molecules.

Figure 23 Visualizing Hydrogen Bonding

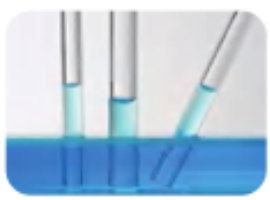
Hydrogen Bonding



A water molecule is made up of one oxygen atom and two hydrogen atoms. A water molecule is polar in nature. Its bent shape results in a slightly positive charge on the hydrogen atoms and a slightly negative charge on the oxygen atom. As a result, it forms hydrogen bonds. Water is called the universal solvent because many substances dissolve in it.

Adhesion

Water is adhesive—it forms hydrogen bonds with molecules on other surfaces. Capillary action is the result of adhesion; it's why water can travel up the stems of plants. Water travels up the paper, and carries the dye to the middle glass via adhesion.



Capillary action in glass tubes

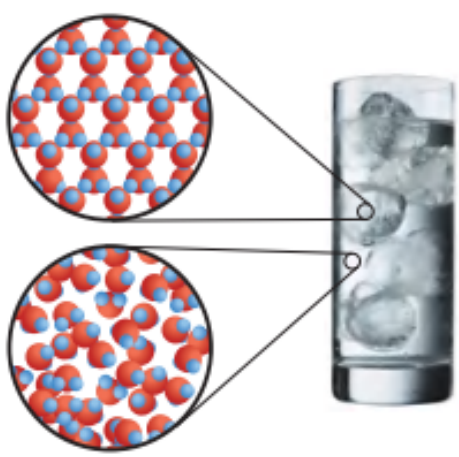
Cups demonstrating adhesion

Cohesion

Water is cohesive—the molecules are attracted to each other because of hydrogen bonds. The positive polarity of the hydrogen atom is attracted to the negative polarity of the oxygen atoms. This attraction creates surface tension, which causes water to form droplets and allows insects and leaves to rest on the surface of a body of water.

Water strider

Dew on grass



Ice Floats

Liquid water becomes more dense as it cools to 4°C. Yet, ice is less dense than liquid water. As a result, nutrients in bodies of water mix because of changes in water density during spring and fall. Also, fish can survive in winter because ice floats—they continue to live and function in the water beneath the ice.

Mixtures with Water

You are probably familiar with powdered drink products that dissolve in water. When you add a powdered substance to water, it does not react with water to form a new product. You create a **mixture.** A mixture is a combination of two or more substances in which each substance retains its individual characteristics and properties

Homogeneous mixtures

A mixture with a uniform composition throughout is called a homogeneous (hoh muh JEE nee us) mixture. A **solution** is another name for a homogeneous mixture. In the powdered drink mix solution shown in **Figure 24**, the drink mix is on top, in the middle, and at the bottom. The water retains its properties, and the drink mix retains its properties.

In a solution, there are two components: a solvent and a solute. A **solvent** is a substance in which another substance is dissolved. A **solute** is the substance that is dissolved in the solvent. In the drink mix, water is the solvent, and the powder is the solute. A mixture of salt and water is another example of a solution because the solute (salt) dissolves completely in the solvent (water). Saliva moistens your mouth and begins the digestion of some foods. It is a solution that contains water, proteins, and salts. Air is a solution of gases.

Figure 24 The drink mix forms a homogeneous mixture in water. The particles of the solute (drink mix) are dissolved and spread throughout the solvent (water).

Heterogeneous mixtures

A salad containing lettuce, croutons, and dressing is a heterogeneous mixture. In a heterogeneous mixture, the components remain distinct; you can tell what they are individually. Compare the mixture of sand and water to the solution of salt and water next to it in **Figure 25**. Sand and water form a type of heterogeneous mixture called a suspension. Over time, the particles in a suspension settle to the bottom.

Figure 25 Sand and water form a heterogeneous mixture; you can see both the liquid and the solid. The homogeneous mixture of salt and water is a liquid; you cannot see the salt.

Get It?
Distinguish between solutions and suspensions.

ACADEMIC VOCABULARY

suspend
to keep from falling or sinking
A slender thread suspended the spider from the web.

Colloids A colloid is a heterogeneous mixture in which the particles do not settle out. You are probably familiar with many colloids, including smoke, butter, milk, paint, and ink. Blood, as shown in **Figure 26**, is a colloid made up of plasma, cells, and other substances.

Figure 26 Blood is a heterogeneous mixture called a colloid.

Acids and bases

Many solutes readily dissolve in water because of water's polarity. This means that an organism, which might be as much as 70 percent water, can be a container for a variety of solutions. When a substance that contains hydrogen is dissolved in water, the substance might release a hydrogen ion (H^+) because it is attracted to the negatively charged oxygen atoms in water, as shown in **Figure 27.** Substances that release hydrogen ions when they are dissolved in water are called **acids.** The more hydrogen ions a substance releases, the more acidic the solution becomes.

Similarly, substances that release hydroxide ions (OH^-) when they are dissolved in water are called **bases.** Sodium hydroxide (NaOH) is a common base that breaks apart in water to release sodium ions (Na^+) and hydroxide ions (OH^-). The more hydroxide ions a substance releases, the more basic the solution becomes.

Acids and bases are key substances in biology. Many of the foods and beverages that we eat and drink are acidic, and the substances in the stomach that break down the food, called gastric juices, are highly acidic.

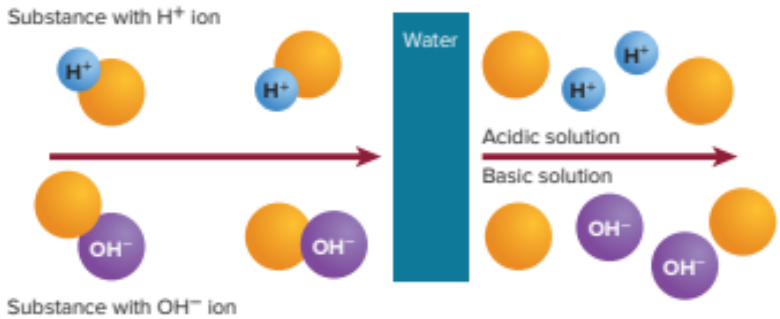


Figure 27 Substances that release H^+ in water are acids. Substances that release OH^- in water are bases.

STEM CAREER Connection

Environmental Science and Protection Technician

Are you interested in making sure that people work and live in a clean and safe environment? Environmental science and protection technicians take samples from the environment and analyze them in a laboratory. They use the results to help science and business professionals meet environmental safety standards.

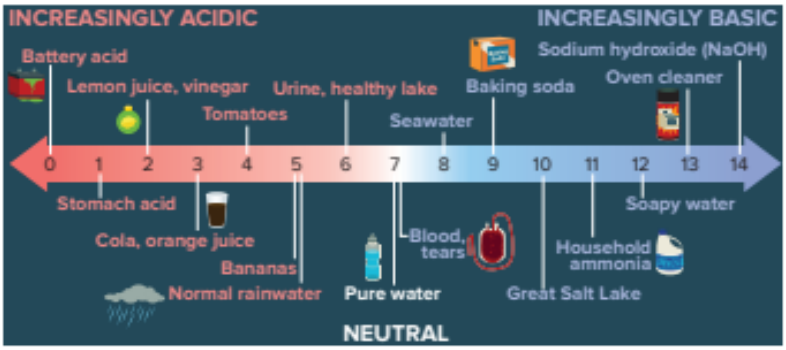


Figure 28 The pH scale is used to indicate the relative strength of acids and bases.

pH and buffers Scientists have a method to measure how acidic or basic a solution is. The measure of concentration of H^+ in a solution is called **pH.** As shown in **Figure 28**, pure water is neutral; it has a pH value of 7.0. Acidic solutions have an abundance of H^+ and have pH values lower than 7. Basic solutions have more OH^- than H^+ and have pH values higher than 7.

HEALTH Connection Most cellular processes occur between pH 6.5 and 7.5. To maintain homeostasis, it is important to control H^+ levels. If you've ever had an upset stomach, you might have taken an antacid, which is a buffer. **Buffers** are mixtures that can react with acids or bases to keep the pH within a particular range. In cells, buffers keep the pH in a cell within the 6.5 to 7.5 pH range.

Check Your Progress

Summary

- Water is a polar molecule.
- Solutions are homogeneous mixtures formed when a solute is dissolved in a solvent.
- Water's properties contribute to Earth's suitability for life.
- Acids are substances that release hydrogen ions into solutions. Bases are substances that release hydroxide ions into solutions.
- pH is a measure of the concentration of hydrogen ions in a solution.

Demonstrate Understanding

1. **Describe** one way in which water helps maintain homeostasis in an organism.
2. **Relate** the structure of water to its ability to act as a solvent.
3. **Draw** a pH scale and label water (H_2O), hydrochloric acid (HCl), and sodium hydroxide (NaOH) in their general areas on the scale.
4. **Compare and contrast** solutions and suspensions. Give examples of each.

Explain Your Thinking

5. **Explain** how baking soda ($NaHCO_3$) is basic. Describe the effect of baking soda on the H^+ ion concentration of stomach contents with pH 4.
6. **Predict** If you add hydrochloric acid (HCl) to water, what effect would this have on the H^+ ion concentration? On the pH?

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LESSON 4

THE BUILDING BLOCKS OF LIFE

FOCUS QUESTION

Why is carbon essential to life?

Organic Chemistry

The element carbon is a component of almost all biological molecules. For this reason, life on Earth often is considered carbon-based. Because carbon is an essential element, scientists have devoted an entire branch of chemistry, called organic chemistry, to the study of organic compounds, which are those compounds containing carbon.

As shown in **Figure 29**, carbon has four electrons in its outermost energy level. Recall that the second energy level can hold eight electrons, so one carbon atom can form four covalent bonds with other atoms. These covalent bonds enable the carbon atoms to bond to each other, which results in a variety of important organic compounds. These compounds can be in the shape of straight chains, branched chains, and rings, such as those illustrated in **Figure 29.**

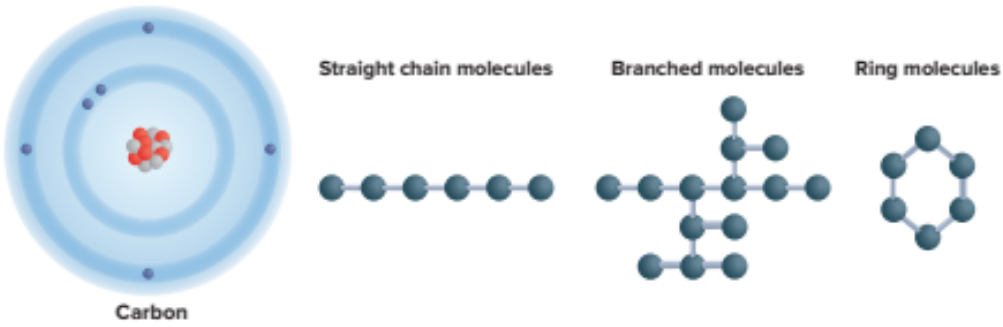

Figure 29 Life is based on carbon compounds. The half-filled outer energy level of carbon, shown in the image on the left, allows for the formation of straight chain, branched, and ring molecules.

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COLLECT EVIDENCE

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INVESTIGATE

GO ONLINE to find these activities and more resources.

Applying Practices: Exploring Macromolecules

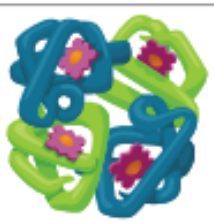
HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

Macromolecules

Carbon atoms can be joined to form carbon molecules. Similarly, most cells store small carbon compounds that serve as building blocks for large molecules. **Macromolecules** are large molecules that are formed by joining smaller organic molecules together. These large molecules are also called polymers. **Polymers** are molecules made from repeating units of identical or nearly identical compounds called monomers that are linked together by a series of covalent bonds. As shown in **Table 1,** biological macromolecules are organized into four major categories: carbohydrates, lipids, proteins, and nucleic acids.

Get It?
Use an analogy to describe macromolecules.

Table 1 Summary of Biological Macromolecules

Group	Example	Function
Carbohydrates		• Store energy • Provide structural support
Lipids		• Store energy • Provide barriers
Proteins		• Transport substances • Speed reactions • Provide structural support • Control cell growth
Nucleic Acids		• Store and communicate genetic information

Carbohydrates

Compounds composed of carbon, hydrogen, and oxygen in a ratio of one oxygen and two hydrogen atoms for each carbon atom are called **carbohydrates.** A general formula for carbohydrates is written as $(CH_2O)_n$. Here the subscript n indicates the number of CH_2O units in a chain. Biologically important carbohydrates that have values of n ranging from three to seven are called simple sugars, or monosaccharides (mah nuh SA kuh ridz). The monosaccharide glucose, shown in **Figure 30**, plays a central role as an energy source for organisms.

Monosaccharides can be linked to form larger molecules. Two monosaccharides joined together form a disaccharide (di SA kuh rid). Like glucose, disaccharides serve as energy sources. Maltose, also shown in **Figure 30**, and lactose, which is a component of milk, are both disaccharides. Longer carbohydrate molecules are called polysaccharides. One important polysaccharide is glycogen, which is shown in **Figure 30**. Glycogen is an energy storage form of glucose that is found in the liver and skeletal muscle. When the body needs energy between meals or during physical activity, glycogen is broken down into glucose.

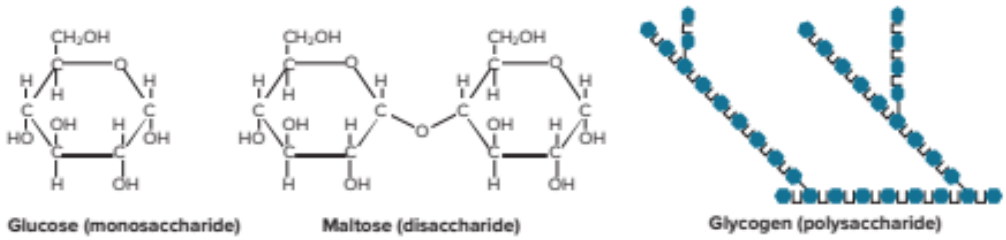


Figure 30 Glucose is a monosaccharide. Maltose is a disaccharide composed of two glucose molecules. Glycogen is a branched polysaccharide made from glucose monomers.

In addition to their roles as energy sources, carbohydrates have other important functions in biology. In plants, a carbohydrate called cellulose provides structural support in cell walls. As shown in **Figure 31**, cellulose is made of chains of glucose linked together into tough fibers that are well suited for their structural role. Chitin (KI tun) is a nitrogen-containing polysaccharide that is the main component in the hard outer shells of shrimp, lobsters, and some insects, as well as the cell walls of some fungi.

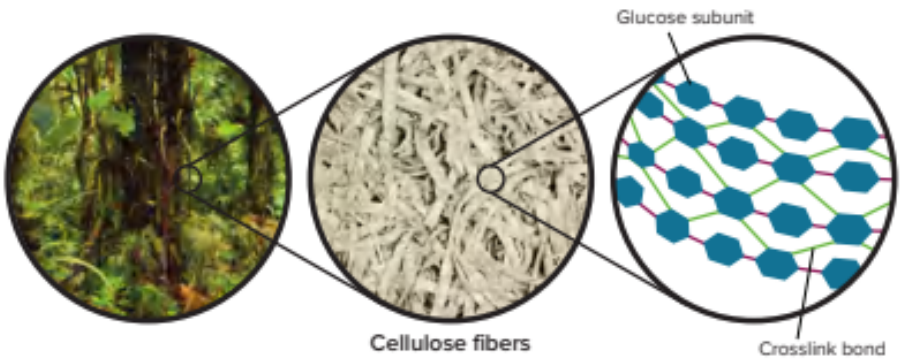


Figure 31 The cellulose in plant cells provides the structural support for trees to stand in a forest.

Lipids

Another important group of biological macromolecules is the lipid group. **Lipids** are molecules made mostly of carbon and hydrogen that make up the fats, oils, and waxes. Lipids are composed of fatty acids, glycerol, and other components. The primary function of lipids is to store energy. A lipid called a triglyceride (tri GLIH suh rid) is a fat if it is solid at room temperature and an oil if it is liquid at room temperature. In addition, triglycerides are stored in the fat cells of the body. Plant leaves are coated with lipids called waxes to prevent water loss, and the honeycomb in a beehive is made of beeswax.

Saturated and unsaturated fats Organisms need lipids to function properly. The basic structure of a lipid includes fatty acid tails, as shown in **Figure 32**. Each tail is a chain of carbon atoms bonded to hydrogen and other carbon atoms by single or double bonds. Lipids that have tail chains with only single bonds between the carbon atoms are called saturated fats because no more hydrogens can bond to the tail. Lipids that have at least one double bond between carbon atoms in the tail chain can accommodate at least one more hydrogen and are called unsaturated fats. Fats with more than one double bond in the tail are called polyunsaturated fats.

Phospholipids A special lipid shown in **Figure 32**, called a phospholipid, is responsible for the structure and function of the cell membrane. Lipids are hydrophobic, which means they do not dissolve in water. This characteristic is important because it allows lipids to serve as barriers in biological membranes.

Steroids Another important category of lipids is the steroid group. Steroids include substances such as cholesterol and hormones. Despite its reputation as a "bad" lipid, cholesterol provides the starting point for other necessary lipids such as vitamin D and the hormones estrogen and testosterone.

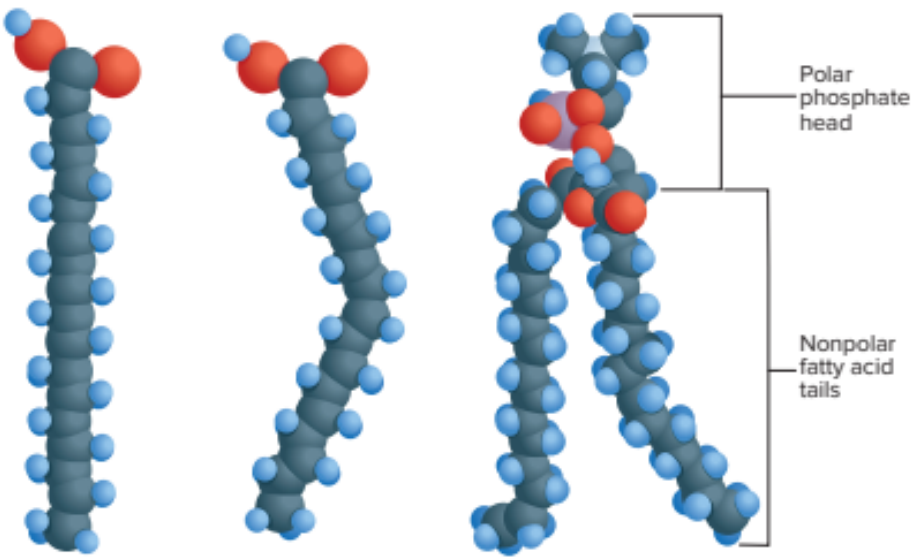


Figure 32 Stearic acid has no double bonds between carbon atoms; oleic acid has one double bond. Phospholipids have a polar head and two nonpolar tails.

Proteins

Another primary building block of living things is protein. A **protein** is a compound made of small carbon compounds called amino acids. **Amino acids** are small compounds that are made of carbon, nitrogen, oxygen, hydrogen, and sometimes sulfur. All amino acids share the same general structure.

Amino acid structure Amino acids have a central carbon atom like the one shown in **Figure 33**. Recall that carbon can form four covalent bonds. One of those bonds is with hydrogen. The other three bonds are with an amino group ($–NH_2$), a carboxyl group (–COOH), and a variable group (–R). The variable group makes each amino acid different. There are 20 different variable groups, and proteins are made of different combinations of all 20 different amino acids. Several covalent bonds called peptide bonds join amino acids together to form proteins, which is also shown in **Figure 33**. A peptide bond forms between the amino group of one amino acid and the carboxyl group of another.

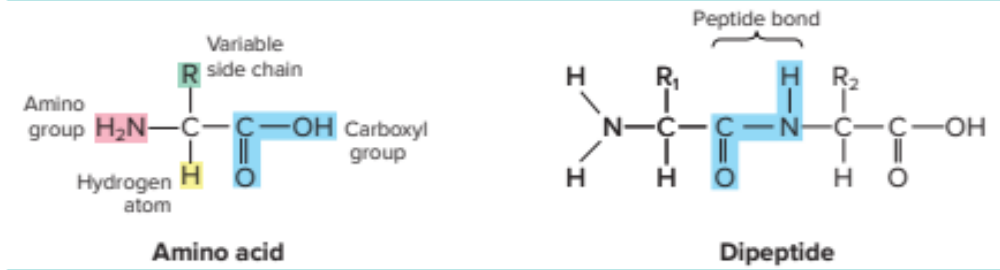


Figure 33 **Left:** The general structure of an amino acid has four groups around a central carbon. **Right:** The peptide bond in a protein happens as a result of a chemical reaction.

Interpret *which other molecule is a product when a peptide bond forms.*

Protein function Proteins make up about 15 percent of your total body mass and are involved in nearly every function of your body. For example, your muscles, skin, and hair are made of proteins. Your cells contain about 10,000 different proteins that provide structural support, transport substances inside the cell and between cells, communicate signals within a cell and between cells, speed up chemical reactions, and control cell growth.

Get It?

Describe What are the primary functions of proteins?

CCC CROSSCUTTING CONCEPTS

Energy and Matter Nine of the 20 amino acids are essential, which means our bodies cannot make them. Using evidence from the text or other sources, construct an explanation about how the atoms found in essential amino acids get into our bodies.

WORD ORIGINS

polymer

poly- prefix; from Greek, meaning *many*

–meros from Greek, meaning *part*

Three-dimensional protein structure Based on the variable groups contained in the different amino acids, proteins can have up to four levels of structure. The number of amino acids in a chain and the order in which the amino acids are joined define the protein's primary structure.

After an amino acid chain is formed, it folds into a unique three-dimensional shape, which is the protein's secondary structure. **Figure 34** shows two basic secondary structures: the helix and the pleat. A protein might contain many helices, pleats, and folds. The tertiary structure of many proteins is globular, such as the hemoglobin protein shown in **Table 1**, but some proteins form long fibers. Some proteins form a fourth level of structure by combining with other proteins.

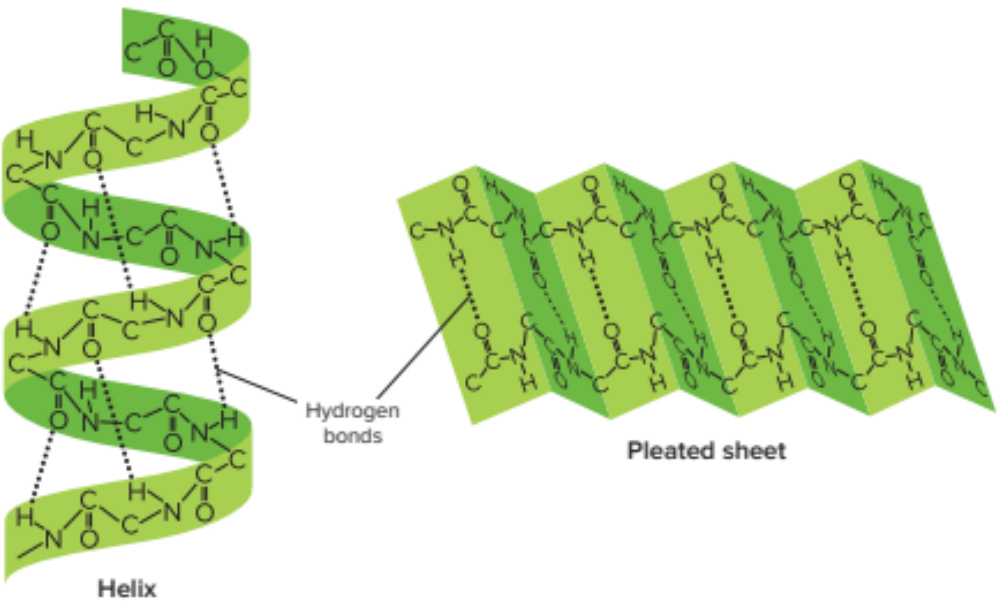


Figure 34 The shape of a protein depends on the interactions among the amino acids. Hydrogen bonds help the protein hold its shape.

Nucleic acids

The fourth group of biological macromolecules are nucleic acids. **Nucleic acids** are complex macromolecules that store and transmit genetic information. There are two types of nucleic acids found in living organisms: deoxyribonucleic (dee AHK sih rib oh noo klay ihk) acid (DNA) and ribonucleic (rib oh noo KLAY ihk) acid (RNA).

Nucleic acids are made of smaller repeating subunits composed of carbon, nitrogen, oxygen, phosphorus, and hydrogen atoms, called **nucleotides.** Adenosine triphosphate (ATP) is a nucleotide with three phosphate groups. ATP is a storehouse of chemical energy that can be used by cells in a variety of reactions. It releases energy when the bond between the second and third phosphate group is broken. Less energy is released when the bond between the first and second phosphate group is broken.

Figure 35 shows the basic structure of a nucleotide and nucleic acid. There are five major nucleotides, all of which have three units—a phosphate, a nitrogenous base, and a ribose sugar. In nucleic acids, the sugar of one nucleotide bonds to the phosphate of another. The nitrogenous base that sticks out from the chain is available for hydrogen bonding with other bases in other nucleic acids.

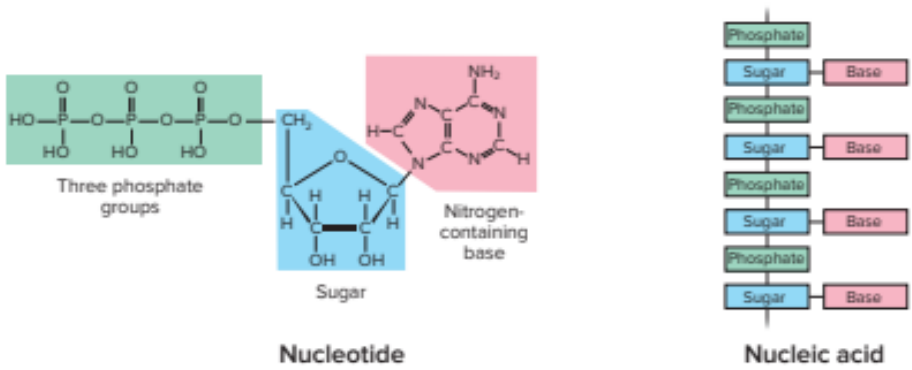


Figure 35 **Left:** DNA nucleotides contain the sugar deoxyribose. RNA nucleotides contain the sugar ribose. **Right:** Nucleotides are joined together by bonds between their sugar group and phosphate group.

Check Your Progress

Summary

- Carbon compounds are the basic building blocks of living organisms.
- Biological macromolecules are formed by joining small carbon compounds into polymers.
- There are four types of biological macromolecules.
- Peptide bonds join amino acids in proteins.
- Chains of nucleotides form nucleic acids.

Demonstrate Understanding

1. **Explain** If an unknown substance found on a meteorite contains no trace of carbon, can scientists conclude that there is life at the meteorite's origin?
2. **Compare** the types of biological macromolecules and their functions.
3. **Identify** the components of carbohydrates.
4. **Discuss** the importance of amino acid order to a protein's function.

Explain Your Thinking

5. **Summarize** Given the large number of proteins in the body, explain why the shape of an enzyme is important to its function.
6. **Connect** Explain the relationship between the carbon in a molecule of glucose and the cellulose found in a plant cell wall.

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SCIENCE & SOCIETY

Balancing Your Plate

Most people would agree that eating well is essential to good health. Defining what it means to eat well, however, is no easy task. For example, what is the optimal proportion of fat, protein, and carbohydrates in the human diet? Scientists who study nutrition have investigated this topic extensively. It is important that the public be scientifically literate so that they can examine the evidence for themselves.

Doctors disagree about the amounts of fat, protein, and carbohydrates that the average adult diet should contain.

Low fat, low carb

People have a variety of reasons for adjusting the proportions of fat, protein, and carbohydrates in their diet. Some want to lose or gain weight or improve their athletic performance. Others are trying to prevent heart disease or manage other health problems.

For many decades, doctors recommended diets low in fat for weight loss and prevention of heart disease. Fat makes up 20 to 30 percent of consumed kilocalories on a low-fat diet. The long-term success of these diets has been unclear, however, and low-fat diets have other disadvantages, such as poor absorption of fat-soluble vitamins.

Recently, an increasing number of studies have focused on a diet in which people restrict carbohydrates. On the ketogenic diet, people get 60 to 70% or more of their kilocalories from fat and just 5 to 10% from carbohydrates. The goal of this diet is to induce ketosis, an alternative metabolic process that your body uses when it does not have access to glucose. As the body breaks down fat for energy through the process of ketosis, it produces substances called ketones.

People have reported rapid weight loss and other health benefits from ketogenic eating, including better control of epilepsy. But there are concerns associated with this way of eating, too, such as the possibility of nutrient deficiencies. Ketosis can also lead to a potentially fatal condition called ketoacidosis, in which acids build up in the blood.

The jury is still out on low-fat and low-carb diets. By understanding how to critically evaluate claims about a diet plan's benefits and drawbacks, people can make better decisions about what they eat.

ASK QUESTIONS TO CLARIFY

Record two questions that you have about fat, protein, and carbohydrates in the diet. Conduct research online to answer your questions. Record the answers and the sources you used.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 MATTER

- Atoms consist of protons, neutrons, and electrons.
- Elements are pure substances made up of only one kind of atom.
- Isotopes are forms of the same element that have a different number of neutrons.
- Compounds are substances with unique properties that are formed when elements combine.
- Elements can form covalent and ionic bonds.

- atom
- nucleus
- proton
- neutron
- electron
- element
- isotope
- compound
- ion
- ionic bond
- covalent bond
- molecule

Lesson 2 CHEMICAL REACTIONS

- Balanced chemical equations must show an equal number of atoms for each element on both sides.
- Activation energy is the energy required to begin a reaction.
- Catalysts are substances that alter chemical reactions.
- Enzymes are biological catalysts that lower the activation energy of biochemical reactions.
- Factors such as pH and temperature affect enzyme activity.

- chemical reaction
- reactant
- product
- activation energy
- catalyst
- enzyme
- substrate
- active site

Lesson 3 WATER AND ITS SOLUTIONS

- Water is a polar molecule.
- Solutions are homogeneous mixtures formed when a solute is dissolved in a solvent.
- Water's properties contribute to Earth's suitability for life.
- Acids are substances that release hydrogen ions into solutions. Bases are substances that release hydroxide ions into solutions.
- pH is a measure of the concentration of hydrogen ions in a solution.

- polar molecule
- van der Waals forces
- hydrogen bond
- mixture
- solution
- solvent
- solute
- acid
- base
- pH
- buffer

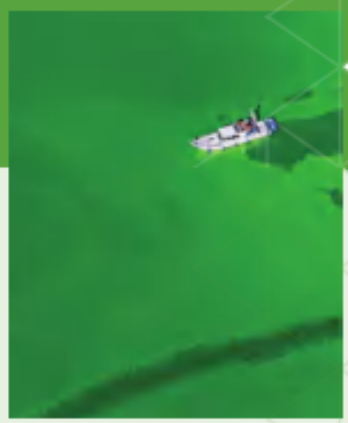
Lesson 4 THE BUILDING BLOCKS OF LIFE

- Carbon compounds are the basic building blocks of living organisms.
- Biological macromolecules are formed by joining small carbon compounds into polymers.
- There are four types of biological macromolecules.
- Peptide bonds join amino acids in proteins.
- Chains of nucleotides form nucleic acids.

- macromolecule
- polymer
- carbohydrate
- lipid
- protein
- amino acid
- nucleic acid
- nucleotide

THREE-DIMENSIONAL THINKING

Module Wrap-Up



REVISIT THE PHENOMENON

What is wrong with the water?

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

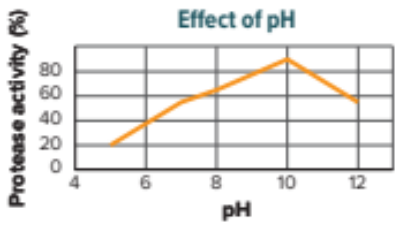
How do pH and temperature affect protease activity?

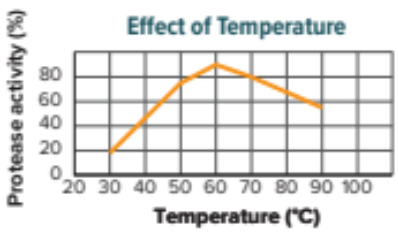
Proteases are enzymes that break down protein. Bacterial proteases are often used in detergents to help remove stains such as egg, grass, blood, and sweat from clothes.

Data and Observations A protease from a newly isolated strain of bacteria was studied over a range of pH values and temperatures.

CER Analyze and Interpret Data

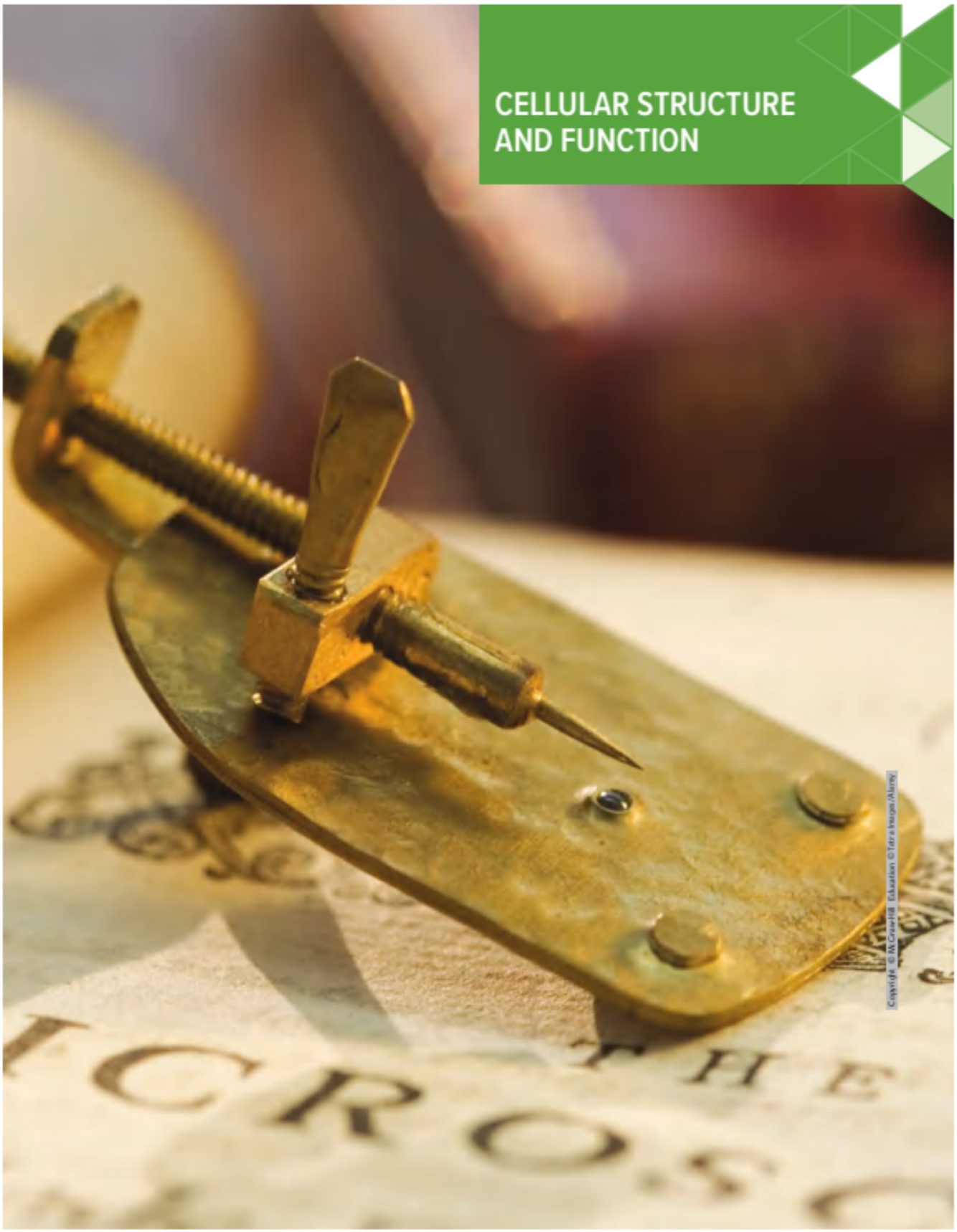
1. **Identify** the range of pH values and temperatures used in the experiment.
2. **Summarize** the results of the two graphs.
3. **Claim, Evidence, Reasoning** If a laundry detergent is basic and requires hot water to be most effective, would this protease be useful? Explain.





*Data obtained from: Adinarayana, et al. 2003. Purification and partial characterization of thermostable serine alkaline protease from a newly isolated *Bacillus subtilis* PE-11. *AAPS PharmSciTech* 4: article 56.

CELLULAR STRUCTURE AND FUNCTION



CELLULAR STRUCTURE AND FUNCTION

ENCOUNTER THE PHENOMENON

What could you see if you used this microscope?

SEP Ask Questions

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

CER Claim, Evidence, Reasoning

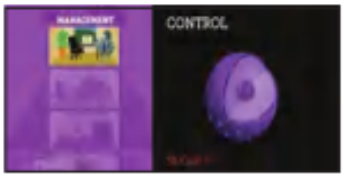
Make Your Claim Use your CER chart to make a claim about various cell structures and their functions within organisms. Explain your reasoning.

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: Cell Discovery and Cell Theory



LESSON 4: Explore & Explain: Controlling Cell Activities

LESSON 1

CELL DISCOVERY AND THEORY

FOCUS QUESTION

How did the invention of the microscope lead to the discovery of cells?

History of the Cell Theory

For centuries, scientists had no idea that the human body or the bodies of other complex organisms consist of trillions of cells. Cells are so small that their existence was unknown before the invention of the microscope. In 1665, as indicated in the timeline on the next page, an English scientist named Robert Hooke made a simple microscope and looked at a piece of cork, the dead cells of oak bark.

Hooke observed small, box-shaped structures, such as those shown in **Figure 1**. He called them cellulae (the Latin word meaning *small rooms*) because the boxlike cells of cork reminded him of the cells in which monks live at a monastery. It is from Hooke's work that we have the term cell. A **cell** is the basic structural and functional unit of all living organisms.

During the late 1600s, Dutch scientist Anton van Leeuwenhoek (LAY vun hook) designed his own microscope after he was inspired by a book written by Hooke. To his surprise, he saw living organisms in pond water, milk, and various other substances.

Continuous investigations by these scientists and many others, along with the development of new technologies, led to new scientific information. This has led to the development of new branches of science, and many new and exciting discoveries, as shown in the timeline in **Figure 2**, on the next page. Research on cells and cell processes is ongoing.

Light micrograph 100x

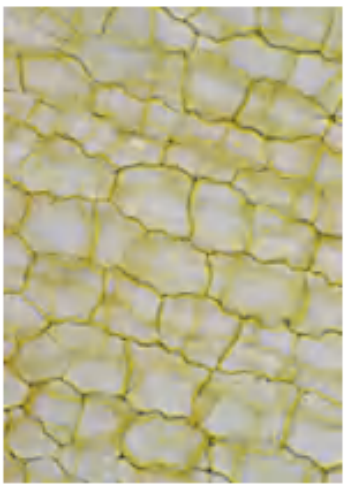


Figure 1 Robert Hooke used a basic light microscope to see what looked like empty chambers in a cork sample.

Infer *what you think Hooke would have seen if these were living cells.*

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

COLLECT EVIDENCE

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

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Discover Cells

Communicate the structures of cells observed in a microscope.

Review the News

Obtain information from a current news story about cell discovery. Evaluate your source and communicate your findings to your class.

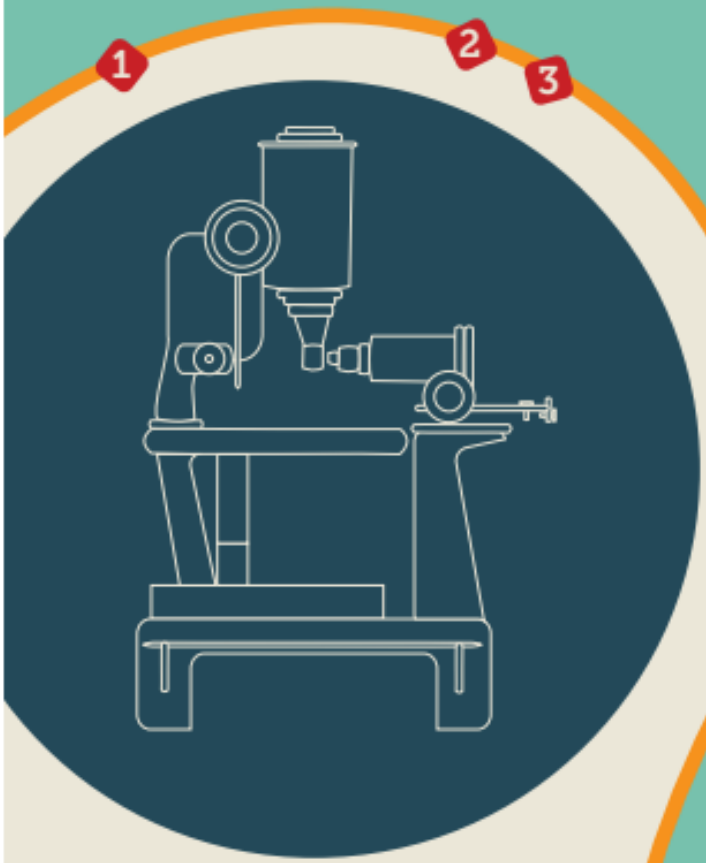


Figure 2

Microscopes in Focus

The invention of microscopes, improvements to the instruments, and new microscope techniques have led to the development of the cell theory and a better understanding of cells.

1. **1590** Dutch lens grinders Hans and Zacharias Janssen invent the first compound microscope by placing two lenses in a tube.
2. **1665** Robert Hooke observes cork and names the tiny chambers that he sees cells. He publishes drawings of cells, fleas, and other minute bodies in his book *Micrographia*.
3. **1683** Dutch biologist Anton van Leeuwenhoek discovers single-celled, animal-like organisms, now called protozoans.
4. **1830–1855** Scientists discover the cell nucleus (1833) and propose that both plants and animals are composed of cells (1839).
5. **1939** Ernest Everett Just writes the textbook *Biology of the Cell Surface* after years of studying the structure and function of cells.
6. **1981** The scanning tunneling microscope (STM) allows scientists to see individual atoms.
7. **2008** Three-dimensional structured illumination microscopy (3-D SIM) combines a 3-D view, high resolution, and multiple colors.

The cell theory

Scientists continued observing the living microscopic world using glass lenses. In 1838, German scientist Matthias Schleiden carefully studied plant tissues and concluded that all plants are composed of cells. A year later, another German scientist, Theodor Schwann, reported that animal tissues also consisted of individual cells. Prussian physician Rudolph Virchow proposed in 1855 that all cells are produced from the division of existing cells. The observations and conclusions of these scientists and others are summarized as the cell theory. The **cell theory** is one of the fundamental ideas of modern biology and includes the following three principles:

1. All living organisms are composed of one or more cells.
2. Cells are the basic unit of structure and organization of all living organisms.
3. Cells arise only from previously existing cells, with cells passing copies of their genetic material on to their daughter cells.

Get It?

Explain Can cells appear spontaneously without genetic material from previous cells?

Microscope Technology

The discovery of cells and the development of the cell theory would not have been possible without microscopes. However, Hooke and van Leeuwenhoek would not have been able to see the individual structures within human skin cells with their microscopes. Developments in microscope technology have given scientists the ability to study cells in greater detail than early scientists ever thought possible.

Optical microscopes

An optical microscope uses visible light and lenses to magnify an object. A compound light microscope is a type of optical microscope. Each lens in the series magnifies the image of the previous lens. For example, when two lenses each individually magnify 10 times, the total magnification is 100 times (10 × 10). Scientists often stain cells when using a light microscope because cells are so tiny, thin, and translucent. Scientists have developed techniques for light microscopes, but the properties of visible light will always limit their resolution (the ability of the microscope to make individual components visible). Objects cause light to scatter, which blurs images. The maximum magnification without blurring is around 1000×.

STEM CAREER Connection

Cytotechnologist

Do you have a keen eye for detail and like to solve puzzles? Cytotechnologists act as disease detectives by analyzing cell and tissue samples, often in a medical setting. The information from a cytotechnologist's report can be used by a pathologist or doctor to diagnose and treat disease.

Non-optical microscopes

As they began to study cells, scientists needed greater magnification to see the details of tiny parts of cells. In the early 1930s, Ernst Ruska developed the electron microscope. Instead of lenses, the electron microscope uses magnets to aim a beam of electrons at thin slices of cells. This type of electron microscope is called a transmission electron microscope (TEM) because electrons are transmitted through a specimen to a fluorescent screen. Thick parts of the specimen absorb more electrons than thin parts, forming a black-and-white shaded image of the specimen.

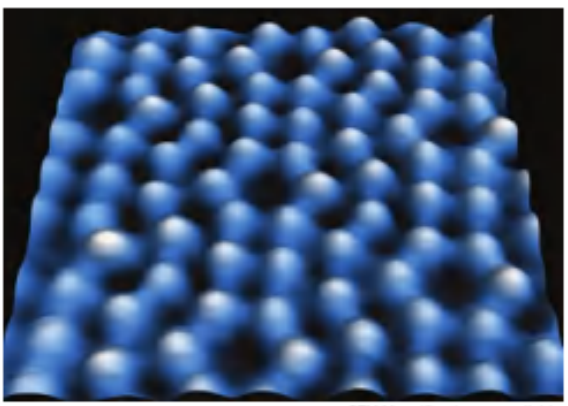
Transmission electron microscopes have advantages and disadvantages. They can magnify up to 500,000×, but the specimen must be dead, sliced very thin, and stained with heavy metals.

Many modifications have been made to the original electron microscopes over the years. For example, the scanning electron microscope (SEM) is a modification that directs electrons over the surface of the specimen, producing a three-dimensional image. One disadvantage of using a SEM is that only nonliving cells and tissues can be observed.

Get It?

Compare and contrast a TEM and a SEM.

Another type of microscope, the scanning tunneling electron microscope (STM), involves bringing the charged tip of a probe extremely close to the specimen so that the electrons "tunnel" through the small gap between the specimen and the tip. This instrument has enabled scientists to create three-dimensional computer images of objects as small as atoms. In contrast to TEM and SEM, STM can be used with live specimens. **Figure 3** shows an STM of a silicon chip surface. Each protrusion is a single silicon atom.



STM Magnification: unavailable

Figure 3 The scanning tunneling microscope (STM) provides images, such as this silicon chip surface

Compare and contrast *the structures and functions of a STM to those of other types of microscopes.*

ACADEMIC VOCABULARY

enable
to make possible
The development of the STM has enabled scientists to make three-dimensional computer images of atoms.

Basic Cell Types

You have learned, according to the cell theory, that cells are the basic units of all living organisms. By observing your own body and the living things around you, you might infer that cells must exist in various shapes and sizes. You also might infer that cells differ based on the functions they perform for an organism. However, all cells have at least one physical trait in common: they all have a structure called a plasma membrane. A **plasma membrane,** shown in **Figure 4**, is a boundary that helps control what enters and leaves the cell. Each of your skin cells has a plasma membrane, as do the cells of a rattlesnake.

Cells generally have a number of functions in common.

- Most cells have genetic material in some form that provides instructions for making substances that the cell needs.
- Cells also break down molecules to generate energy.

Two basic cell types Scientists group cells into two basic types. These types are prokaryotic (pro kar ee AW tik) cells and eukaryotic (yew kar ee AW tik) cells. Eukaryotic cells generally are one to one hundred times larger than prokaryotic cells. When you compare the prokaryotic and eukaryotic cells in **Figure 4** you will notice that both have a plasma membrane, but one cell contains many distinct internal structures called **organelles**—specialized membrane-bound structures that carry out specific cell functions in different parts of the cell at the same time.

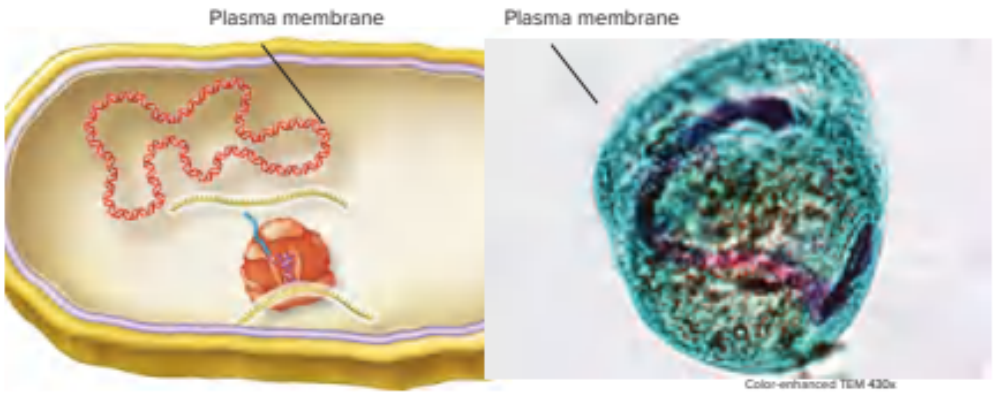


Figure 4 The prokaryotic cell on the left is smaller and appears less complex than the eukaryotic cell on the right. The prokaryotic cell has been enlarged for the purpose of comparing each cell's internal structures.

WORD ORIGINS

eukaryotic
prokaryotic
eu- prefix; from Greek, meaning *true*
pro- prefix; from Greek, meaning *before*
-kary from Greek, meaning *nucleus*

CCC CROSSCUTTING CONCEPTS

Structure and Function An analogy is a comparison of two things that can help to explain a concept. A cell's genetic material provides instructions for making what the cell needs. An analogy for this genetic material, then, might be a recipe. Using evidence from the text, decide on something that could serve as an analogy for the plasma membrane. Justify your analogy in a short paragraph.

Eukaryotic cells are defined as cells with a nucleus and other organelles that are bound by membranes. The **nucleus** is a central organelle that contains the cell's genetic material in the form of DNA. Multicellular organisms made up of eukaryotic cells are called eukaryotes. Some unicellular organisms, such as some yeast, also are eukaryotes.

Prokaryotic cells are simpler than eukaryotic cells. Prokaryotic cells are defined as cells without a nucleus or other membrane-bound organelles. Most unicellular organisms, such as bacteria, are prokaryotic cells. Thus, they are called prokaryotes. Many scientists think that prokaryotes are similar to the first organisms that lived on Earth.

Get It?

Compare and contrast eukaryotic and prokaryotic cells.

Origin of cell diversity

Scientists continue to investigate why there are two types of cells. The answer might be that eukaryotic cells evolved from prokaryotic cells millions of years ago. According to the endosymbiont theory, a symbiotic relationship involving one prokaryotic cell living inside another, with both cells benefiting from the relationship, might have been key to the evolution of eukaryotic cells.

Imagine how organisms would be different if the eukaryotic form had not evolved. Eukaryotic cells are larger and have distinct organelles. These cells have developed specific functions, which has led to cell diversity, and thus more diverse organisms. Life-forms more complex than bacteria might not have evolved without eukaryotic cells.

Check Your Progress

Summary

- The invention of microscopes led to the study of cells.
- The cell theory summarizes three principles.
- There are two broad groups of cell types: prokaryotic cells and eukaryotic cells.

Demonstrate Understanding

1. **Explain** how the development and improvement of microscopes changed the study of living organisms.
2. **Compare and contrast** the structure and function of various types of microscopes.
3. **Describe** the cell theory.
4. **Differentiate** the plasma membrane and the organelles.

Explain Your Thinking

5. **Describe** how you would determine whether the cells of a newly discovered organism were prokaryotic or eukaryotic.
6. MATH Connection If the overall magnification of a series of two lenses is 30×, and one lens magnifies 5×, what is the magnification of the other lens? Calculate the total magnification if the 5× lens is replaced by a 7× lens.

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LESSON 2

THE PLASMA MEMBRANE

FOCUS QUESTION

Why is the plasma membrane an important structure of the cell?

Structure of the Plasma Membrane

CHEMISTRY Connection Most of the molecules in the plasma membrane are lipids. Lipids are large molecules that are composed of glycerol and three fatty acids. If a phosphate group replaces a fatty acid, a phospholipid forms. A phospholipid (fahs foh LIH pid) is a molecule that has a glycerol backbone, two fatty acid chains, and a phosphate-containing group. The plasma membrane is composed of a **phospholipid bilayer,** in which two layers of phospholipids are arranged tail-to-tail, as shown in **Figure 5**. In the plasma membrane, phospholipids arrange themselves in a way that allows the plasma membrane to exist in the watery environment.

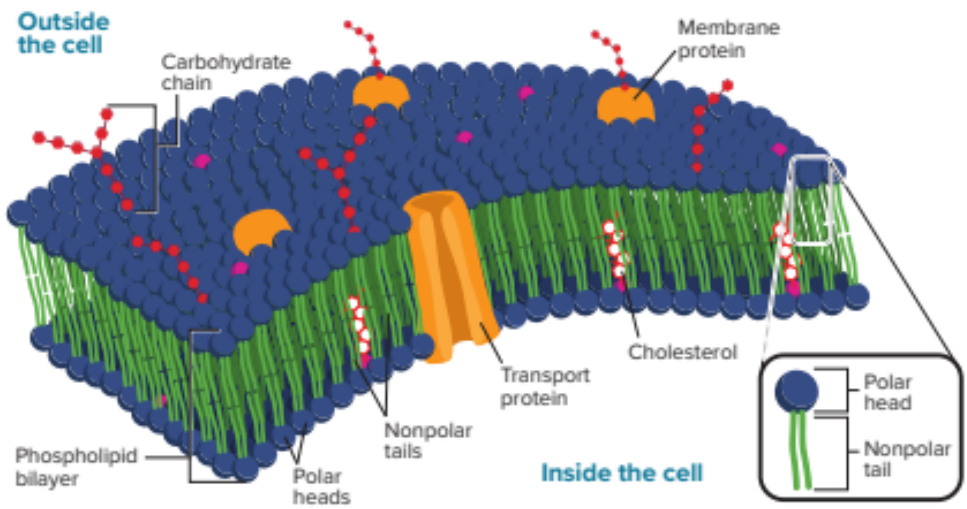


Figure 5 The phospholipid bilayer looks like a sandwich, with the polar heads facing the outside and the nonpolar tails facing the inside.

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 plasma membrane. Evaluate your source and communicate your findings to your class.

The phospholipid bilayer

Review **Figure 5** and note that each phospholipid is diagrammed as a head with two tails. The phosphate group in each phospholipid makes the head polar. The polar head is attracted to water because water also is polar. The two fatty acid tails are nonpolar and are repelled by water.

The two layers of phospholipid molecules resemble a sandwich, with the fatty acid tails forming the interior of the plasma membrane and the phospholipid heads facing the watery environments found inside and outside the cell, as shown in **Figure 5**. This bilayer structure is critical for the formation and function of the plasma membrane. The phospholipids are arranged in such a way that the polar heads can be closest to the water molecules and the nonpolar tails can be farthest away from the water molecules.

When many phospholipid molecules come together in this manner, a barrier is created that is polar at its surfaces and nonpolar in the middle. Water-soluble substances will not move easily through the plasma membrane because they are stopped by the nonpolar middle. Therefore, the plasma membrane can separate the environment inside the cell from the environment outside the cell.

Get It?

Describe the benefit of the bilayer structure of the plasma membrane.

Other components of the plasma membrane

Moving with and among the phospholipids in the plasma membrane are cholesterol, proteins, and carbohydrates. When found on the outer surface of the plasma membrane, proteins called receptors transmit signals to the inside of the cell. Proteins at the inner surface anchor the plasma membrane to the cell's internal support structure, giving the cell its shape. Other proteins span the entire membrane and create tunnels through which certain substances enter and leave the cell. These **transport proteins** move needed substances or waste materials through the plasma membrane and therefore contribute to the selective permeability of the plasma membrane.

Locate the cholesterol molecules in **Figure 5**. Nonpolar cholesterol is repelled by water and is positioned among the phospholipids. Cholesterol helps to prevent the fatty-acid tails of the phospholipid bilayer from sticking together, which contributes to the fluidity of the plasma membrane. It is an important substance for maintaining homeostasis in a cell.

Other substances in the membrane, such as carbohydrates attached to proteins, stick out from the plasma membrane to define the cell's characteristics and help cells identify chemical signals.

SCIENCE USAGE V. COMMON USAGE

polar

Science usage: completely opposite

Water and phospholipids are polar molecules because they have positively-charged ends and negatively charged ends.

Common usage: relating to Earth's North or South Pole

Polar bears live in the region near the North Pole.

STUDY TIP

Question Session Work with a partner and ask each other questions about the plasma membrane. Discuss each other's answers. Ask as many questions as you think of while taking turns.

Together, the phospholipids in the bilayer create a "sea" in which other molecules can float, like apples floating in a barrel of water. This "sea" concept is the basis for the **fluid mosaic model** of the plasma membrane. The phospholipids can move sideways within the membrane, just as apples move around in water. At the same time, other components in the membrane, such as proteins, also move among the phospholipids. Because there are different substances in the plasma membrane, a pattern, or mosaic, is created on the surface. You can see this pattern in **Figure 6**. The components of the plasma membrane are in constant motion, sliding past one another.

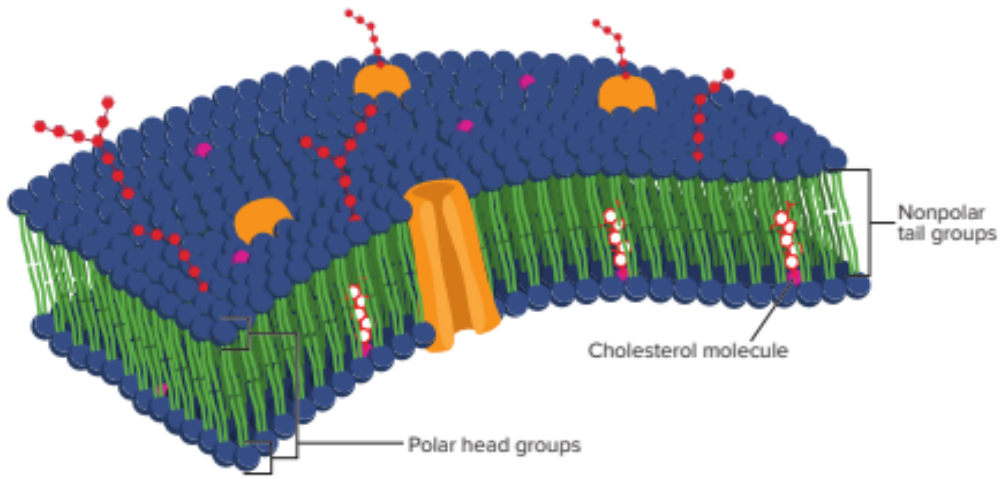


Figure 6 The fluid mosaic model refers to a plasma membrane with substances that can move around within the membrane.

Function of the Plasma Membrane

Recall that the process of maintaining balance in an organism's internal environment is called homeostasis. Homeostasis is essential to the survival of a cell. One of the structures that is primarily responsible for homeostasis is the plasma membrane.

The plasma membrane is a thin, flexible boundary between a cell and its environment that allows nutrients into the cell and allows waste and other products to leave the cell. All prokaryotic cells and eukaryotic cells have a plasma membrane to separate them from the watery environments in which they exist.

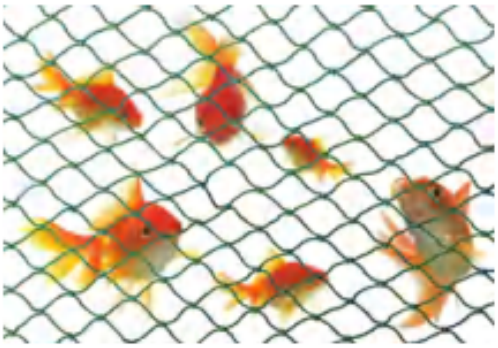
ACADEMIC VOCABULARY

component
a part or constituent of
The components of the plasma membrane are in constant motion.

CCC CROSSCUTTING CONCEPTS

Stability and Change People with the disease cystic fibrosis (CF) have a problem with the transport protein that helps water to exit through the membrane of lung cells. This water is necessary to keep the layer of mucus in the lungs thin. Using evidence from the text, predict how the mucus in the lungs of people with CF changes as a result. Relate your prediction to the function of the plasma membrane.

A key property of the plasma membrane is **selective permeability** (pur mee uh BIH luh tee), by which a membrane allows some substances to pass through while keeping others out. Consider a fish net as an analogy of selective permeability. The net shown in **Figure 7** has holes that allow water and other substances in the water to pass through but not the fish. The diagram in **Figure 7** illustrates selective permeability of the plasma membrane. The arrows show that substances enter and leave the cell through the plasma membrane. Control of how, when, and how much of these substances enter and leave a cell relies on the structure of the plasma membrane.



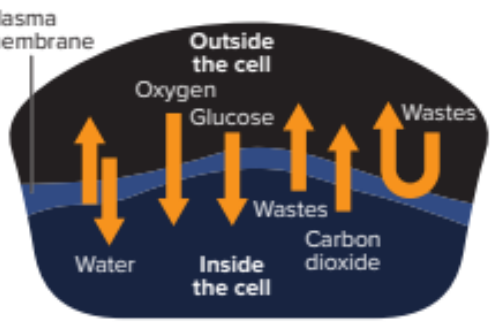


Figure 7 **Left:** The fish net selectively captures fish while allowing water and other debris to pass through. **Right:** Similarly, the plasma membrane is selective for substances entering and leaving the cell.

Check Your Progress

Summary

- The plasma membrane is made up of two layers of phospholipid molecules.
- Cholesterol and transport proteins aid in the function of the plasma membrane.
- The fluid mosaic model describes the plasma membrane.
- Selective permeability is a property of the plasma membrane that allows it to control what enters and leaves the cell.

Demonstrate Understanding

1. **Identify** the molecules in the plasma membrane that provide basic membrane structure, cell identity, and membrane fluidity.
2. **Explain** how the inside of a cell remains separate from its environment.
3. **Diagram** the plasma membrane and label each component.
4. **Describe** how the plasma membrane helps maintain homeostasis in a cell.

Explain Your Thinking

5. **Explain** what effect more cholesterol in the plasma membrane will have on the membrane.
6. **WRITING Connection** Using what you know about the term *mosaic*, write a paragraph describing another biological mosaic.

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LESSON 3

CELLULAR TRANSPORT

FOCUS QUESTION

What processes enable substances to move into or out of a cell?

Diffusion

CHEMISTRY Connection As the aroma of baking cookies makes its way to you, particles are moving and colliding with each other in the air. This happens because the particles in gases, liquids, and solids are in random motion. Similarly, substances dissolved in water move constantly in random motion called Brownian motion. This random motion causes **diffusion,** which is the net movement of particles from an area where there are many particles of a substance to an area where there are fewer particles of the substance. The amount of a substance in a particular area is called concentration. Therefore, substances diffuse from areas of high concentration to low concentration.

Figure 8 illustrates the process of diffusion. Additional energy input is not required for diffusion because the particles already are in motion. If you drop blue and yellow ink into a container of water at opposite ends of the container, which is similar to the watery environment of a cell, the process of diffusion begins, as shown in **Figure 8(A).** In a short period of time, the ink particles have mixed as a result of diffusion to the point where a green-colored blended area is visible. **Figure 8(B)** shows the initial result of this diffusion.

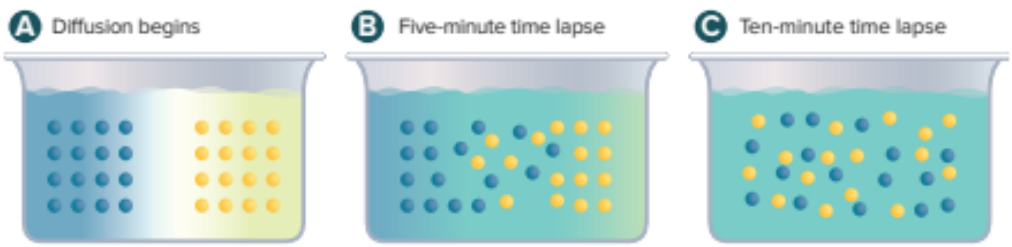

Figure 8 Diffusion causes the inks to move from high-ink concentration to low-ink concentration until the color become evenly blended in the water.

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: Investigate Osmosis

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

Given more time, the ink particles continue to mix and, in this case, continue to form the uniform mixture shown in **Figure 8(C)**, on the previous page. Mixing continues until the concentrations of yellow ink and blue ink are the same in all areas. After mixing is complete, the particles continue to move randomly, but no further change in concentration will occur. This condition, in which there is continuous movement but no overall change, is called **dynamic equilibrium.**

One of the key characteristics of diffusion is the rate at which diffusion takes place. Three main factors affect the rate of diffusion: concentration, temperature, and pressure. When concentration is high, diffusion occurs more quickly because there are more particles to collide and bounce off one another. Similarly, when temperature or pressure increases, the number of collisions increases, thus increasing the rate of diffusion. Recall that at higher temperatures particles move faster, and at higher pressure the particles are closer together. In both cases, more collisions occur, and diffusion is faster. The size and charge of a substance also affects the rate of diffusion.

Diffusion across the plasma membrane

In addition to water, cells need certain ions and small molecules, such as chloride ions and sugars, to perform cellular functions. Water can diffuse across the plasma membrane, as shown in **Figure 9(A),** but most other substances cannot. Another form of transport, called **facilitated diffusion,** uses transport proteins to move other ions and small molecules across the plasma membrane. By this method, substances move into the cell through a water-filled transport protein, called a channel protein, that opens and closes to allow the substance to diffuse through the plasma membrane, as shown in **Figure 9(B).**

Another type of transport protein, called a carrier protein, also can help substances diffuse across the plasma membrane. Carrier proteins change shape as the diffusion process continues to help move the particle through the membrane, as illustrated in **Figure 9(C).**

Diffusion of water and facilitated diffusion of other substances require no additional input of energy because the particles are moving from an area of high concentration to an area of lower concentration. This is also known as passive transport. You will learn later in this lesson about a form of cellular transport that does require energy input.

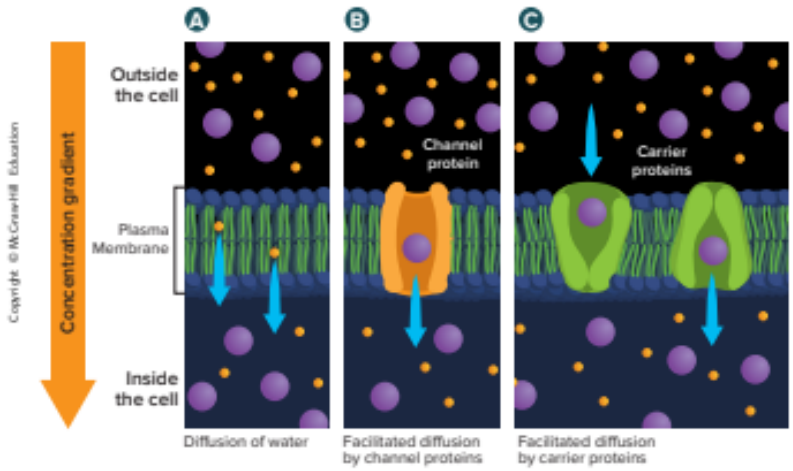

Figure 9 Although water moves freely through the plasma membrane (A), other substances cannot pass through the phospholipid bilayer on their own. Channel proteins (B) and carrier proteins (C) are kinds of transport proteins that help ions and small molecules move across the membrane in a process called facilitated diffusion.

Osmosis: Diffusion of Water

The diffusion of water across a selectively permeable membrane is called **osmosis** (ahs MOH sus). Water molecules pass freely into and out of a cell through aquaporins. Aquaporins are channel proteins embedded in the plasma membrane composed of tiny holes that selectively allow small uncharged molecules, such as water, to pass through. Regulating the movement of water across the plasma membrane is an important factor in maintaining homeostasis within the cell.

How osmosis works

Recall that in a solution, a substance called the solute is dissolved in a solvent. Water is the solvent in a cell and its environment. Concentration is a measure of the amount of solute dissolved in a solvent. The concentration of a solution decreases when the amount of solvent increases. In other words, a more concentrated solution has more solute than a less concentrated solution.

Examine **Figure 10**, which shows a U-shaped tube containing solutions with different sugar concentrations separated by a selectively permeable membrane. What will happen if the solvent (water) can pass through the membrane but the solute (sugar) cannot?

Water molecules diffuse toward the side with the greater sugar concentration—the right side. As water moves to the right, the concentration of the sugar solution decreases. The water continues to diffuse until dynamic equilibrium occurs—the concentration of the solutions is the same on both sides. Notice in **Figure 10** that the result is an increase in solution level on the right side. During dynamic equilibrium, water molecules continue to diffuse back and forth across the membrane. But, the concentrations on each side no longer change.

Get It?

Compare and contrast diffusion and osmosis.

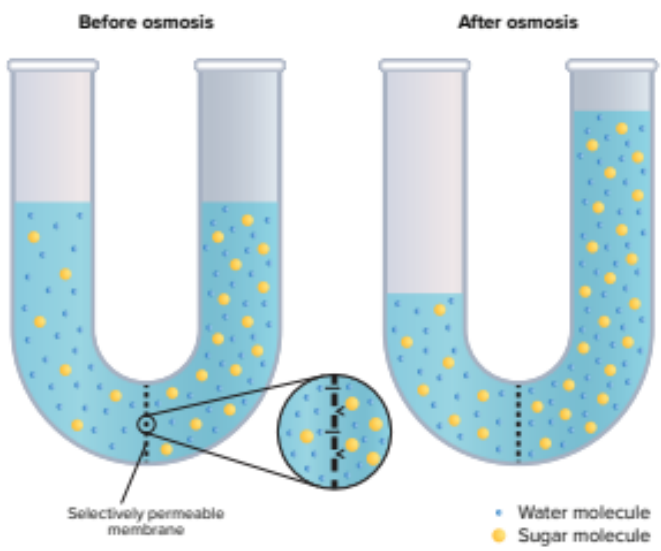

Figure 10 Before osmosis, the sugar concentration is greater on the right side. After osmosis, the concentrations are the same on both sides. Water molecules continue to move across the membrane.

Name *the term for the phenomenon shown in this figure.*

Cells in an isotonic solution

When a cell is in a solution that has the same concentration of water and solutes—ions, sugars, proteins, and other substances—as its cytoplasm, the cell is said to be in an **isotonic solution.** *Iso-* comes from the Greek word meaning equal. Water still moves through the plasma membrane, but water enters and leaves the cell at the same rate. The cell is at equilibrium with the solution, and there is no net movement of water. The cells retain their normal shape, as shown in **Figure 11(A)** on the next page. Most cells in organisms are in isotonic solutions, such as blood.

Cells in a hypotonic solution

If a cell is in a solution that has a lower concentration of solute, the cell is said to be in a **hypotonic solution.** *Hypo-* comes from the Greek word meaning under. There is more water outside of the cell than inside. As a result of osmosis, the net movement of water through the plasma membrane is into the cell, as illustrated in **Figure 11(B)**. Pressure generated as water flows through the plasma membrane is called osmotic pressure.

In an animal cell, as water moves into the cell, the pressure increases, and the plasma membrane swells. If the solution is extremely hypotonic, the plasma membrane might be unable to withstand this pressure, and the cell might burst.

Because they have a rigid cell wall that supports them, plant cells do not burst when they are placed in a hypotonic solution. As the pressure inside a cell increases, the plant's central vacuole fills with water, pushing the plasma membrane against the cell wall, shown in the plant cells in **Figure 11(B)**. Instead of bursting, the plant cell becomes firmer. Grocers use this process to keep produce looking fresh by misting fruits and vegetables with water.

Cells in a hypertonic solution

When a cell is placed in a **hypertonic solution,** the concentration of the solute outside of the cell is higher than it is inside. *Hyper-* comes from the Greek word meaning above. During osmosis, the net movement of water is out of the cell, as illustrated in **Figure 11(C)**. Animal cells in a hypertonic solution shrivel because of decreased pressure in the cells. Plant cells in a hypertonic solution lose water, mainly from the central vacuole. The plasma membrane shrinks away from the cell wall. Loss of water in a plant cell causes wilting.

Get It?

Compare and contrast the three types of solutions.

ACADEMIC VOCABULARY

concentration
the amount of a component in a given area or volume
The concentration of salt in the aquarium was too high.

CCC CROSSCUTTING CONCEPTS

Stability and Change Both freshwater and saltwater fish must maintain a relatively consistent amount of water in their bodies. Predict what each type of fish must do to maintain water homeostasis, and why. Use evidence from the text to justify your predictions.

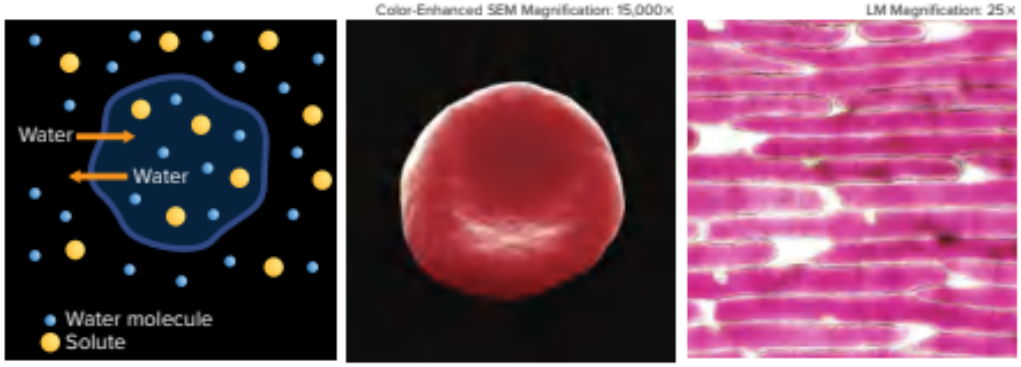

Figure 11(A) In an isotonic solution, water molecules move into and out of the cell at the same rate, and cells retain their normal shape. The animal cell and the plant cells have their normal shapes in an isotonic solution.

Figure 11(B) In a hypotonic solution, water enters a cell by osmosis, causing the cell to swell. Animal cells may continue to swell until they burst. Plant cells swell beyond their normal size as internal pressure increases.

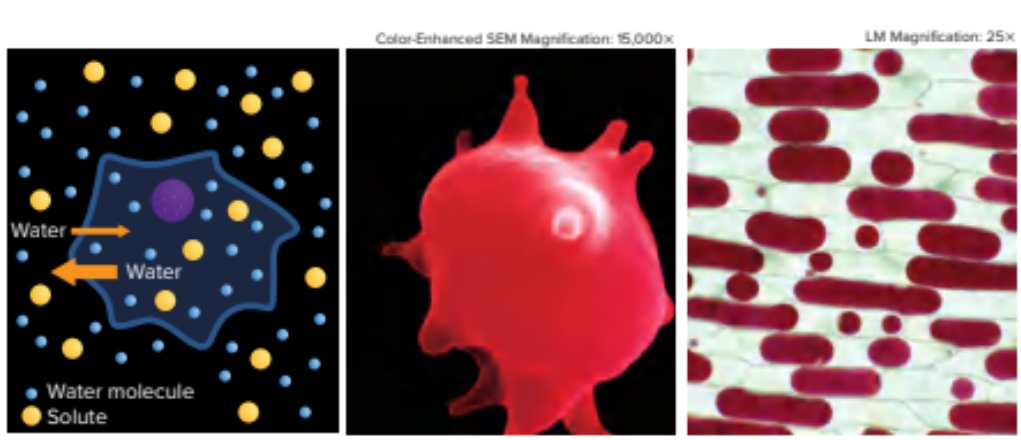

Figure 11(C) In a hypertonic solution, water leaves a cell by osmosis, causing the cell to shrink. Animal cells shrivel up as they lose water. As plant cells lose internal pressure, the plasma membrane shrinks away from the cell wall.

Active Transport

Sometimes substances must move from a region of lower concentration to a region of higher concentration. This movement of substances across the plasma membrane against a concentration gradient requires energy; therefore, it is called **active transport.** **Figure 12** illustrates how active transport occurs with the aid of carrier proteins, commonly called pumps. Some pumps move one type of substance in only one direction, while others move two substances either across the membrane in the same direction or in opposite directions. Because of active transport, the cell maintains the proper balance of substances it needs. Active transport helps maintain homeostasis.

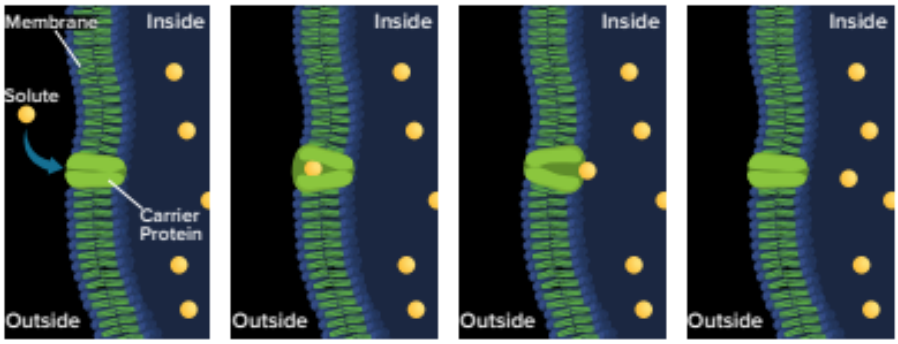

Figure 12 Carrier proteins pick up and move substances across the plasma membrane against the concentration gradient and into the cell.

Na^+/K^+ ATPase pump

The sodium-potassium ATPase pump, shown in **Figure 13,** is an active transport pump found in the plasma membrane of animal cells.

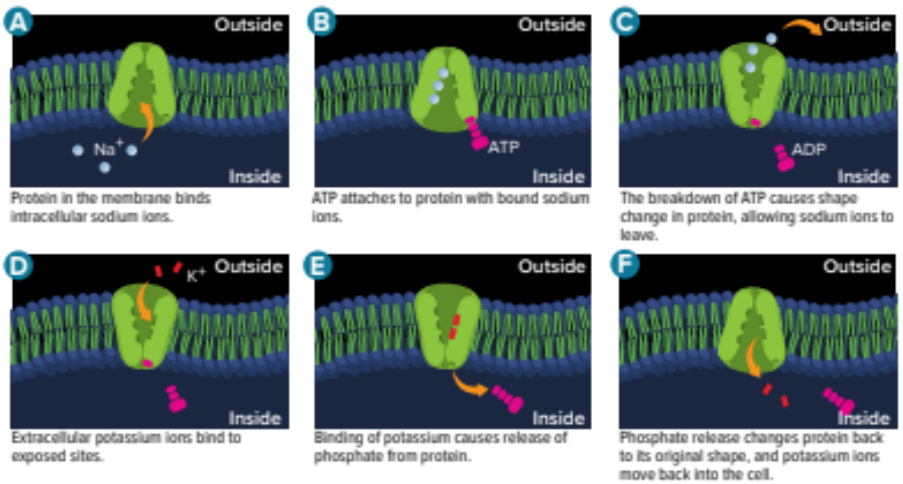

Figure 13 Some cells use the Na^+/K^+ ATPase pump to help move substances through the plasma membrane.

The pump maintains the level of sodium ions (Na^+) and potassium ions (K^+) inside and outside the cell. This protein pump is an enzyme that catalyzes the breakdown of an energy-storing molecule. The pump uses the energy to transport three sodium ions out of the cell while moving two potassium ions into the cell. The high level of sodium on the outside of the cell creates a concentration gradient. Follow the steps in **Figure 13**, on the previous page, to see the action of the Na^+/K^+ ATPase pump.

The activity of the Na^+/K^+ ATPase pump can result in yet another form of cellular transport. Substances, such as sugar molecules, must come into the cell from the outside, where the concentration of the substance is lower than it is inside. This requires energy. Recall, that the Na^+/K^+ ATPase pump moves Na^+ out of the cell, creating a low concentration of Na^+ inside the cell. In a process called coupled transport, the Na^+ ions that have been pumped out of the cell can couple with sugar molecules and be transported into the cell through a membrane protein called a coupled channel. The sugar molecule, coupled to a Na^+ ion, enters the cell by facilitated diffusion of the sodium, as shown in **Figure 14.** As a result, sugar enters the cell without spending any additional cellular energy. The type of transport shown in **Figure 14** occurs in some plant tissues. Sugar moves by coupled transport into plant tissues. These tissues carry the sugar to parts of the plant where it is stored until needed.

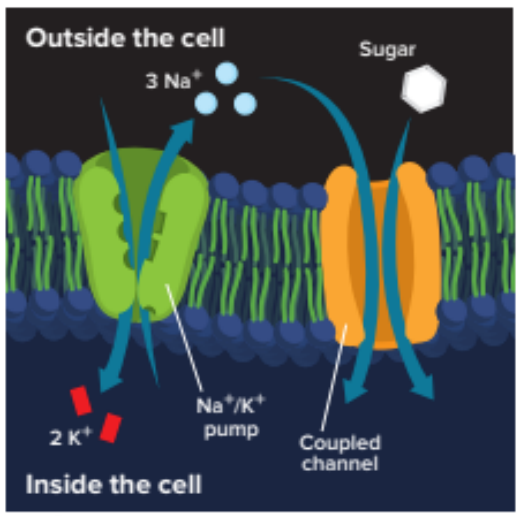

Figure 14 Substances "piggy-back" their way into or out of a cell by coupling with another substance that uses an active transport pump.

Describe *how coupled transport can help a plant to maintain energy homeostasis.*

Get It?

Compare and contrast active and passive transport across the plasma membrane.

Transport of Large Particles

Some substances are too large to move through the plasma membrane by diffusion or transport proteins and must get inside the cell by a different process. **Endocytosis** is the process by which a cell surrounds a substance in the outside environment, enclosing the substance in a portion of the plasma membrane. The membrane then pinches off and leaves the substance inside the cell. **Exocytosis** is the secretion of materials at the plasma membrane.

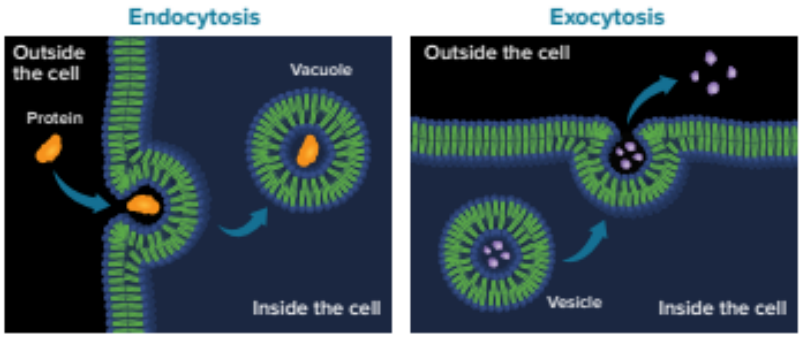

Figure 15 **Left:** Large substances can enter a cell by endocytosis. **Right:** Substances can be deposited outside the cell by exocytosis.

The substance shown on the left in **Figure 15** is engulfed and enclosed by a portion of the cell's plasma membrane. The membrane then pinches off inside of the cell, and the resulting vacuole, with its contents, moves to the inside of the cell. **Figure 15** shows that exocytosis is the reverse of endocytosis. Cells use exocytosis to expel wastes and to secrete substances, such as hormones, produced by the cell. Both endocytosis and exocytosis require the input of energy. Cells maintain homeostasis by moving substances into and out of the cell. Some transport processes require additional energy input, while others do not. Together, the different types of transport allow a cell to interact with its environment while maintaining homeostasis.

Check Your Progress

Summary

- Cells maintain homeostasis using passive and active transport.
- Concentration, temperature, and pressure affect the rate of diffusion.
- Cells must maintain homeostasis in all types of solutions, including isotonic, hypotonic, and hypertonic.
- Some large molecules are moved into and out of the cell using endocytosis and exocytosis.

Demonstrate Understanding

1. **List and describe** the types of cellular transport.
2. **Explain** the role of the cell membrane during passive transport and active transport.
3. **Sketch** a before and an after diagram of an animal cell placed in a hypotonic solution.
4. **Contrast** how facilitated diffusion is different from active transport.

Explain Your Thinking

5. **Describe** Some organisms that normally live in pond water contain water pumps. These pumps continually pump water out of the cell. Describe a scenario that might reverse the action of the pump.
6. **Summarize** the role of the phospholipid bilayer in cellular transport in living cells.

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

LESSON 4

STRUCTURES AND ORGANELLES

FOCUS QUESTION

What are the structures and their functions in prokaryotic and eukaryotic cells?

Cell Structures

In a factory, there are separate areas set up for performing different tasks. Eukaryotic cells, such as the cells shown in **Figure 16,** also have separate areas for different tasks. Membrane-bound organelles make it possible for different chemical processes to take place at the same time in different parts of the cytoplasm. Organelles carry out essential cell processes, such as protein synthesis, energy transformation, digestion of food, transport and storage of materials, excretion of wastes, and cell division. Each type of organelle within a cell has a unique structure and function. You can compare a cell's organelles to a factory's offices, assembly lines, loading docks, and other important areas that keep the factory functioning. As you read about the different cell structures and organelles, refer to the diagrams of cells in **Figure 17,** on the next page to see the structures and organelles of each type. **Figure 17** compares and contrasts the general structures of prokaryotic cells and eukaryotic (plant and animal) cells.

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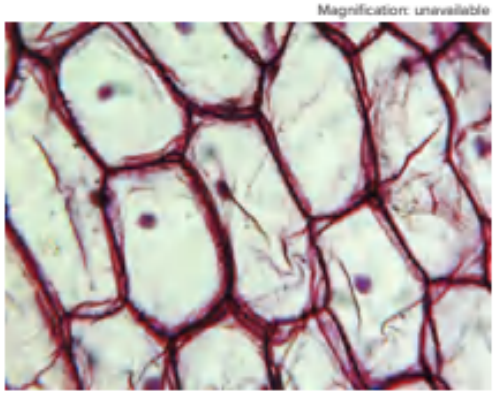


Figure 16 Eukaryotic cells have structures and organelles that perform specific tasks.

Cell shape and movement

The environment inside the plasma membrane is a semifluid material called **cytoplasm.** In a prokaryotic cell, all of the chemical processes of the cell, such as breaking down sugar to generate the energy used for other cell functions, take place directly in the cell's cytoplasm. Eukaryotic cells perform these processes within membrane-bound organelles in their cytoplasm.

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.

Virtual Investigation: Communities and Ecosystems

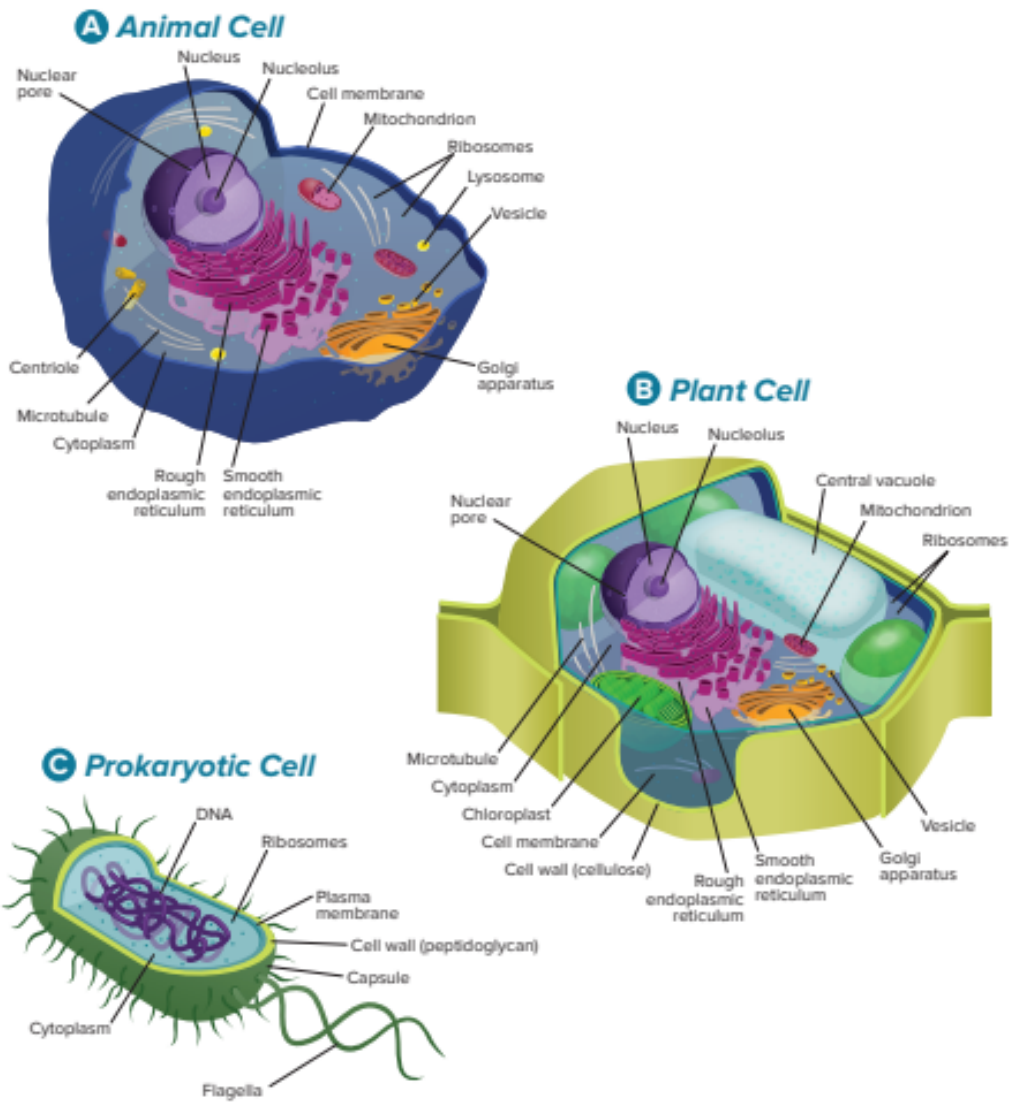
Use a model to illustrate the structures of a cell.

CCC Identify Cross Cutting Concepts

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

Figure 17 Visualizing Cells

Compare the illustrations of a plant cell, animal cell, and prokaryotic cell. Some organelles are found only in plant cells; others are found only in animal cells. Prokaryotic cells do not have membrane-bound organelles.



Components of the cytoskeleton

At one time, scientists thought that cell organelles floated in a sea of cytoplasm. More recently, cell biologists have discovered that organelles do not float freely in a cell. Instead, the organelles are supported by a structure within the cytoplasm similar to the structure shown in **Figure 18**. The **cytoskeleton** is a supporting network of long, thin protein fibers that form a framework for the cell and provide an anchor for the organelles inside the cell. The cytoskeleton also has a function in cell movement and other cellular activities.

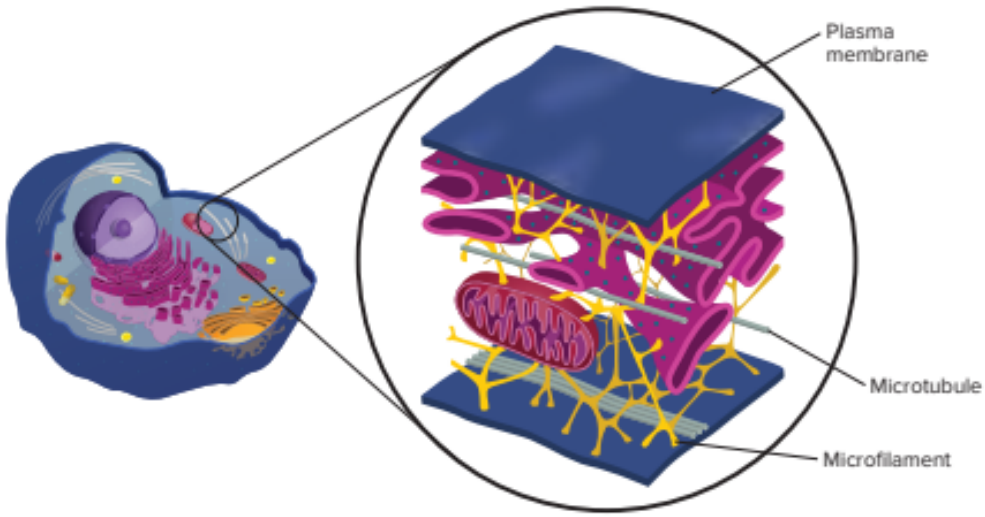


Figure 18 The cytoskeleton forms a framework for the cell.

Microtubules and microfilaments

The cytoskeleton is composed of substructures called microtubules and microfilaments. Microtubules are long, hollow protein cylinders that form a rigid skeleton for the cell and assist in moving substances within the cell. Microfilaments are thin protein threads that help give the cell shape and enable the entire cell or parts of the cell to move. Microtubules and microfilaments rapidly assemble and disassemble and slide past one another. This allows cells and organelles to move.

Get It?

Summarize the structure and function of the cytoskeleton.

WORD ORIGIN

cytoplasm
cytoskeleton
cyte– *prefix; from Greek, meaning cell*

STEM CAREER Connection

Science Journalist

If it sometimes feels like scientists speak their own language, that's because, in a way, they do! Scientists often communicate to each other using words specific to their field of study. A science journalist's job is to present scientific information in a way that's easy for the general public to grasp. This might be by writing newspaper articles, medical pamphlets, press releases, or even advertisements.

Centrioles

Groups of microtubules form another structure called a centriole (SEN tree ol). **Centrioles,** shown in **Figure 19,** are organelles made of microtubules that function during cell division. Centrioles are located in the cytoplasm of animal cells and most protists and usually are near the nucleus.

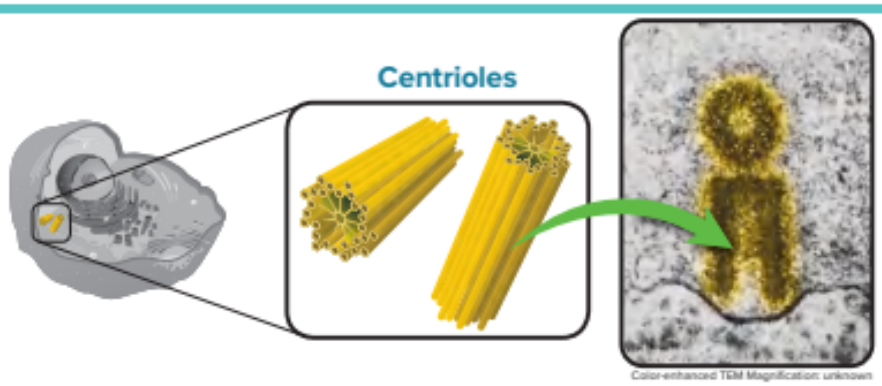


Figure 19 Centrioles are made of microtubules and play a role in cell division.

Cell appendages

Some eukaryotic cell surfaces have structures called cilia and flagella that project outside the plasma membrane. As shown in **Figure 20**, **cilia** (singular, cilium) are short, numerous projections that look like hairs. The motion of cilia is similar to the motion of oars in a rowboat. **Flagella** (singular, flagellum) are longer and less numerous than cilia. These projections move with a whiplike motion.

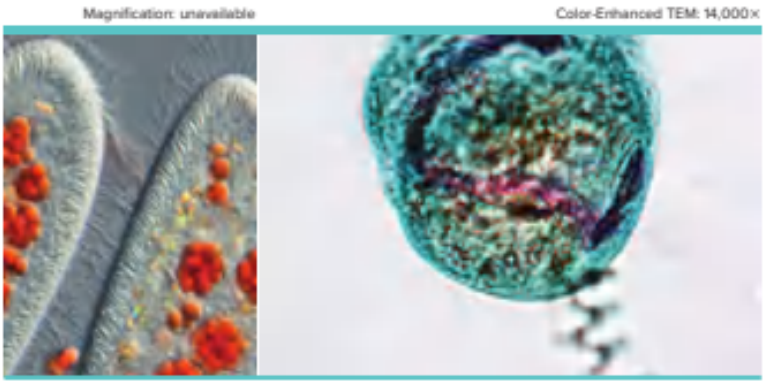


Figure 20 The hairlike structures in the photomicrograph are cilia, and the tail-like structures are flagella. Both structures function in cell movement. Cilia are also found on cells that do not move.

Infer *where in the body of an animal cilia might be found.*

Microtubule configuration Cilia and flagella are composed of microtubules arranged in a 9 + 2 configuration, in which nine pairs of microtubules surround two single microtubules. Cells with flagella typically have one or two flagella.

Prokaryotic cilia and flagella contain cytoplasm and are enclosed by the plasma membrane. These structures are made of complex proteins. While both structures are used for cell movement, cilia are also found on stationary cells.

Cell wall

Plant cell wall A structure associated with plant cells is the **cell wall,** shown in **Figure 21**. The cell wall is a thick, rigid, mesh of fibers that surrounds the outside of the plasma membrane, protects the cell, and gives it support. Rigid cell walls allow plants to stand at various heights—from blades of grass to California redwood trees. Plant cell walls are made of a carbohydrate called cellulose, which gives the cell walls their inflexible characteristic.

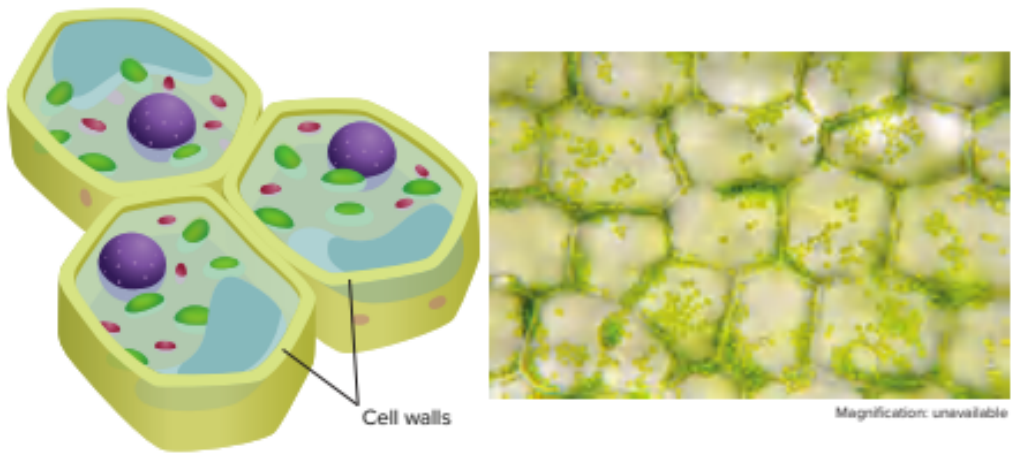


Figure 21 The illustration shows plant cells and their cell walls. Compare this to the photomicrograph showing cell walls of adjacent plant cells.

Prokaryote cell wall Prokaryotes, such as bacteria, also have a cell wall surrounding the cell. The functions of a prokaryotic cell wall are similar to the functions of the plant cell wall. A prokaryotic cell wall protects the cell, helps to maintain the cell's shape, and gives the cell support.

However, prokaryotic cell walls are not made of cellulose, like plant cells are. The prokaryotic cell wall is made of a material called peptidoglycan, which is a combination of disaccharides and peptide fragments. All prokaryotes have peptidoglycan in their cell walls.

Get It?

Compare and contrast the cells walls of prokaryotic and eukaryotic cells.

Controlling Cell Activities

Just as a factory needs a manager to direct and oversee the tasks carried out in the factory, a cell needs an organelle to direct the cell processes.

The nucleus

The nucleus, shown in **Figure 22,** is the cell's managing structure. It contains most of the cell's DNA, which stores information used to make proteins for cell growth, function, and reproduction. Within the nucleus is the site of ribosome production called the **nucleolus.**

The nucleus is surrounded by a double membrane called the nuclear envelope. The nuclear envelope is similar to the plasma membrane, except the nuclear membrane has nuclear pores that allow larger-sized substances to move in and out of the nucleus. Chromatin, which is a complex DNA attached to protein, is spread throughout the nucleus.

Get It?
Describe the role of the nucleus.

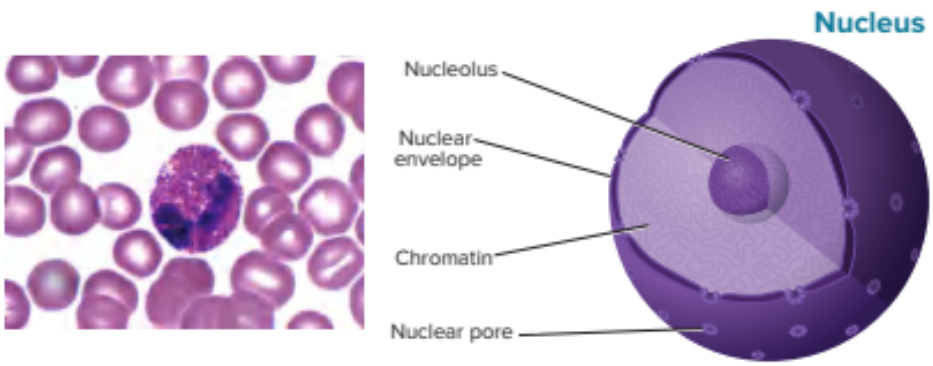


Figure 22 The nucleus of a cell is a three-dimensional shape.

ACADEMIC VOCABULARY
site
location
The nucleolus is the site of ribosome production.

Processing Energy

Mitochondria

Cells have energy generators called **mitochondria** (mi tuh KAHN dree uh; singular, mitochondrion), which convert fuel (mainly sugars) into usable energy. **Figure 23** shows that a mitochondrion has an outer membrane and a highly folded inner membrane that provides a large surface area for breaking the bonds in sugar molecules. The energy produced is stored in the bonds of other molecules and later used by the cell.

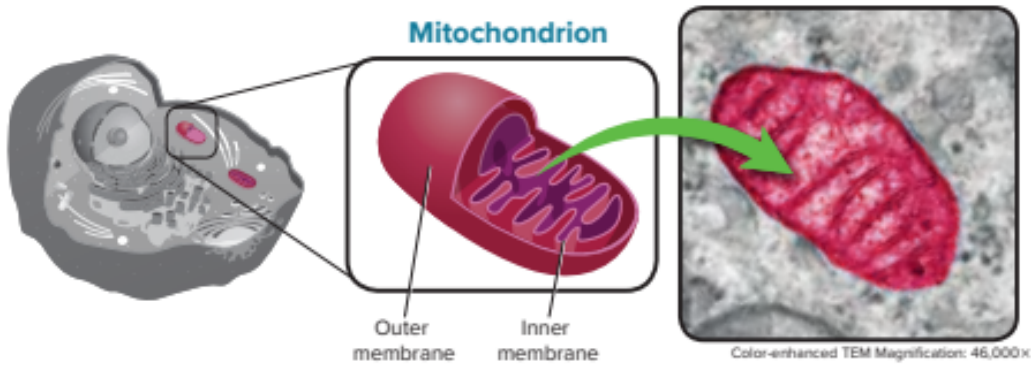


Figure 23 Mitochondria make energy available to the cell.

Chloroplasts

In addition to mitochondria, plants and some other eukaryotic cells contain **chloroplasts,** organelles that capture light energy and convert it to chemical energy through a process called photosynthesis. Examine **Figure 24**. Notice that inside the inner membrane are many small, disk-shaped compartments called thylakoids. This structure relates to their function—trapping energy from sunlight in a pigment called chlorophyll. Chlorophyll gives leaves and stems their green color.

Chloroplasts belong to a group of plant organelles called plastids, some of which are used for storage. Some plastids store starches or lipids. Others, such as chromoplasts, contain red, orange, or yellow pigments that trap light energy and give color to plant structures such as flowers and leaves.

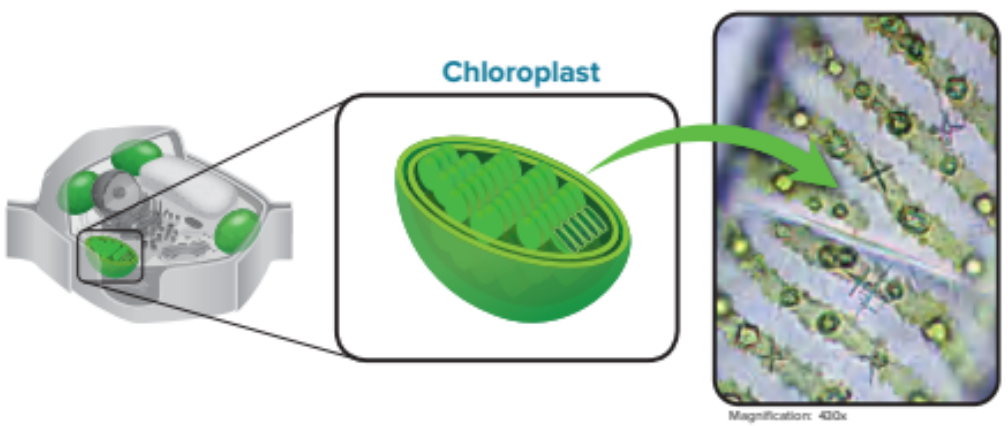


Figure 24 In plants, chloroplasts capture and convert light energy to chemical energy.

Manufacturing Proteins

Ribosomes

One of the functions of a cell is to produce proteins. The organelle that help manufacture proteins is called the **ribosome.** Ribosomes are made of two components—RNA and protein—and are not bound by a membrane like other organelles are. The nucleolus is the site of ribosome production.

Cells have many ribosomes that produce a variety of proteins that are used by the cell or are moved out and used by other cells. Some ribosomes float freely in the cytoplasm, while others are bound to another organelle called the endoplasmic reticulum. Free-floating ribosomes produce proteins for use within the cytoplasm of the cell. Bound ribosomes produce proteins that will be bound within membranes or used by other cells.

Endoplasmic reticulum

The **endoplasmic reticulum** (en duh PLAZ mihk • rih TIHK yuh lum), also called ER, is a membrane system of folded sacs and interconnected channels that serves as the site for protein and lipid synthesis. The structure of the ER, with many pleats and folds, provides a large amount of surface area where cellular functions can take place.

Rough endoplasmic reticulum The area of ER where ribosomes are attached is called rough endoplasmic reticulum. Notice in **Figure 25** that the rough ER appears to have bumps on it. These bumps are the attached ribosomes that will produce proteins for export to other cells.

Smooth endoplasmic reticulum Notice that **Figure 25** also shows that there are areas of the ER that do not have ribosomes attached. The area of ER where no ribosomes are attached is called smooth endoplasmic reticulum. Although the smooth ER has no ribosomes, it does perform important functions for the cell. For example, the smooth ER provides a membrane surface where a variety of complex carbohydrates and lipids, including phospholipids, are synthesized. Smooth ER in the liver detoxifies harmful substances.

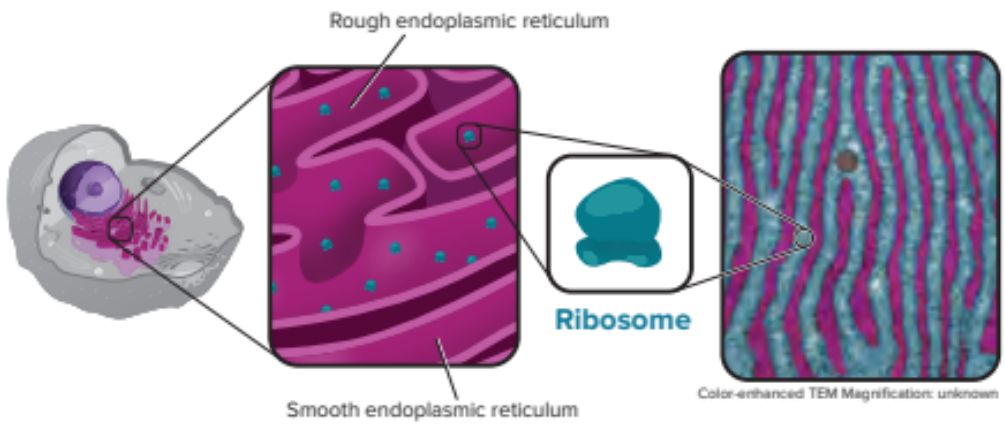


Figure 25 Ribosomes are simple structures made of RNA and protein that may be attached to the surface of the rough endoplasmic reticulum. They look like bumps on the endoplasmic reticulum.

Processing, Transporting, and Storing Molecules

Golgi apparatus

After hiking boots are made in a factory, they must be organized into pairs, boxed, and shipped. Similarly, after proteins are made in the endoplasmic reticulum, some might be transferred to the Golgi (GAWL jee) apparatus, illustrated in **Figure 26**. The **Golgi apparatus** is a flattened stack of membranes that modifies, sorts, and packages proteins into sacs called vesicles. Vesicles then can fuse with the cell's plasma membrane to release proteins to the environment outside the cell.

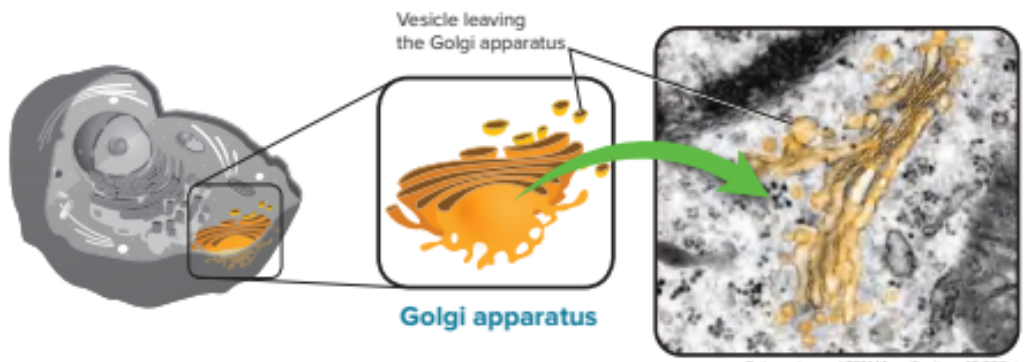


Figure 26 Flattened stacks of membranes make up the Golgi apparatus.

Vesicles

Vacuoles A factory needs a place to store materials and waste products. Similarly, cells have membrane-bound vesicles called vacuoles for temporary storage of materials within the cytoplasm. A **vacuole,** such as the plant vacuole shown in **Figure 27**, is a sac used to store food, enzymes, and other materials needed by a cell. Some vacuoles store waste products. In contrast to plant cells, animal cells usually do not contain vacuoles. If animal cells do have vacuoles, they are much smaller than those in plant cells.

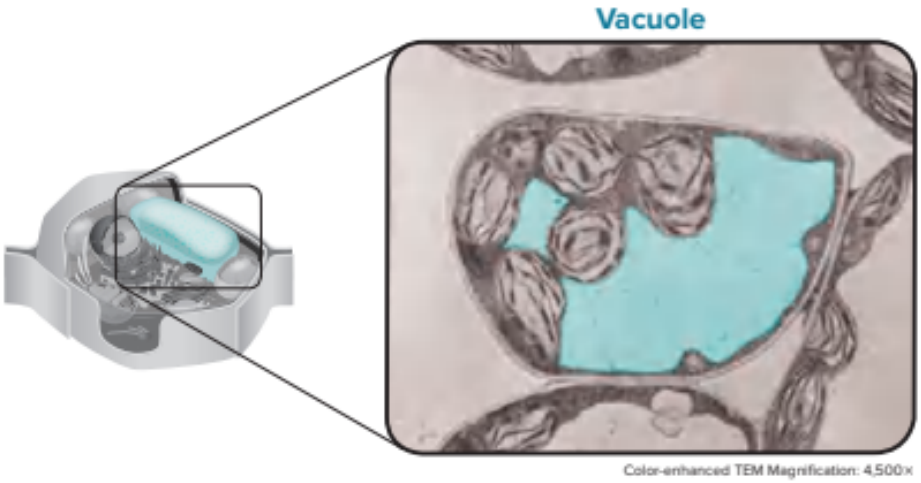


Figure 27 Plant cells have large membrane-bound storage compartments called vacuoles.

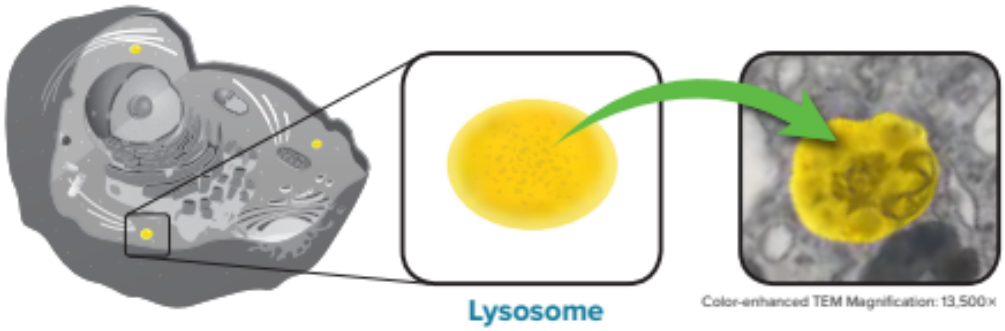


Figure 28 Lysosomes contain digestive enzymes that can break down the wastes contained in vacuoles.

Lysosomes Factories and cells also need cleanup crews. In a cell, there are **lysosomes,** shown in **Figure 28**, which are vesicles that contain substances that digest excess or worn-out organelles and food particles. Lysosomes also digest bacteria and viruses that have entered the cell. The membrane surrounding a lysosome prevents the digestive enzymes inside from destroying the cell. Lysosomes can fuse with vacuoles and dispense their enzymes into the vacuoles. These enzymes digest the wastes inside.

Get It?

Explain the role of lysosomes in cells.

Comparing cells

Table 1, on the next page, summarizes, compares, and contrasts the general structures of plant cells and animal cells. Notice that plant cells contain chlorophyll; they can capture and transform energy from the Sun into a usable form of chemical energy. This is one of the main distinctions between plant cells and animal cells. In addition, recall that animal cells usually do not contain vacuoles. If they do, vacuoles in animal cells are much smaller than vacuoles in plant cells. Also, animal cells do not have cell walls. Cell walls give plant cells protection and support.

There are many structures found in both plant and animal cells. For example, the nucleus controls the activities of both plant and animal cells. The plasma membrane plays a vital role in maintaining homeostasis in both plant and animal cells, and the ribosomes are the site of protein synthesis for both types of cells.

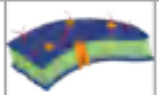
ACADEMIC VOCABULARY

distinction
a difference
A distinction between plant cells and animal cells is that plant cells contain chloroplasts.

CCC CROSSCUTTING CONCEPTS

Systems and System Models Working with a partner or small group, make a list of materials that you might use to build a model cell. The model should include at least three of the organelles listed in **Table 1**. Each material should reflect the function of the organelle. (For example, you might choose to represent the mitochondria of the cell with batteries.)

Table 1 Summary of Cell Structures

Cell Structure	Example	Function	Cell Type
Cell wall		An inflexible barrier that provides support and protects the plant cell	Plant cells, fungi cells, and some prokaryotes
Centrioles		Organelles that occur in pairs and are important for cell division	Animal cells and most protist cells
Chloroplasts		A double-membrane organelle with thylakoids containing chlorophyll; where photosynthesis takes place	Plant cells and some protist cells
Cilia		Projections from cell surfaces that aid in locomotion and feeding; also used to sweep substances along surfaces	Some animal cells, protist cells, and prokaryotes
Cytoskeleton		A framework for the cell within the cytoplasm	All eukaryotic cells
Endoplasmic reticulum		A highly folded membrane that is the site of protein synthesis	All eukaryotic cells
Flagella		Projections that aid in locomotion and feeding	Some animal cells, prokaryotes, and some plant cells
Golgi apparatus		A flattened stack of tubular membranes that modifies proteins and packages them for distribution outside the cell	All eukaryotic cells
Lysosome		A vesicle that contains digestive enzymes for the breakdown of excess or worn-out cellular substances	Animal cells and rare in plant cells
Mitochondria		A membrane-bound organelle that makes energy available to the rest of the cell	All eukaryotic cells
Nucleus		The control center of the cell that contains coded directions for the production of proteins and cell division	All eukaryotic cells
Plasma membrane		A flexible boundary that controls the movement of substances into and out of the cell	All cells
Ribosome		Organelle that is the site of protein synthesis	All cells
Vacuole		A membrane-bound vesicle for the temporary storage of materials	Plant cells–one large; rarely animal cells–a few small

Organelles at work

With a basic understanding of the structures found within a cell, it becomes easier to envision how those structures work together to perform cell functions. Take, for example, the synthesis of proteins. Protein synthesis begins in the nucleus with the information contained in the DNA. Genetic information is copied and transferred to another genetic molecule called RNA. Then RNA and ribosomes, which have been manufactured in the nucleolus, leave the nucleus through the pores of the nuclear membrane. Together, RNA and ribosomes manufacture proteins. Each protein made on the rough ER has a particular function; it might become a protein that forms a part of the plasma membrane, a protein that is released from the cell, or a protein transported to other organelles. Other ribosomes will float freely in the cytoplasm and also make proteins.

Most of the proteins made on the surface of the ER are sent to the Golgi apparatus. The Golgi apparatus packages the proteins in vesicles. It then transports the proteins to other organelles or out of the cell. Other organelles use these proteins as they carry out cell processes. For example, lysosomes use proteins, enzymes in particular, to digest food and waste. Mitochondria use enzymes as they produce a usable form of energy for the cell.

After reading about the structures and organelles in a cell and how they work together, it becomes clear why people often equate the cell to a factory. Like the parts of a factory, each organelle has a specific job to do. Different structures are involved in completing different tasks. The health of the cell depends on all of the components working together.

Get It?

Infer Justify the statement, "Cells are the most important units in all living organisms."

Check Your Progress

Summary

- Eukaryotic cells contain membrane-bound organelles in the cytoplasm that perform cell functions.
- Ribosomes are the sites of protein synthesis.
- Mitochondria are the powerhouses of cells.
- Plant and animal cells contain many of the same organelles, while other organelles are unique to either plant cells or animal cells.

Demonstrate Understanding

1. **Identify** the role of the nucleus in a eukaryotic cell.
2. **Summarize** the role of the endoplasmic reticulum.
3. **Create** a flowchart comparing the parts of a cell to an automobile production line.
4. **Compare and contrast** the structures found in plant and animal cells. Relate these structures to the function of each cell.

Explain Your Thinking

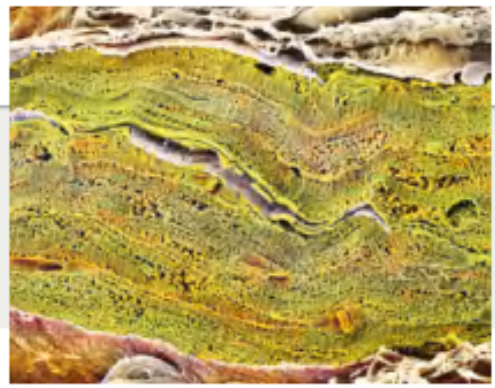
5. **Hypothesize** how lysosomes would be involved in changing a caterpillar into a butterfly.
6. WRITING Connection Categorize the structures and organelles in Table 1 into lists based on cell type, and then draw a concept map illustrating your organization.

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

NATURE OF SCIENCE

Mitochondria: More Than Just a Powerhouse

Ask a biology student to state the function of cell mitochondria, and they will probably say that mitochondria provide the cell with energy. What this answer doesn't do, though, is to account for the numerous other functions that mitochondria have in a cell.



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Defects in the mitochondrial DNA found in heart cells have been linked to some forms of heart disease.

Mitochondria's many functions

Scientists have known of the existence of mitochondria for well over 100 years. Still, it took more than 60 years of rigorous study and debate before the scientific community was confident in the connection between mitochondria and cell energy. In 1957, a cell biologist dubbed mitochondria the "powerhouses of the cell," and the textbook definition of mitochondrial function was born.

This was not the end of research on the mitochondria. In the 1960s, scientists discovered that mitochondria, like nuclei, housed DNA molecules. By the late 1980s, advances in technology helped scientists determine that changes in mitochondrial DNA might be linked to some diseases. As knowledge of the mitochondria increased, so did scientists' questions. Is providing energy the mitochondrion's most important role? What other functions might mitochondria have? Could discovering these functions help scientists cure or treat diseases?

Today, scientists think that mitochondria play a role in autism, aging, and other conditions. Scientists have also discovered that mitochondria are essential for the formation of new red blood cells and even play a vital part in gene expression. By not accepting that an important function of mitochondria was their **only** function, scientists have made discoveries that promise to improve the quality of life. We may soon have a definition for mitochondria that extends well beyond "the powerhouse of the cell."

COMMUNICATE SCIENTIFIC INFORMATION

Using digital or print resources, gather information about one way mitochondria might play a role in a disease or condition. Design a pamphlet or infographic showing how mitochondria are connected to your topic.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 CELL DISCOVERY AND THEORY

- Microscopes have been used as tools for scientific study since the late 1500s.
- Scientists use different types of microscopes to study cells.
- The cell theory summarizes three principles.
- There are two broad groups of cell types: prokaryotic cells and eukaryotic cells.
- Eukaryotic cells each contain a nucleus and organelles.

- cell
- cell theory
- plasma membrane
- organelle
- eukaryotic cell
- nucleus
- prokaryotic cell

Lesson 2 THE PLASMA MEMBRANE

- The plasma membrane is made up of two layers of phospholipid molecules.
- Cholesterol and transport proteins aid in the function of the plasma membrane.
- The fluid mosaic model describes the plasma membrane.
- Selective permeability is the property of the plasma membrane that allows it to control what enters and leaves the cell.

- phospholipid bilayer
- transport protein
- fluid mosaic model
- selective permeability

Lesson 3 CELLULAR TRANSPORT

- Cells maintain homeostasis using passive and active transport.
- Concentration, temperature, and pressure affect the rate of diffusion.
- Cells must maintain homeostasis in all types of solutions, including isotonic, hypotonic, and hypertonic.
- Some large molecules are moved into and out of the cell using endocytosis and exocytosis.

- diffusion
- dynamic equilibrium
- facilitated diffusion
- osmosis
- isotonic solution
- hypotonic solution
- hypertonic solution
- active transport
- endocytosis
- exocytosis

Lesson 4 STRUCTURES AND ORGANELLES

- Eukaryotic cells contain membrane-bound organelles in the cytoplasm that perform cell functions.
- Ribosomes are the sites of protein synthesis.
- Mitochondria are the powerhouses of cells.
- Plant and animal cells contain many of the same organelles, while other organelles are unique to either plant cells or animal cells.

- cytoplasm
- cytoskeleton
- centriole
- cilium
- flagellum
- cell wall
- nucleolus
- mitochondrion
- chloroplast
- ribosome
- endoplasmic reticulum
- Golgi apparatus
- vacuole
- lysosome

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

What could you see if you used this microscope?

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

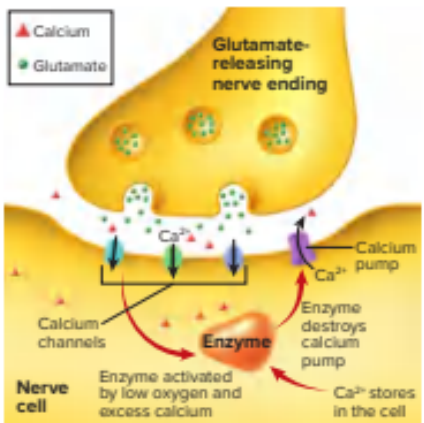
SEP Data Analysis Lab

How are protein channels involved in the death of nerve cells after a stroke?

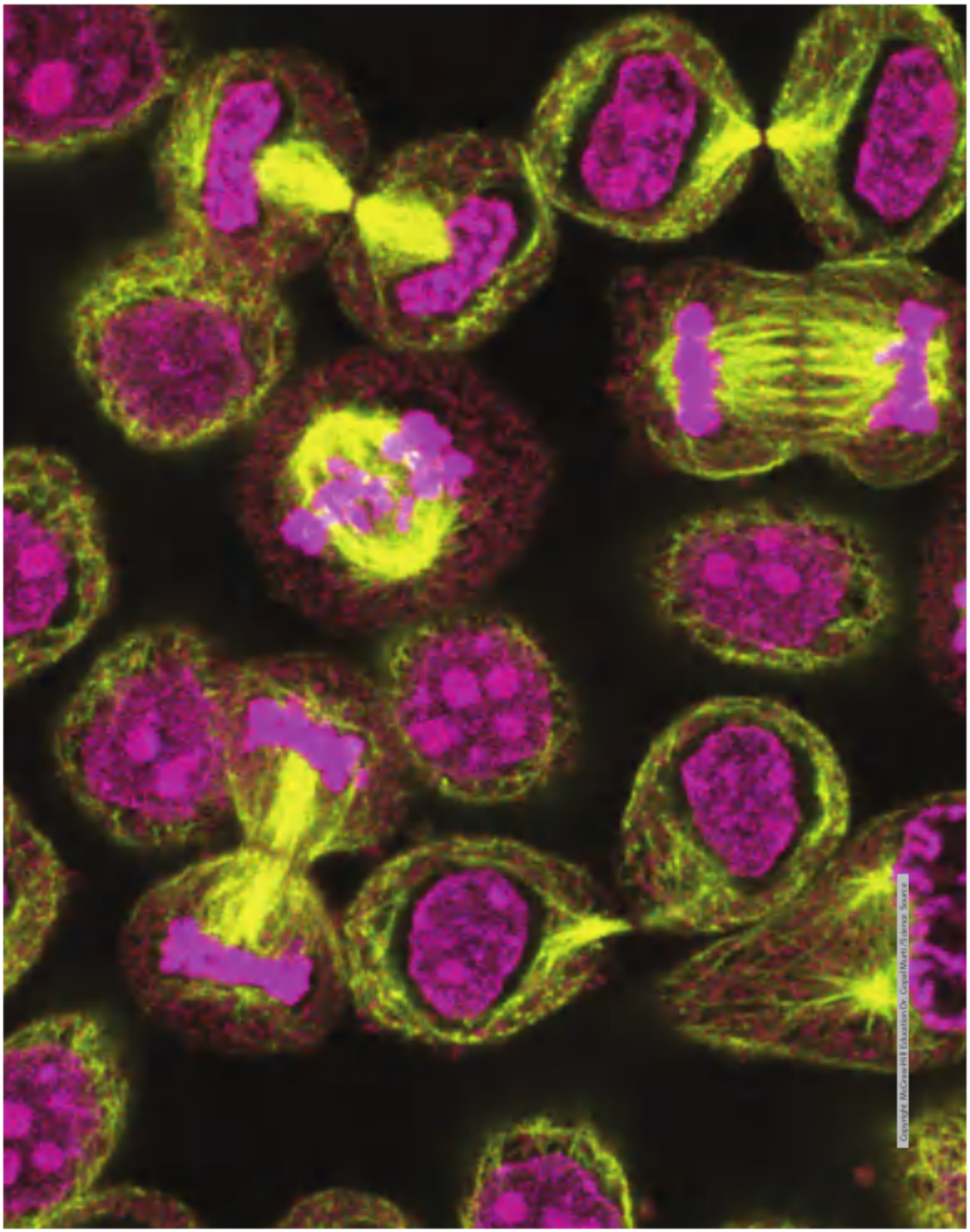
A stroke occurs when a blood clot blocks the flow of oxygen-containing blood in a portion of the brain. Nerve cells in the brain that release glutamate are sensitive to the lack of oxygen and release a flood of glutamate when oxygen is low. During the glutamate flood, the calcium pump is destroyed. This affects the movement of calcium ions into and out of nerve cells. When cells contain excess calcium, homeostasis is disrupted.

CER Analyze and Interpret Data

1. **Interpret** how the glutamate flood destroys the calcium pump.
2. **Claim, Evidence, Reasoning** What would happen if Ca^{2+} levels were lowered in the nerve cell during a stroke?



*Data obtained from: Choi, D.W. 2005. Neurodegeneration: cellular defences destroyed. *Nature* 433: 696–698.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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.

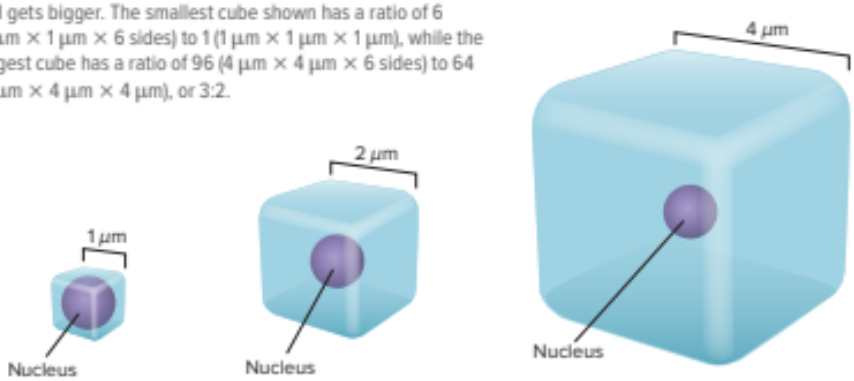
BioLab: How long does each phase of the cell cycle last?

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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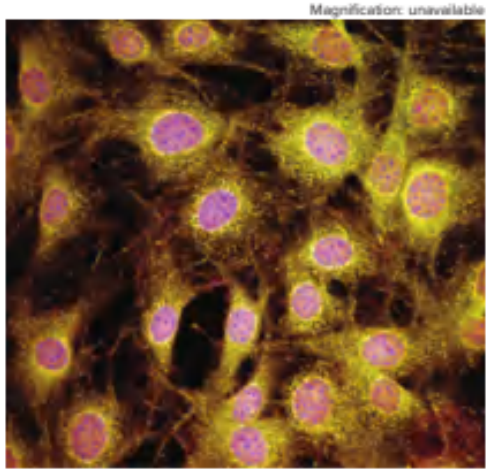


Figure 2 In order for the cytoskeleton to be an efficient transportation railway, the distances that substances have to travel within a cell must be limited.

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**.

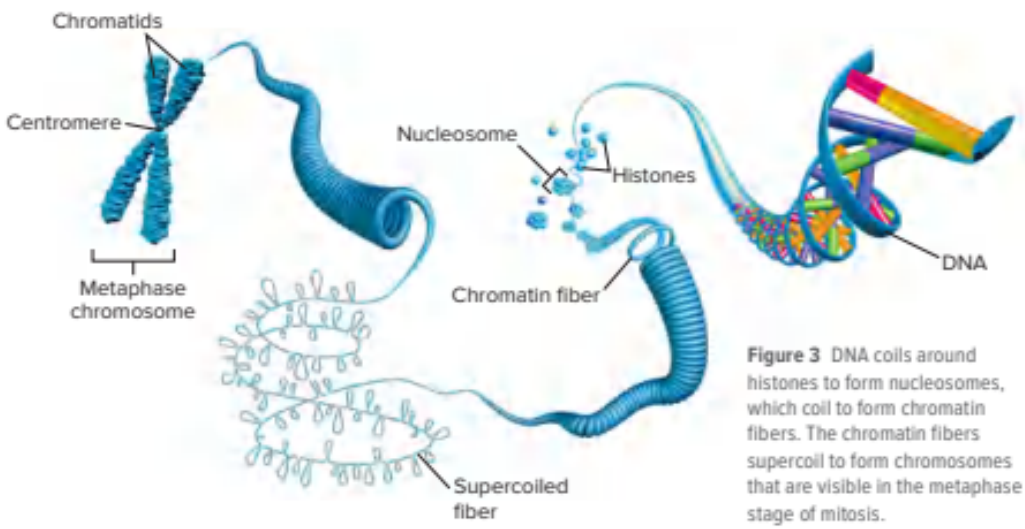


Figure 3 DNA coils around histones to form nucleosomes, which coil to form chromatin fibers. The chromatin fibers supercoil to form chromosomes that are visible in the metaphase stage of mitosis.

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.

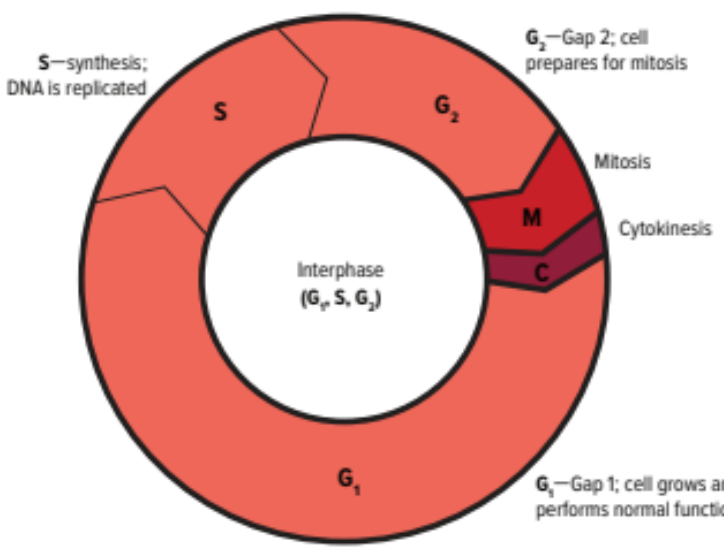


Figure 4 The cell cycle involves three stages—interphase, mitosis, and cytokinesis. Interphase is divided into three substages.

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.

SEM Magnification: unavailable

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

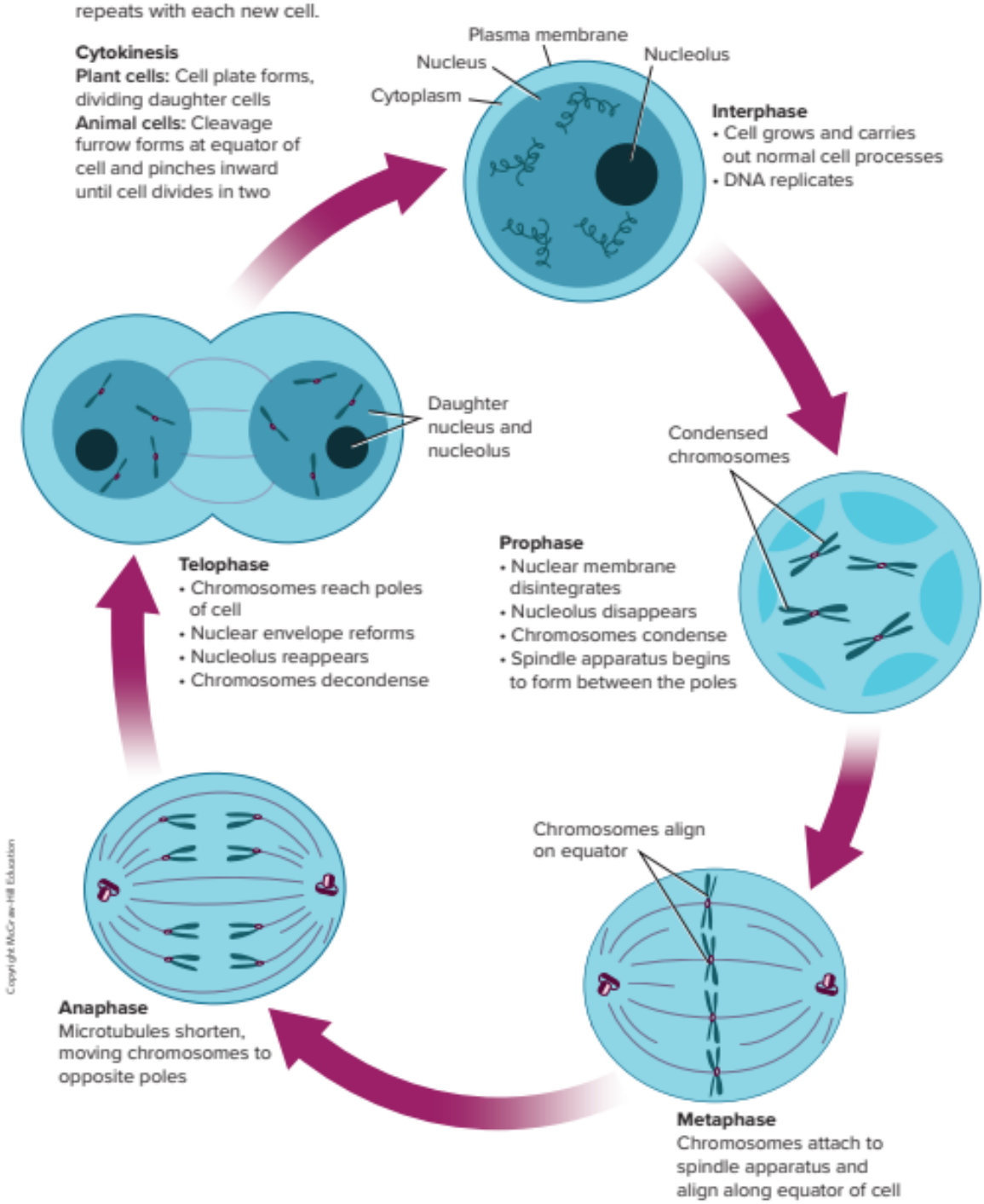
In prophase, the chromosomes are shaped like an X, as shown in **Figure 5**. Each half of this X is called a sister chromatid. **Sister chromatids** are structures that contain identical copies of DNA.

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.

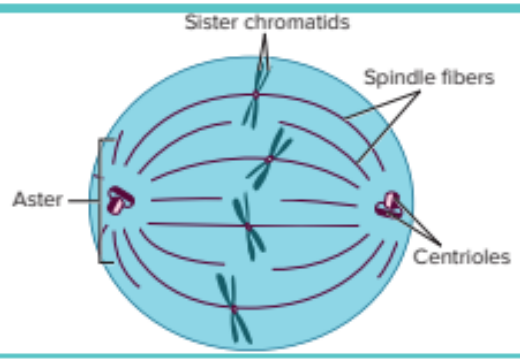


Figure 7 In animal cells, the spindle apparatus is made of spindle fibers, centrioles, and aster fibers.

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.

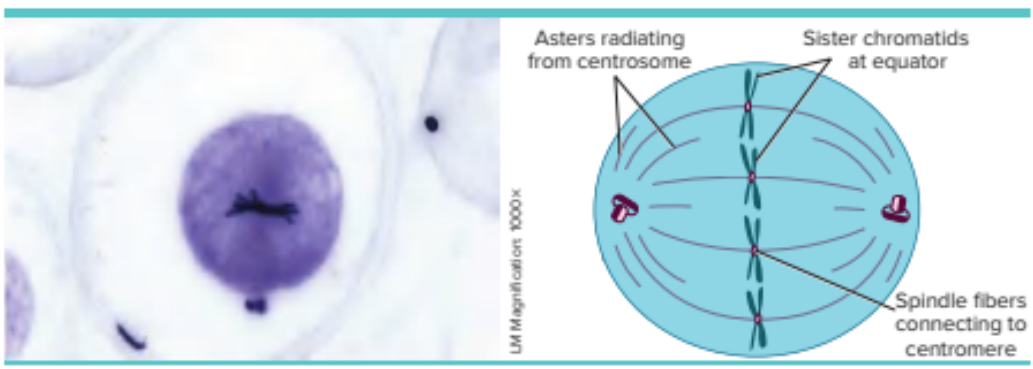


Figure 8 In metaphase, the chromosomes align along the equator of the cell.

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.

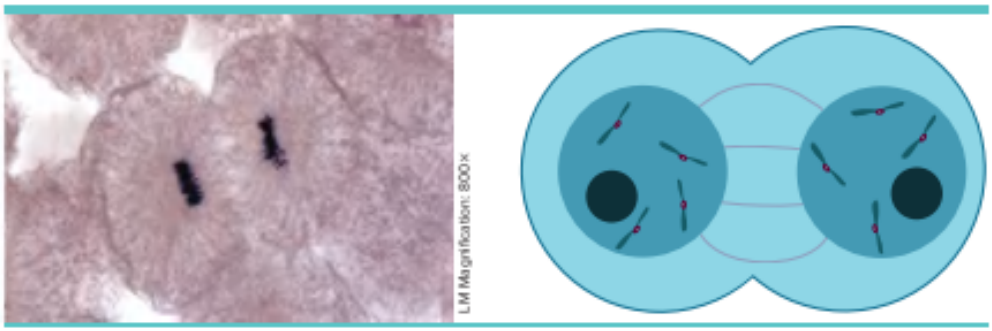


Figure 9 By the end of telophase, the cell has completed the work of duplicating the genetic material and dividing it into two "packages," but the cell has not completely divided.

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.

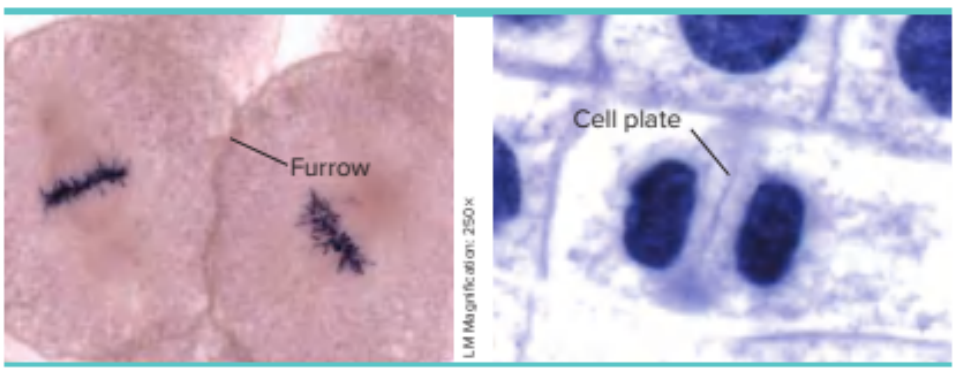


Figure 10 **Left:** In animal cells, cytokinesis begins with a furrow that pinches the cell and eventually splits the two cells apart. **Right:** Plant cells build a cell plate that divides the cell into the two daughter cells.

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.

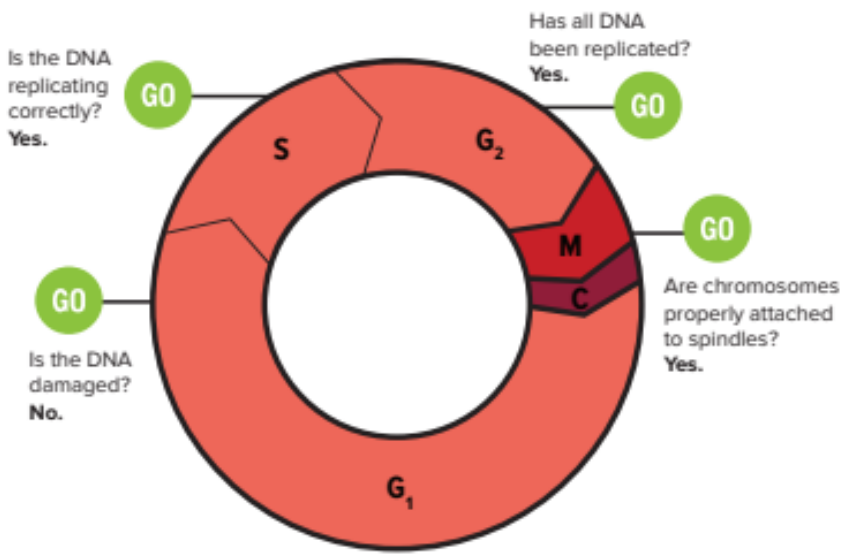


Figure 11 Signaling molecules made of a cyclin bound to a CDK kick off the cell cycle and drive it through mitosis. Checkpoints monitor the cell cycle for errors and can stop the cycle if an error occurs.

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.

Magnification: unavailable

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.

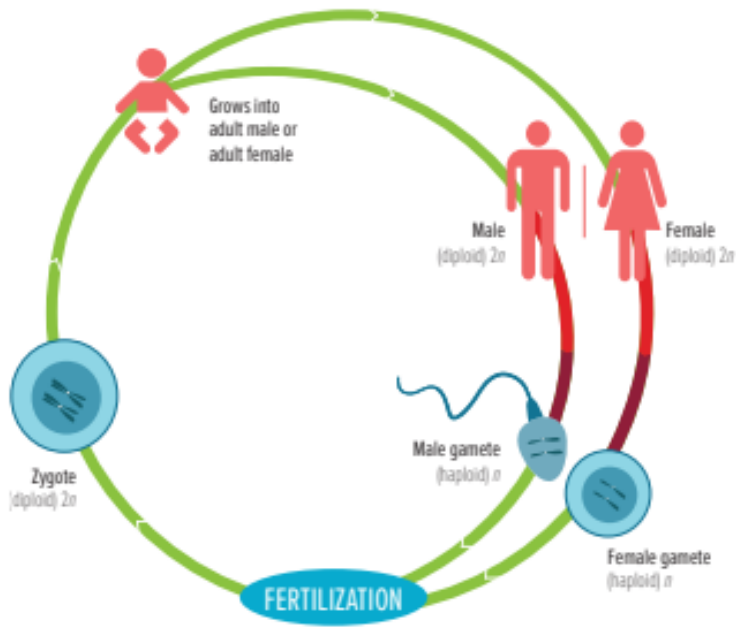


Figure 15 The sexual life cycle in animals involves meiosis, which produces gametes. When gametes combine in fertilization, the number of chromosomes is restored.

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**.

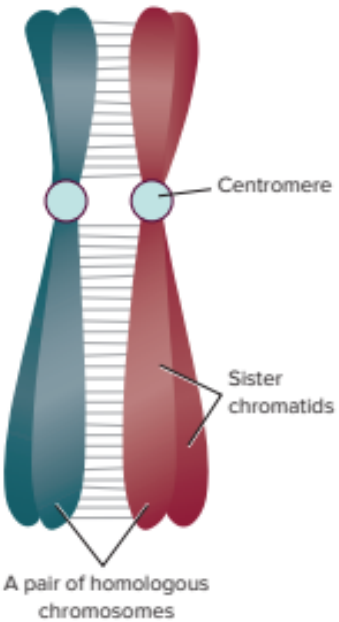


Figure 16 The homologous chromosomes are physically bound together during synapsis in prophase I.

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.

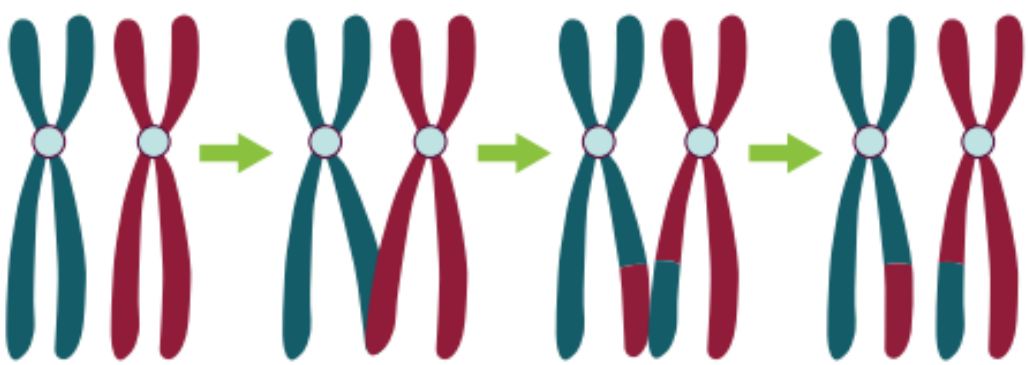


Figure 17 The results of crossing over are new combinations of genes.

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

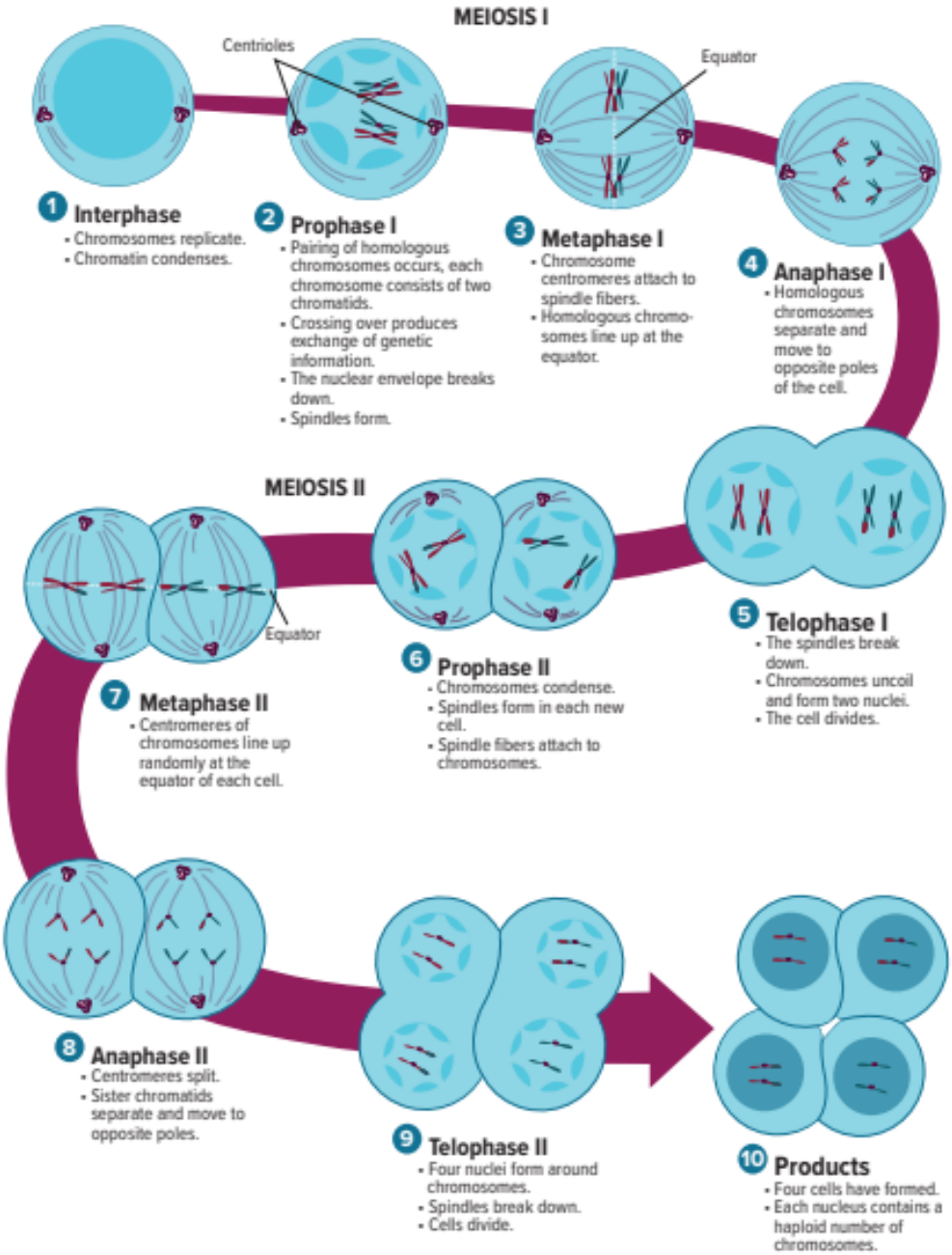
Meiosis is only halfway completed at the end of meiosis I. During prophase II, a second set of phases begins as the spindle apparatus forms and the chromosomes condense. During metaphase II, the chromosomes are positioned at the equator by the spindle fibers. During mitosis metaphase, a diploid number 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.

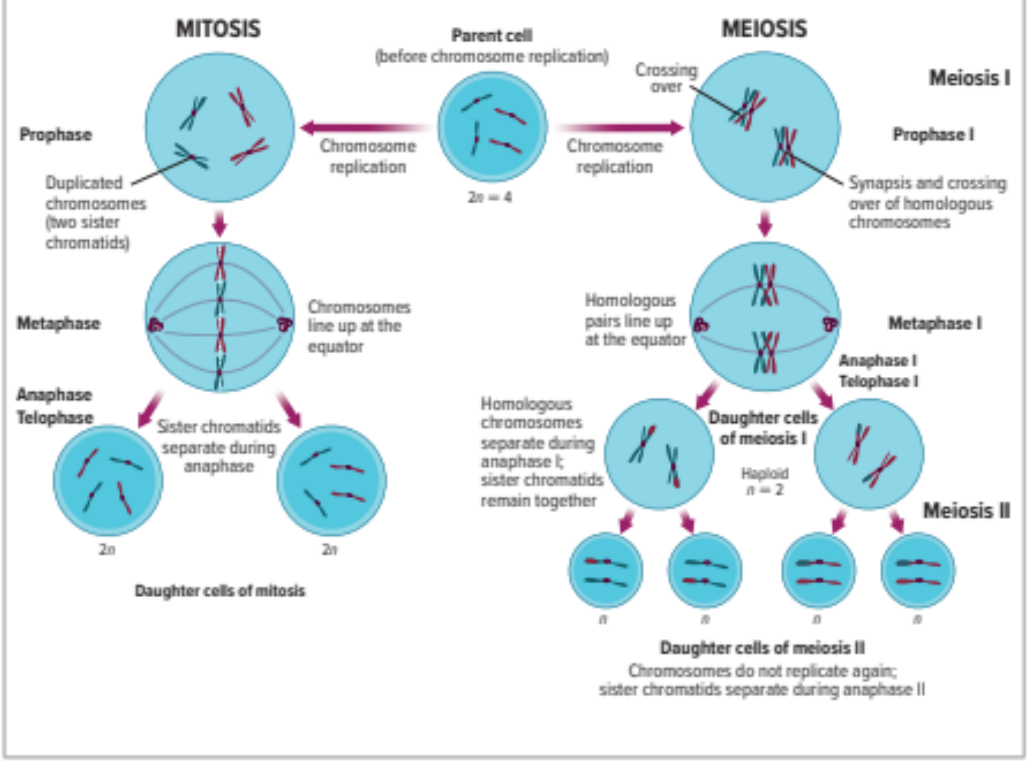


The Importance of Meiosis

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.

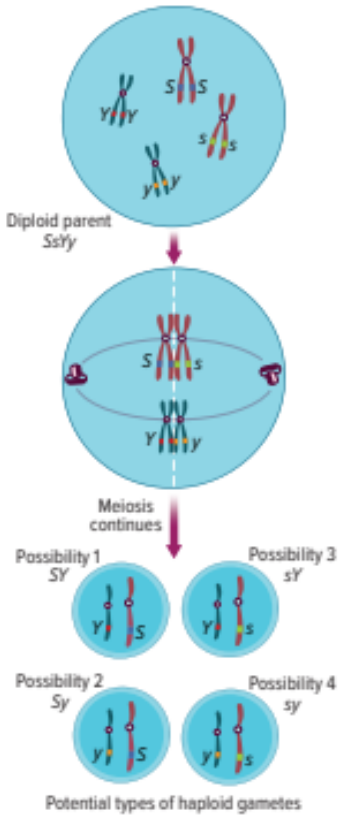


Figure 19 The order in which the homologous pairs line up explains how a variety of sex cells can be produced.

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.

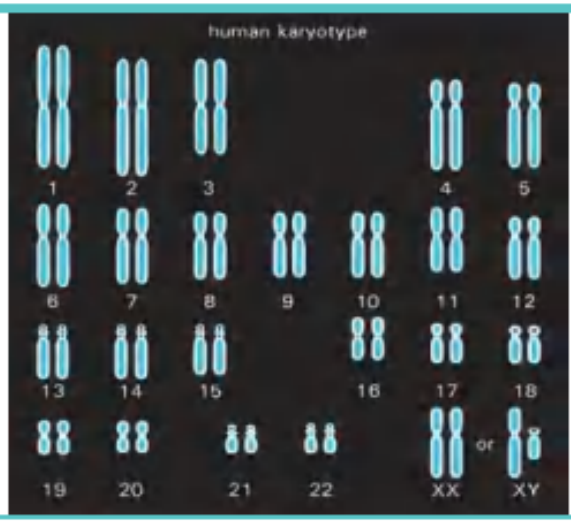


Figure 20 Karyotypes arrange the pairs of homologous chromosomes in order of decreasing size.
Distinguish *which two chromosomes are arranged separately from the other pairs.*

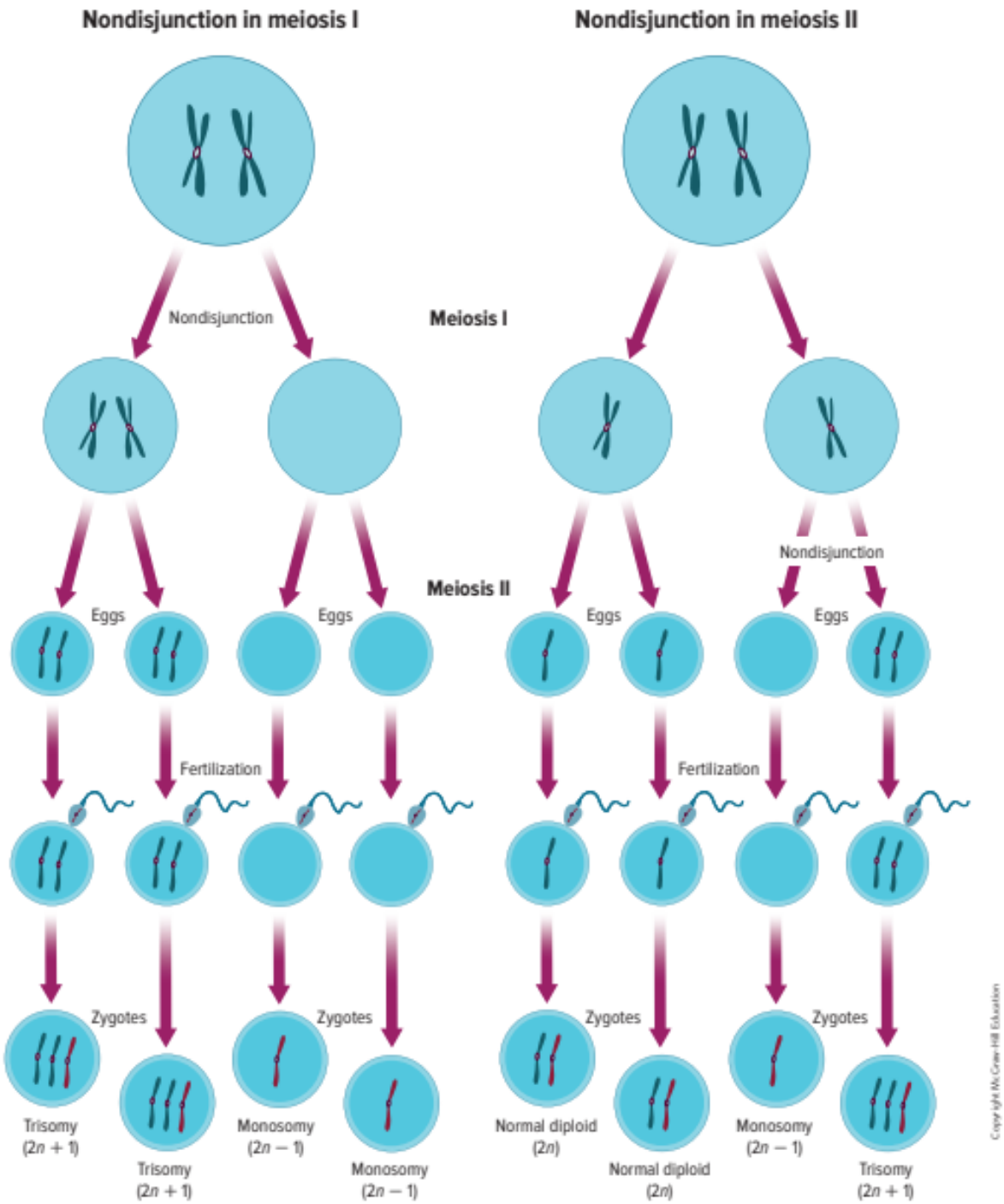
Nondisjunction

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.

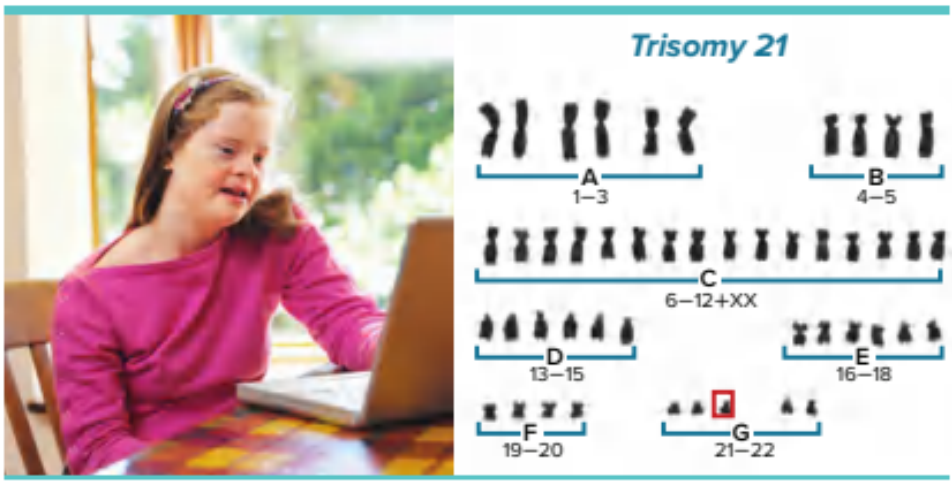


Figure 22 A person with Down syndrome has distinctive features and will have a karyotype that shows three copies of chromosome number 21.

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.

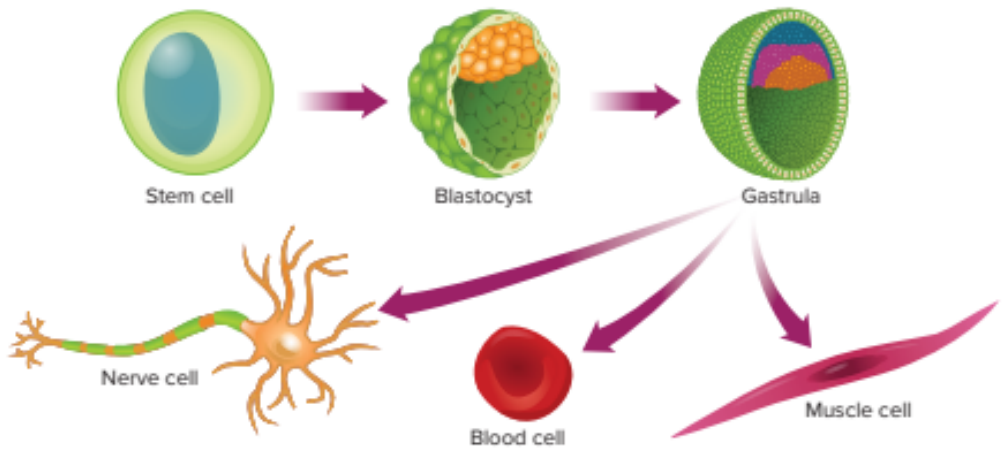
Figure 23 Scientists work with stem cells looking for new treatments for diseases such as cancer, Alzheimer's disease and Parkinson's disease.

Figure 24 Visualizing Stem Cells

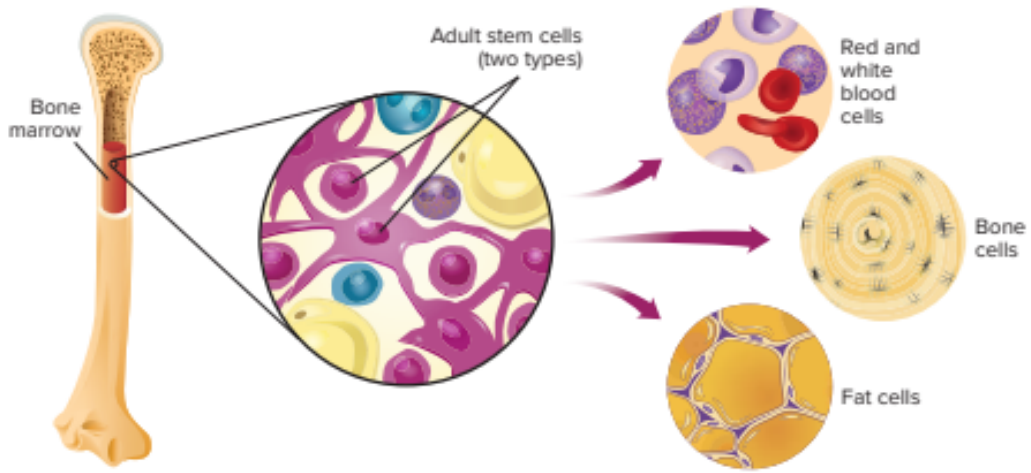
Because stem cells are not locked into becoming one particular type of cell, they might be the key to curing many medical conditions and genetic defects.

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.

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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

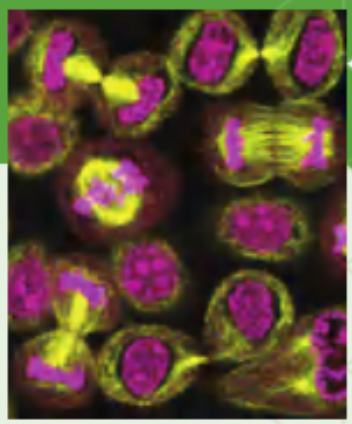
Lesson 2 MEIOSIS AND SEXUAL REPRODUCTION

- 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.

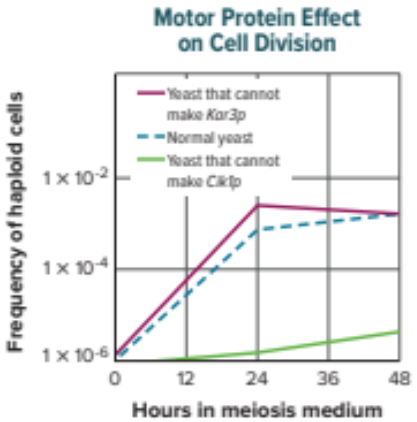
GO FURTHER

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.



*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.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INTRODUCTION TO PLANTS

ENCOUNTER THE PHENOMENON

Why are these trees shaped this way?

SEP Ask Questions

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

CER Claim, Evidence, Reasoning

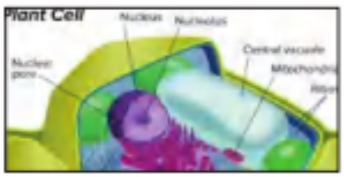
Make Your Claim Use your CER chart to make a claim about why the trees are shaped this way. Explain your reasoning.

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: Plant Evolution and Adaptations



LESSON 2: Explore & Explain: Plant Cells

LESSON 1

PLANT EVOLUTION AND DIVERSITY

FOCUS QUESTION

How did plants adapt to survive on land?

Plant Evolution

Plants are vital to our survival. The oxygen we breathe, the food we eat, and many of the things that make our lives comfortable, such as clothing, furniture, and our homes, come from or are parts of plants. Biologists describe plants as multicellular eukaryotes with tissues and organs that have specialized structures and functions. For example, most plants have photosynthetic tissues, and organs that anchor them in soil or to an object or another plant. However, does this description apply to ancient plants?

EARTH SCIENCE Connection Recall that Earth is about 4.6 billion years old. Can you imagine ancient Earth without land plants? That was the case until about 400 million years ago, when primitive land plants appeared. However, fossil evidence from about 500 million years ago indicates that the shallow waters of ancient Earth were filled with a variety of organisms—archaea, bacteria, algae and other protists, and animals, such as sponges, corals, and worms.

There is strong evidence, including biochemical and fossil evidence, that multicellular land plants and present-day green algae share a common ancestor, as diagrammed in the evolutionary tree in **Figure 1**.

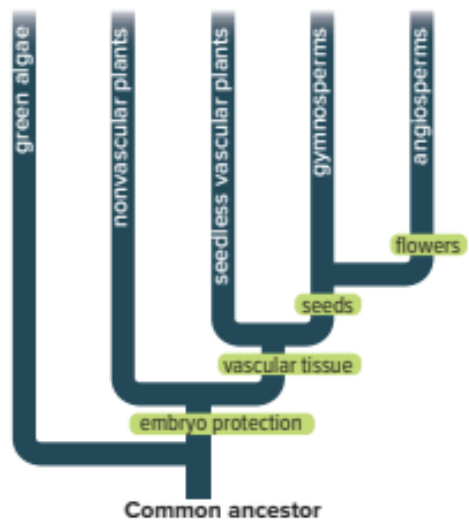


Figure 1 This evolutionary tree shows the relationship of ancient freshwater green algae to present-day plants.

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 Plant Cuticles

Analyze and interpret data to determine patterns of cuticle thickness of different plants.

Virtual Investigation: Biotechnology Knocking Out Genes

Use a model to determine patterns among missing genes of wild and mutant plants.

This common ancestor might have been able to survive periods of drought. Through natural selection, drought-resistant adaptations in that ancestor, such as protected embryos and other survival characteristics, might have passed to future generations. When scientists compare present-day plants and present-day green algae, they find the following common characteristics:

- cell walls composed of cellulose
- cell division that includes the formation of a cell plate
- the same type of chlorophyll used in photosynthesis
- similar genes for ribosomal RNA
- food stored as starch
- the same types of enzymes in cellular vesicles

Plant Adaptations to Land Environments

While living on land might seem advantageous for many organisms, there are challenges for land organisms that aquatic organisms do not face. Over time, plants that inhabited land developed adaptations that helped them survive limited water resources as well as other environmental factors.

Cuticle

An adaptation found on most above ground plant parts, shown in **Figure 2**, is a fatty coating called the cuticle on the outer surface of their cells. Wax can also be a component of the cuticle, giving it a grayish appearance. Fats and waxes are lipids and are insoluble in water. Because of this, the cuticle helps prevent the evaporation of water from plant tissues and can also act as a barrier to invading microorganisms.

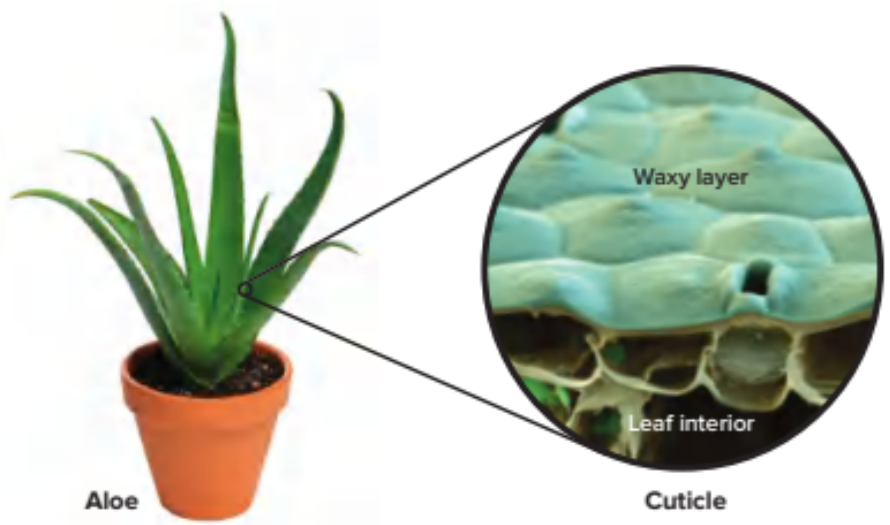


Figure 2 The cuticle is produced by the outer layer of cells. Plants in dry environments often have a thick waxy layer over the cuticle.

Infer *what advantage this waxy layer provides to plants in dry environments.*

Stomata

Like algae, most plants carry on photosynthesis, which produces glucose and oxygen from carbon dioxide and water. The exchange of gases between plant tissues and the environment is necessary for photosynthesis to occur. If the cuticle reduces water loss, it also might prevent the exchange of gases between a plant and its environment. **Stomata** (singular, stoma) are openings in the outer cell layer of leaves and some stems, as shown in **Figure 3**. They are adaptations that enable the exchange of gases even with the presence of a cuticle on a plant. Although photosynthesis can occur in some green stems, plant leaves usually are the sites of photosynthesis and are where most stomata are found.

LM Magnification: unavailable

Figure 3 Stomata are common on the lower surfaces of most plants' leaves.

Describe *the function of stomata in plants.*

Vascular tissues

Another plant adaptation to land environments is **vascular tissue**—specialized transport tissue. Recall that many substances slowly move into and out of cells and from cell to cell by osmosis or diffusion. However, vascular tissue enables faster movement of substances than by osmosis and diffusion, and over greater distances. Plants with vascular tissue are called **vascular plants,** like those in **Figure 4**. In other plants, substances slowly move from cell to cell by osmosis and diffusion. These are **nonvascular plants** and lack specialized transport tissues. Vascular tissues also provide structure and support. The presence of thickened cell walls in some vascular tissue provides additional support. Therefore, vascular plants can grow larger than nonvascular plants can.

Figure 4 Vascular plants have many shapes and sizes.

Identify *the plants that you recognize.*

Get It?

Explain why vascular tissue is advantageous for land plants.

WORD ORIGINS

cuticle

from the Latin diminutive word *cuticula*, meaning *skin*

CCC CROSSCUTTING CONCEPTS

Patterns Using the internet or other approved sources, do research on one type of flowering plant that lives in the desert, and one that lives in the rainforest. Using evidence from your research, create a presentation that shows how both plants have adaptations that help them to live successfully in two different land environments.

Reproductive strategies

A spore is a haploid cell capable of producing an organism. Some land plants reproduce by spores that have waterproof protective coverings. However, the gametophytes of those land plants must have a film of water covering them for sperm to swim to eggs. Water is a limiting factor in the environments of these plants. Seed plants have adaptations that enable a sperm to reach an egg without the presence of water.

Get It?
Explain why water is a limiting factor for some land plants.

Seeds

The evolution of the seed was another important adaptation that helped ensure the success of some vascular plants. A **seed,** as shown in **Figure 5**, is a plant structure that contains an embryo, contains nutrients for the embryo, and is covered with a protective coat. These features enable seeds to survive harsh environmental conditions and then sprout when favorable conditions exist. Seeds also can have different structural adaptations that help scatter them.

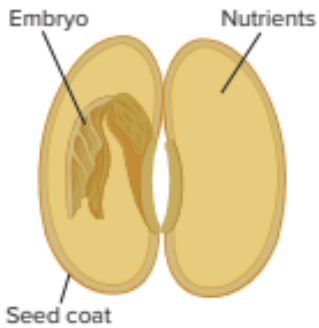


Figure 5 The seed coat protects the embryo—the new sporophyte generation.

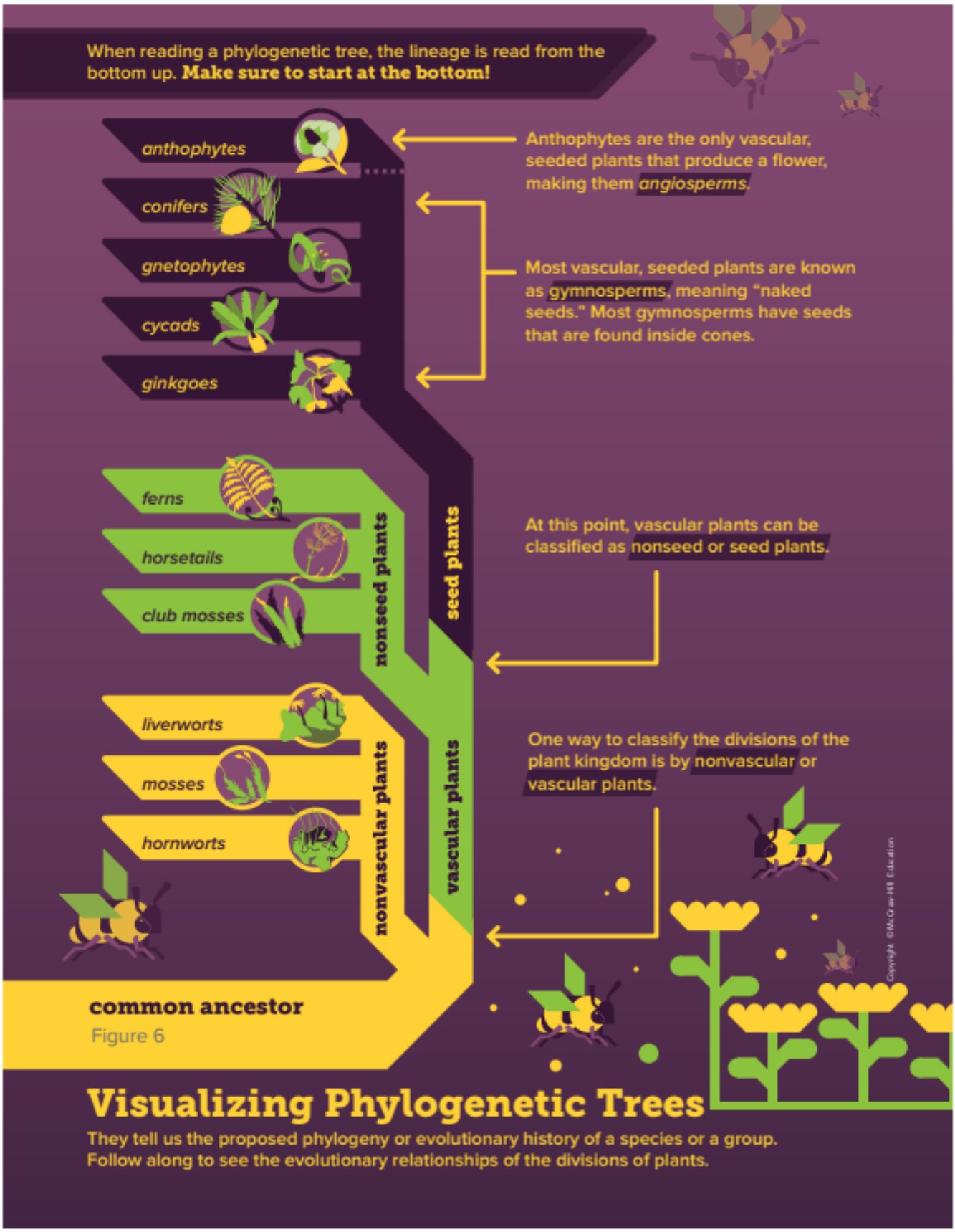
Get It?
Describe the characteristics that enable seeds to survive harsh environmental conditions.

Diversity of Plants

Over time, plant adaptations resulted in a diversity of plant characteristics. Botanists use these characteristics to classify all plants of Kingdom Plantae into divisions. Recall that other kingdoms, except for bacteria, are divided into phyla, not divisions. When referring to members of a division, it is common practice to drop the *–a* from the division name and add *–es*. For example, members of Division Bryophyta are called bryophytes (BRI uh fites).

The plant divisions can be placed in two groups—the nonvascular plants and the vascular plants, eleven of which are illustrated in **Figure 6** on the next page. In **Figure 6**, notice how the vascular and nonvascular plants evolved from a common plant ancestor.

Nonvascular plants (mosses, liverworts, and hornworts) lack specialized transport tissues. Vascular plants have specialized transport tissues. Vascular plants are divided into two smaller groups—plants that do not produce seeds (ferns, horsetails, and club mosses) and plants that produce seeds (angiosperms and gymnosperms).


When reading a phylogenetic tree, the lineage is read from the bottom up. Make sure to start at the bottom!
anthophytes
conifers
gnetophytes
cycads
ginkgoes
Anthophytes are the only vascular, seeded plants that produce a flower, making them angiosperms.
Most vascular, seeded plants are known as gymnosperms, meaning "naked seeds." Most gymnosperms have seeds that are found inside cones.
ferns
horsetails
club mosses
nonseed plants
seed plants
At this point, vascular plants can be classified as nonseed or seed plants.
liverworts
mosses
hornworts
nonvascular plants
vascular plants
One way to classify the divisions of the plant kingdom is by nonvascular or vascular plants.
common ancestor
Figure 6
Visualizing Phylogenetic Trees
They tell us the proposed phylogeny or evolutionary history of a species or a group. Follow along to see the evolutionary relationships of the divisions of plants.

Nonvascular plants

Nonvascular plants, as shown in **Figure 7**, make up one of the four major groups of plants that evolved along with green algae from a common ancestor. In general, nonvascular plants usually are small, which enables most materials to move within them easily. These plants often are found growing in damp, shady areas—environments that provide the water needed by nonvascular plants for nutrient transport and reproduction. Because they lack vascular tissue, they do not have true roots, stems, or leaves.

Study **Table 1** to learn more about the characteristics of the three divisions of nonvascular plants.

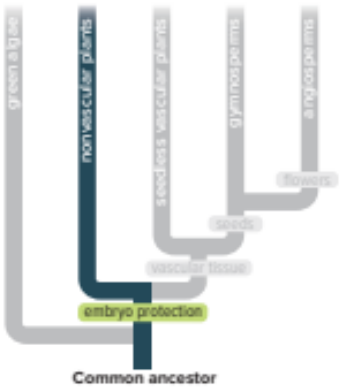
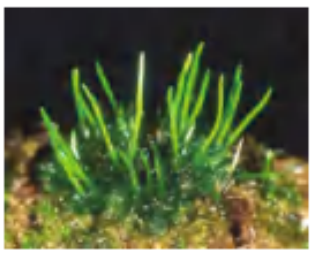


Figure 7 Embryo protection is a characteristic of nonvascular and vascular plants.

Table 1 Characteristics of Nonvascular Plants

		
Division Bryophyta • Includes mosses • Produce rootlike, multicellular rhizoids for support, anchorage, and absorption of water and minerals • Substances move by osmosis and diffusion • *Sphagnum* and other plants together form peat, which is important for fuel and in gardening • Successful in harsh environments	**Division Anthocerophyta** • Smallest division of nonvascular plants • Includes hornworts • "Horns" are actually sporophytes • Substances move by osmosis and diffusion • Each cell of the gametophyte and sporophyte has one large chloroplast • Often found in a mutualistic relationship with cyanobacteria	**Division Hepaticophyta** • Includes liverworts • Named for their appearance and use as medicine a long time ago • Found in many habitats, including tropical and arctic • Substances move by osmosis and diffusion • Have unicellular rhizoids • DNA analysis suggests liverworts are the most primitive land plant

Seedless vascular plants

Club mosses and ferns make up the seedless vascular plant group. Although the common name for a club moss identifies it as a moss, it is not a true moss. As indicated in **Figure 8**, this plant group is one of the three plant groups with vascular tissues. Seedless vascular plants exhibit a great diversity of form and size. An adaptation seen in some seedless vascular plant sporophytes is the strobilus (STROH bih lus) (plural, strobili). A **strobilus** is a compact cluster of spore-bearing structures. If a spore carried by the wind lands in a favorable environment, it can grow to form a gametophyte.

Study **Table 2** to learn more about the characteristics of the divisions of seedless vascular plants.

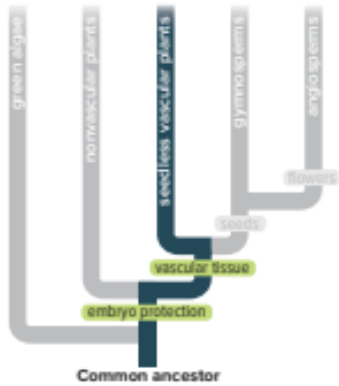


Figure 8 Seedless vascular plants produce spores in strobili instead of seeds.

Table 2 Characteristics of Seedless Vascular Plants

	
Division Lycophyta • Includes club mosses (are not true mosses) • Descendants of the oldest vascular plants • Ancient Lycophytes were up to 30m tall; their remains are part of the coal we use for fuel • Sporophyte generation is dominant • Many are epiphytes, plants that live anchored to another plant. Some draw moisture right from the air	**Division Pterophyta** • Includes ferns and horsetails • Dominant sporophyte generation (leaflike fronds) • Ferns have a thick, underground stem that is used to store food • Treelike ferns were dominant during the Carboniferous period; their remains are also much of the coal we used today • Horsetails produce spores in strobili at the tips of reproductive stems

Vascular seed plants

Vascular seed plants produce seeds, as shown in **Figure 9**. Each seed usually contains a tiny sporophyte surrounded by protective tissue. Seeds have one or more **cotyledons** (kah tuh LEE dunz)—structures that either store food or help absorb food for the tiny sporophyte.

The sporophyte is dominant in seed plants and produces spores. These spores divide by meiosis to both male and female gametophytes. Both gametophytes are dependent on the sporophyte generation for their survival. Unlike the other plants discussed so far, most seed plants do not require water for fertilization. This adaptation enables seed plants to thrive in areas where water is scarce.

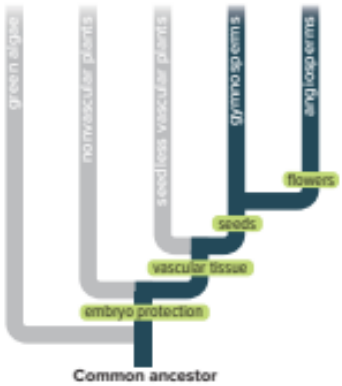


Figure 9 The evolutionary tree shows that the development of cones was an earlier evolutionary adaptation than flowers in seed plants.

Nonflowering seed plants A seed is a reproductive structure that contains a sporophyte embryo and a food supply (called the endosperm) that are enclosed in a protective coating. The food supply nourishes the young plant during the first stages of growth. Like spores, seeds can survive harsh conditions. The seed develops into the sporophyte generation of the plant. **Table 3** shows the characteristics of the groups of nonflowering seed plants.

Table 3 Characteristics of Nonflowering Seed Plants

			
Division Cycadophyta • Resemble palm trees • Live in the tropics and subtropics • Only one species is native to the United States	**Division Gnetophyta** • Can live as long as 1500–2000 years • *Welwitschia* has only two leaves and a large storage root • *Ephedra* is the only genus found in the United States	**Division Ginkophyta** • Represented by only one species, *Ginkgo biloba* • Male and female trees; females produce bad smelling berries • Pollution-resistant, and grow well in urban areas	**Division Coniferophyta** • Includes pines, firs, and redwoods • Economically important • Adaptations include needlelike leaves to conserve moisture

Flowering seed plants The flowering plants, division Anthophyta, form the largest and most diverse group of plants on Earth today. Anthophytes, also known as angiosperms, produce flowers and develop seeds that are part of a fruit. Cotyledons, or "seed leaves," are part of the seed along with the plant embryo. Monocots have one seed leaf. Dicots and eudicots have two seed leaves and are further classified based on the structure of their pollen. About 75 percent of anthophytes are eudicots. Monocots are the second largest group and include palms, lilies, onions, and grasses.

Flowers are the organs of reproduction in anthophytes. The pistil is the female reproductive organ. At the base of the pistil is the ovary. Inside the ovary are the ovules. Ovules contain the female gametophyte. A female gamete—an egg cell—forms in each ovule. The stamen is the male reproductive organ of a flower. Pollen grains that form inside the anther eventually contain male gametes called sperm. In seed plants, the sperm develop inside of the thick-coated pollen grains.

Pollen is an important structural adaptation that has enabled seed plants to live in diverse land habitats. Pollination is the transfer of pollen grains from the anther to the stigma of the pistil. It can be transferred by wind, insects, birds, and even bats. Some flowers have colorful or perfumed petals that attract pollinators. Flowers also can contain sweet nectar, as well as pollen, which provides pollinators with food.

Following fertilization, a fruit with seeds can develop. Fruits help protect seeds until they are mature. Some flowering plants develop fleshy fruits, such as apples, melons, tomatoes, or squash. Other flowering plants develop dry fruits, such as peanuts, walnuts, or sunflowers. Fruits also can help disperse seeds.

Check Your Progress

Summary

- Algae were the ancestors of modern land plants.
- Plants alternate between a sporophyte and gametophyte generation.
- Nonvascular plants transport substances by diffusion and osmosis, are small, and grow near water.
- Seedless vascular plants are adapted to drier conditions, and have a dominate sporophyte generation.
- Vascular seed plants include nonflowering and flowering groups.
- Flowers are the reproductive organ in some seed plants.

Demonstrate Understanding

1. **Identify** adaptations that make it possible for plants to survive on land.
2. **Differentiate** between a gametophyte and a sporophyte.
3. **Compare** the sporophyte and gametophyte generations of vascular and nonvascular plants.
4. **Compare and contrast** a gymnosperm and an angiosperm.

Explain Your Thinking

5. **Assess** the importance of a plant's vascular tissue to its ability to live on land.
6. **Apply** what you know about osmosis and diffusion to suggest why nonvascular plants usually are small.

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

LESSON 2

PLANT STRUCTURE AND FUNCTION

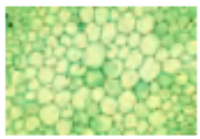
FOCUS QUESTION

What are the structures and functions of plant cells and tissues?

Plant Cells

You can identify a typical plant cell by the presence of a cell wall, a large central vacuole, and chloroplasts. However, there are many different types of plant cells—each with one or more adaptations that enable it to carry out a specific function. Three types of plant cells form most plant tissues. **Table 4** shows each of these cells and their functions.

Table 4 Plant Cells and Functions

Cell Type	Examples	Functions
Parenchyma	 LM Magnification: 20×	• Storage • Photosynthesis • Gas exchange • Protection • Tissue repair and replacement
Collenchyma	 LM Magnification: 20×	• Support • Transport of materials
Sclerenchyma	 LM Magnification: unavailable	• Support for surrounding tissues • Provides flexibility for plant • Tissue repair and replacement

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: Hierarchical Organization in Plants

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

Plant Tissues

Remember that a tissue is a group of cells that work together to perform a function. Depending on its function, a plant tissue can be composed of one or many types of cells. There are four different tissue types found in plants— meristematic (mer uh stem AH tihk), shown in **Figure 10,** dermal, vascular, and ground

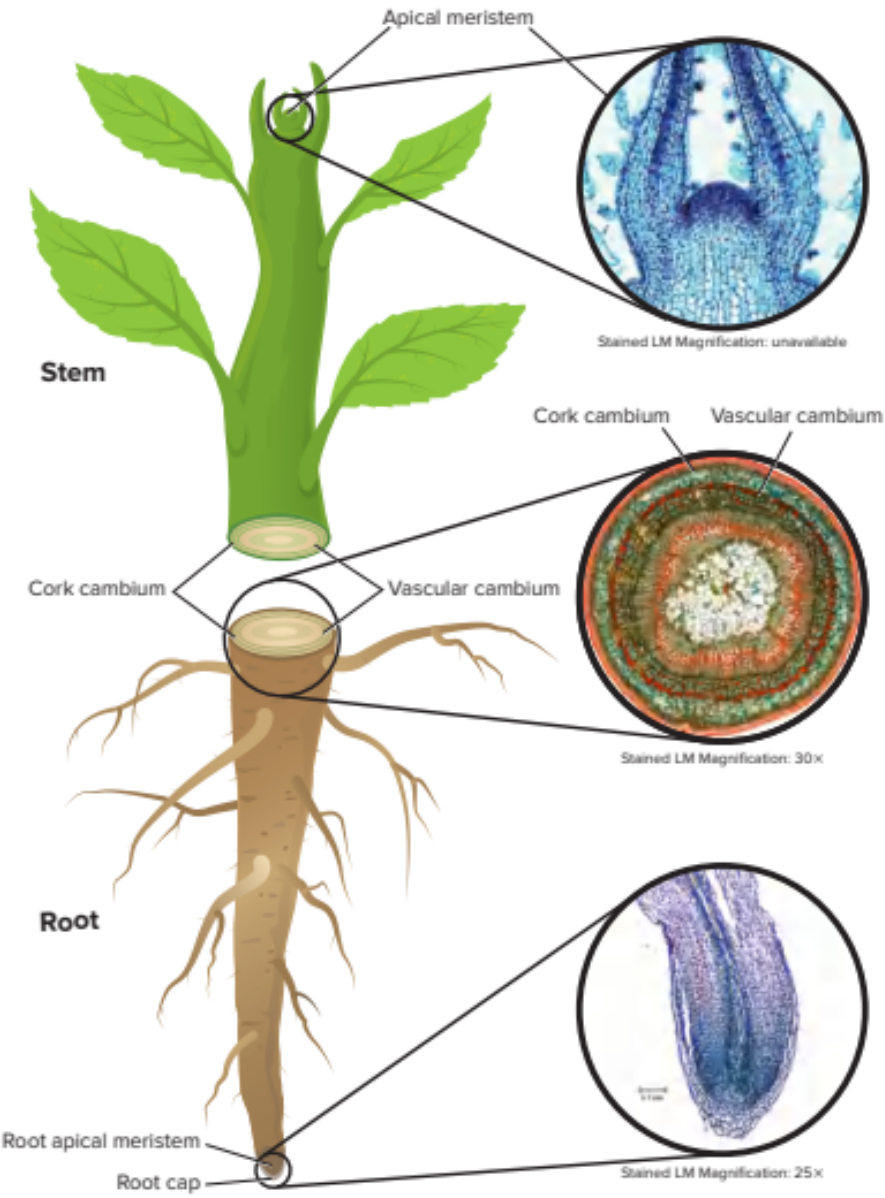


Figure 10 Most plant growth results from the production of cells by meristematic tissues. Stems and roots increase in length mostly due to the production of cells by apical meristems. A plant's vascular cambium is a different kind of meristematic tissue. Cambium produces cells that increase root and stem diameters.

Dermal tissue—the epidermis

The layer of cells that makes up the outer covering on a plant is dermal tissue, also called the **epidermis.** Cells of the epidermis resemble pieces of a jigsaw puzzle with interlocking ridges and dips, as shown in **Figure 11.** Most epidermal cells can secrete a fatty substance that forms the cuticle. The cuticle helps reduce water loss from plants and it prevents bacteria and other disease-causing organisms from entering a plant.

Stomata Plants can have several adaptations of their epidermis, such as stomata—small openings through which gases pass. The two cells that form a stoma are **guard cells.** Changes in the shapes of guard cells open and close the stomata, as shown in **Figure 11.**

Trichomes Some epidermal cells on leaves and stems produce hairlike projections called trichomes (TRI kohmz), shown in **Figure 12.** Trichomes can give leaves a fuzzy appearance and can help protect the plant from insect and animal predators.

Root hairs Some roots have root hairs. Root hairs, as shown in **Figure 12**, increase a root's surface area and enable the root to take in a greater volume of materials.

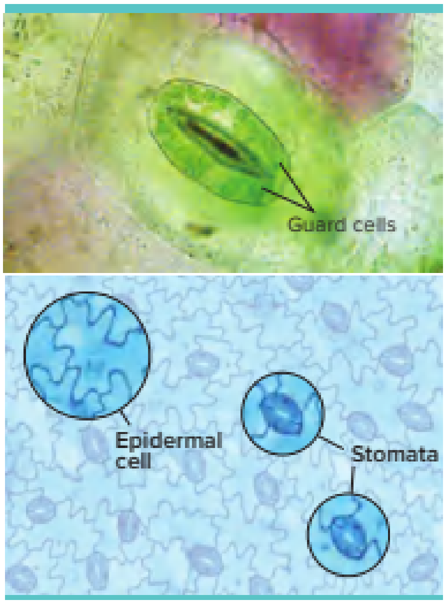


Figure 11 The surface of a leaf is composed of tightly-packed epidermal cells that help protect the plant and prevent water loss. Stomata open and close to allow gases in and out.

Figure 12 Epidermal adaptations help plants survive. **Left:** The tiny glands at the tip of a trichome can contain toxic substances. **Right:** Root hairs are fragile extensions of root epidermal cells that increase the root's surface area.
Explain *how both of these adaptations are considered to be survival mechanisms.*

WORD ORIGINS

trichome
from the Greek word *trickhma*, meaning *growth of hair*

CCC CROSSCUTTING CONCEPTS

Systems and System Models Using evidence from the text, construct a concept map that shows how the tissues that make up each plant organ (root, stem, and leaf) work together.

Vascular tissues

In a plant, the physiological processes of transporting water, food, and dissolved substances is the main function of two types of vascular tissue—xylem and phloem.

Xylem Water that contains dissolved minerals enters a plant through its roots. The water with dissolved minerals is transported throughout a plant within a system of xylem that flows continuously from the roots to the leaves. **Xylem** (ZI lum) is the water-carrying vascular tissue composed of specialized cells called vessel elements and tracheids (tray KEY ihdz). At maturity, each vessel element and tracheid consists of just its cell wall. This lack of cytoplasm at maturity allows water to flow freely through these cells.

Vessel elements are tubular cells that are stacked end-to-end, forming strands of xylem called vessels. Vessel elements are open at each end with barlike strips across the openings. In some plants, mature vessel elements lose their end walls. This enables the free movement of water and dissolved substances from one vessel element to another.

Tracheids are long, cylindrical cells with pitted ends, shown in **Figure 13.** The cells are found end-to-end and form a tubelike strand. Unlike some mature vessel elements, mature tracheids have end walls. For this reason, tracheids are less efficient than vessel elements at transporting materials.

In gymnosperms, or nonflowering seed plants, xylem is composed almost entirely of tracheids. However, in flowering seed plants, xylem consists of tracheids and vessels. Because vessels are more efficient at transporting water and materials, scientists propose that this might explain why flowering plants inhabit many different environments.

Phloem The main food-carrying tissue is **phloem** (FLOH em). It transports dissolved sugars and other organic compounds throughout a plant. Recall that xylem only transports materials away from the roots. Phloem, however, transports substances from the leaves and stems to the roots and from the roots to the leaves and stems. Although not used for transport, there are sclereids and fibers associated with the phloem. These sturdy sclerenchyma cells provide support for the plant.

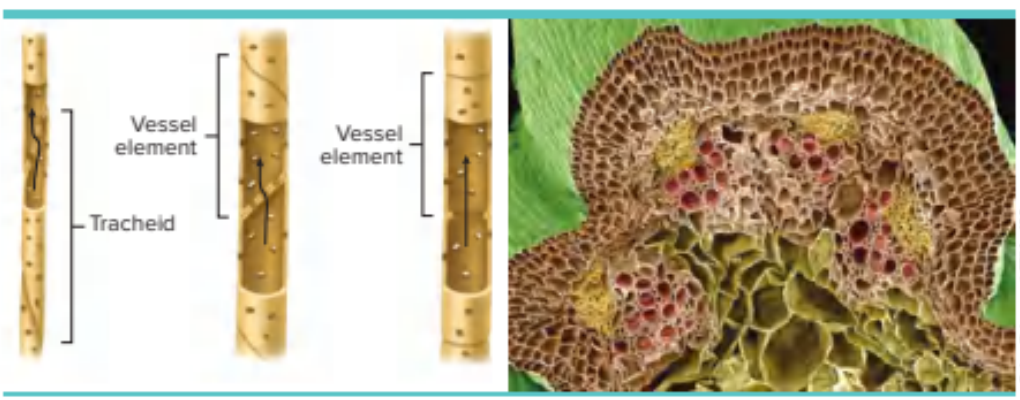


Figure 13 Tracheids and vessel elements are the conducting cells of the xylem.

Phloem consists of two types of cells, sieve tube members and companion cells, as shown in **Figure 14.** Each **sieve tube member** contains cytoplasm but lacks a nucleus and ribosomes when it is mature. Next to sieve tube members are **companion cells,** each with a nucleus. In flowering plants, structures called sieve plates are at the end of the sieve tube members.

Ground tissue The category for plant tissues that are not meristematic tissues, dermal tissues, or vascular tissues is ground tissue. **Ground tissues** consist of parenchyma, collenchyma, and sclerenchyma cells and have diverse functions, including photosynthesis, storage, and support.

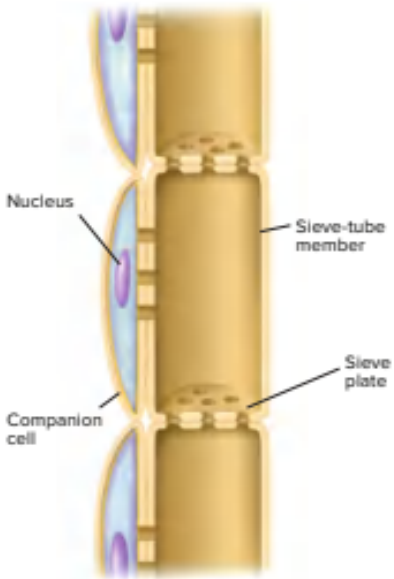


Figure 14 Notice the openings in the sieve plates between the sieve-tube members.

Roots

The structure of a root is illustrated in **Figure 15.** The tip of a root is covered by the **root cap.** It consists of parenchyma cells that help protect root tissues. The layer below the epidermal layer is the **cortex.** It is composed of ground tissues that are involved in transport and storage. At the inner boundary of the cortex is a layer of cells called the **endodermis.** Encircling each cell of the endodermis is a waterproof strip called a Casparian strip. This strip creates a barrier that forces water and dissolved minerals to pass through endodermal cells rather than around them. The layer of cells directly next to the endodermis toward the center of the root is called the **pericycle.** It is the tissue that produces lateral roots. In most eudicots, and some monocots, a vascular cambium develops from part of the pericycle.

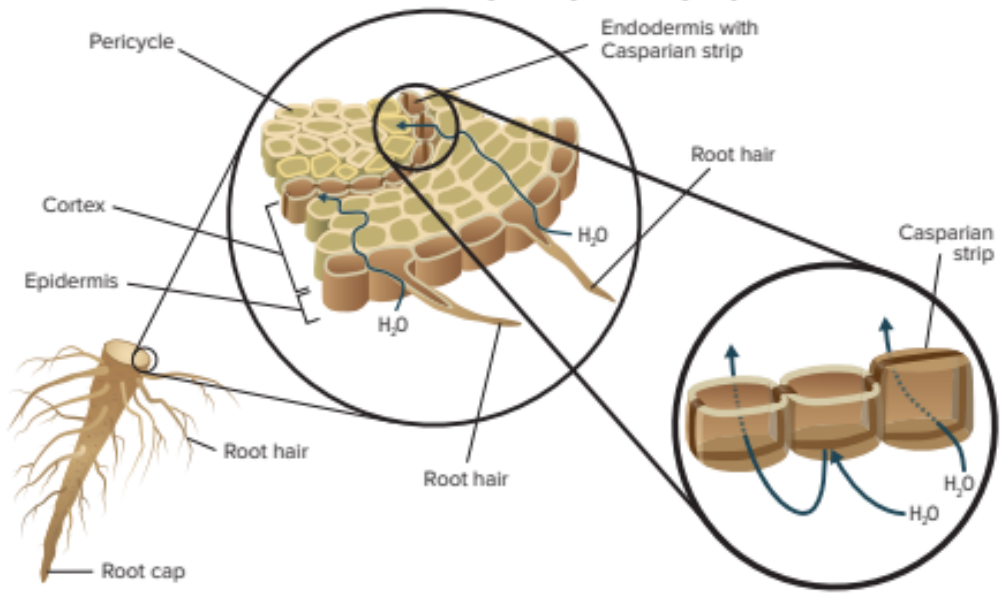


Figure 15 The structure of a plant's roots enables the entry and movement of water and dissolved minerals into the plant.

Types of roots

The two major types of root systems are taproots and fibrous roots. A taproot system consists of a thick root with few smaller, lateral-branching roots. Some plants, such as radishes, beets, and carrots, as shown below in **Table 5**, store food in the parenchyma cells of a taproot. Other taproots, like those of poison ivy plants, grow deep into the soil toward available water. **Table 5** shows types of root systems and their adaptations.

Table 5 Root Systems and Adaptations

Type	Taproot system	Fibrous root system	Modified root
Example			
Function	• Anchors plant • Food and water storage	• Anchors plant • Rapid water storage	• Anchors plant

Type	Modified roots—pneumatophores	Adventitious—prop roots
Example		
Function	• Supplies oxygen to submerged roots	• Supports plant stems

Stems

While you might know that asparagus spears are stems, you might be surprised to learn that there are many types of plant stems. Some stems, like asparagus, are soft, flexible, and green due to the presence of chloroplasts, and therefore can perform photosynthesis. These stems are called herbaceous (hur BAY shus). Most annual plants have this type of stem. Palms and bamboos have rigid, fibrous stems. Trees, shrubs, and many perennials have sturdy, woody stems that do not carry on photosynthesis. Some older plants have stems that are covered with bark. This tough, corky tissue can protect the stem from physical damage and insect invasion. Some trees even have survived a forest fire with minimal damage because of the bark that covers their trunks.

Stem structure and function

The main function of a plant's stem is support of a plant's leaves and reproductive structures. Vascular tissues in stems transport water and dissolved substances throughout the plant and provide support. These tissues are arranged in bundles, or groups, that are surrounded by parenchyma cells.

EARTH SCIENCE Connection Cells produced by the apical meristem result in an increase in the length of the stem. As the plant grows taller, the stem diameter increases. The increase in stem diameter in woody plants is due to the production of cells by the vascular cambium. The production of xylem and phloem throughout the year can produce annual growth rings. The age of a tree can be estimated by counting the annual growth rings at the base of its trunk, like those shown in **Figure 16.**

Figure 16 An annual growth ring forms in the stem of a woody plant when growth resumes after a period of little or no growth.

Infer *how the amount of available moisture might affect the width of an annual growth ring.*

Types of stems

Stems are plant organs and all stems have adaptations that help plants survive, as shown in **Table 6.** In some plants, these adaptations enable stems to store excess food, and in other plants, they help withstand drought, cold, or heat.

Table 6 **Types of Stems**

Type	Tuber	Rhizome	Runner
Example	 **White potato**	 **Iris**	 **Spider plant**
Function	• Food storage	• Food storage • Asexual reproduction	• Asexual reproduction

Type	Bulb	Corm
Example	 **Narcissus**	 **Crocus**
Function	• Food storage	• Food storage

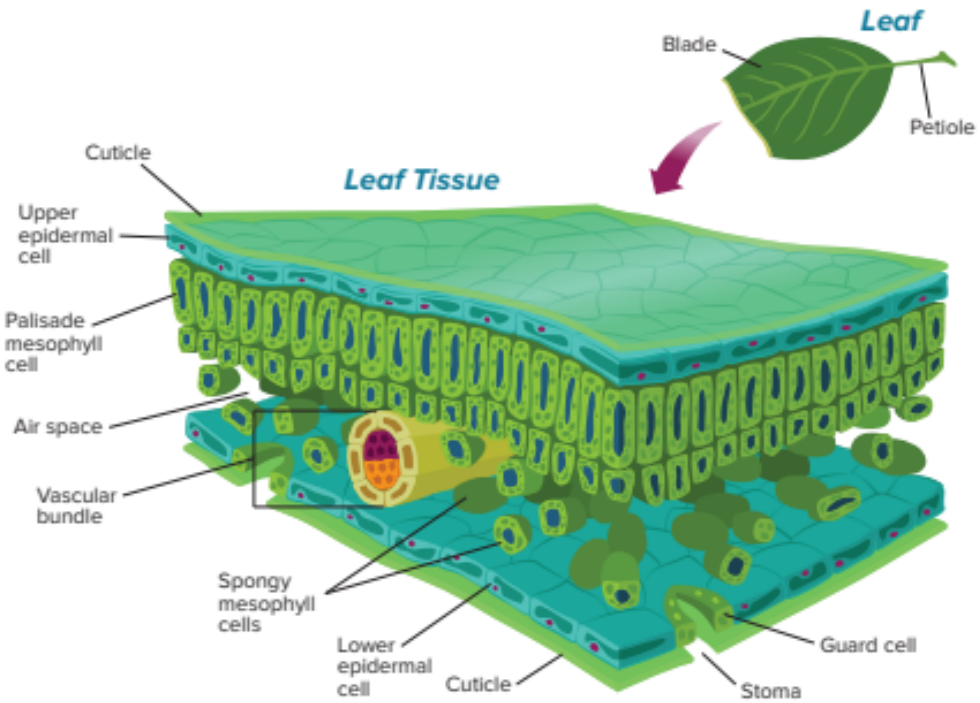


Figure 17 The different tissues of leaves illustrate the relationship between structure and function.

Leaves

There are many shapes and colors of leaves, and their arrangements on plants are different for different species. Also, the sizes of leaves can range from as large as 2 m in diameter to less than 1 mm in length. In a growing season, the number of leaves that a plant can produce varies from a few, such as for a daffodil, to hundreds of thousands produced by a mature hardwood tree.

Leaf structure

Leaves are plant organs. Leaf structure, shown in **Figure 17,** is well-adapted for its main function—photosynthesis. Most leaves have a flattened portion called the blade that has a relatively large surface area. Depending on the plant species, the blade might be attached to the stem by a stalk called a **petiole** (PET ee ohl). The petiole's vascular tissue connects the stem's vascular tissues to the leaf's vascular tissue or veins.

The internal structure of most leaves is well-adapted for photosynthesis. **Figure 17** shows tightly packed cells directly below a leaf's upper epidermis. This location has the maximum exposure to light, and therefore, most photosynthesis takes place in these column-shaped cells. They contain many chloroplasts and make up the tissue called the **palisade mesophyll** (mehz uh fihl), or palisade layer. Below the palisade mesophyll is the **spongy mesophyll,** consisting of irregularly-shaped, loosely packed cells with spaces surrounding them. Oxygen, carbon dioxide, and water vapor move through the spaces in the spongy mesophyll. In most plants, water travels from the roots up through the stems and into the leaves, replacing the water used in photosynthesis and lost from the plant by evaporation. Water evaporates from the inside of a leaf to the outside through stomata in a process called **transpiration** that helps pull the water column upward.

Types of leaves

Some people can use differences in the size, shape, color, and texture of leaves to help them identify types of plants. Some leaves are simple, which means the leaf blade is not divided into smaller parts. Compound leaves have leaf blades that are divided into two or more smaller parts called leaflets, as shown in **Table 7.**

Table 7 Types of Leaves

Leaf Type	Leaf Venation	Leaf Arrangement
Simple 	Palmate 	Opposite 
Compound 	Pinnate 	Alternate 
	Parallel 	Whorled 

Plant Responses

A plant response that causes movement that is not dependent on the direction of the stimulus is a **nastic response.** It is not a growth response, is reversible, and can be repeated. An example of a nastic response is the closing of a Venus flytrap's leaves. Movement of water in the leaves in response to an insect causes the leaves to snap shut.

STEM CAREER Connection

Soil and Plant Scientists

Life on Earth depends on plants. Soil and plant scientists do research to learn as much about these essential organisms as possible. Their work influences a huge variety of fields, including agriculture, landscaping, and architecture.

CCC CROSSCUTTING CONCEPTS

Energy and Matter Using evidence from the text, draw a flow chart that shows how leaves take in the matter used in photosynthesis and release waste.

What do you notice about the plants in **Table 8?** These are examples of tropisms. A **tropism** (TROH pih zum) is a plant's growth response to an external stimulus. If resulting plant growth is toward the stimulus, it is called a positive tropism. If the resulting plant growth is away from the stimulus, it is called a negative tropism.

Table 8 Plant Tropisms

Phototropism	Gravitropism	Thigmatropism
		
Stimulus: Light **Response:** • Growth toward light source	**Stimulus:** Gravity **Response:** • Positive downward growth • Negative upward growth	**Stimulus:** Mechanical **Response:** • Growth toward point of contact

Check Your Progress

Summary

- The structure of plant cells and tissues are related to their function.
- There are several different types of plant tissues—meristematic, dermal, vascular, and ground tissues.
- The three main organs of a plant are roots, stems, and leaves.
- Nastic plant responses are not dependent on the direction of the stimulus; tropisms are responses to stimuli from a specific direction.

Demonstrate Understanding

1. **Compare and contrast** the types of plant cells.
2. **Explain** how a plant tissue's structure is related to its function.
3. **Summarize** the primary functions of each plant organ.
4. **Describe** three plant tropisms.

Explain Your Thinking

5. **Create** a table that summarizes the structures and functions of the different plant tissues.
6. **Evaluate** why the role of stomata in a plant is important.

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LESSON 3

PLANT REPRODUCTION

FOCUS QUESTION

How do plants reproduce?

Vegetative Reproduction

Recall that reproduction without the joining of an egg and a sperm is called asexual reproduction. **Vegetative reproduction** is a form of asexual reproduction in which new plants grow from parts of an existing plant, as shown in **Figure 18.** The new plants are clones of the original plant. Their genetic makeups are identical to the original plant.

There are several advantages of vegetative reproduction. It usually is a faster way to grow plants than from a spore or a seed. Remember that an organism produced sexually will have a combination of features from its parents. However, plants produced vegetatively are more uniform than those that result from sexual reproduction. Some fruits do not produce seeds, and vegetative reproduction is the only way to reproduce.

Figure 18 Gemmae (JE mee) cups or splash cups contain small pieces of liverwort tissue. If knocked from or splashed out of the cup, they can grow into plants.

Infer *the genetic makeup of the new liverworts.*

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 Flower Structures

Carry out an investigation to determine structures that vary in plants.

CCC **Identify Crosscutting Concepts**

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

Alternations of Generations

Recall that the life cycles of some organisms include an alternation of generations—a haploid gametophyte generation and a diploid sporophyte generation. The gametophyte generation produces gametes—sperm and eggs. Some plants produce sperm and eggs on separate gametophytes, while others produce them on one gametophyte. When a sperm fertilizes an egg, a diploid zygote forms that can undergo countless mitotic cell divisions to form a multicellular sporophyte. The sporophyte generation produces spores that can grow to form the next gametophyte generation.

Depending on the type of plant, one generation is dominant over the other. The dominant generation is usually larger and accounts for more time in the plant's life cycle. Most of the plants you see—houseplants, grasses, garden plants, and trees—are the diploid sporophyte generation for those plants. During plant evolution, the trend was from dominant gametophytes to dominant sporophytes that contain vascular tissue.

The life cycle of a plant includes an alternation of generations that has a diploid ($2n$) sporophyte stage, and a haploid (n) gametophyte stage. As shown in **Figure 19**, the sporophyte stage produces haploid spores that divide by mitosis and cell division and form the gametophyte generation. Depending on the plant species, the size of a gametophyte can be tiny or a larger structure. In the plant kingdom, there is an evolutionary trend for smaller gametophytes as plants become more complex.

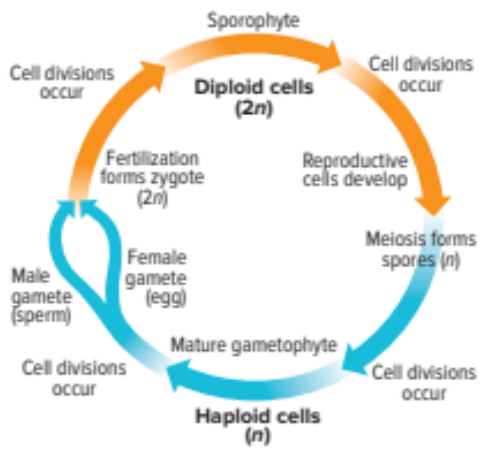

Figure 19 The form of the sporophyte (orange) and gametophyte (blue) is different for every plant species.

Flower Structure

Vivid orange, deep purple, ghostly white, fragrant, rancid, spectacular, and inconspicuous—these all are terms that can be used to describe flowers. The colors, shapes, and sizes of flowers are determined by each species' genetic makeup. It is important to remember that flowers can vary in structure and form from species to species. In each, though, the flower has one main function—to ensure that the plant reproduces successfully.

Flower organs

Flowers have several organs. Some organs provide support or protection, while others can be involved directly in reproduction. In general, flowers have four organs—sepals, petals, stamens, and one or more pistils, illustrated in **Figure 20.** **Sepals** protect the flower bud and can look like small leaves or even resemble the flower's petals. **Petals** usually are colorful structures that can both attract pollinators and provide them with a landing platform. Sepals and petals, if present, are attached to a flower stalk, called a peduncle.

Most flowers have several **stamens**—the male reproductive organs. A stamen is composed of two parts—the filament and the anther.

The filament, or stalk, supports the anther. Inside the anther are cells that undergo meiosis and then mitotic cell divisions, forming pollen grains. Two sperm eventually form inside each pollen grain. Each sperm cell will eventually fertilize a different structure inside the female reproductive organ.

The female reproductive organ of a flower is the **pistil.** In the center of a flower is one or more pistils. A pistil usually has three parts—the stigma, the style, and the ovary.

The stigma is the tip of the pistil and is where pollination occurs. The style is the part that connects the stigma to the ovary that contains one or more ovules. A female gametophyte develops in each ovule, and an egg forms inside each female gametophyte.

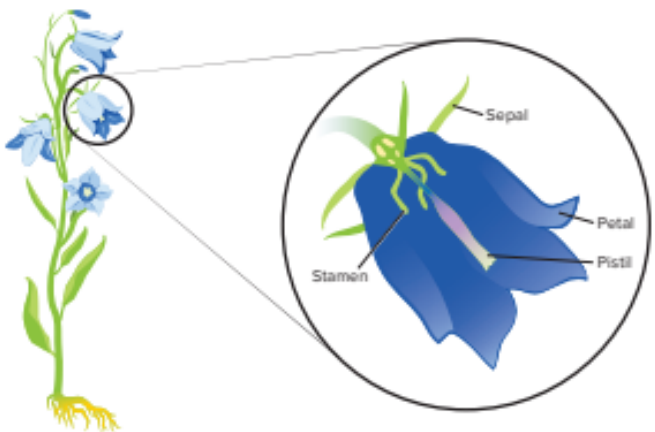

Figure 20 The typical flower has four organs—sepals, petals, stamens, and one or more pistils.

Get It?

Explain How do petals help flowers to reproduce?

Flower adaptations

Structural differences Flowers that have sepals, petals, stamens, and one or more pistils are called complete flowers. If a flower is missing one or more of these organs, it is an incomplete flower. Other descriptive terms relating to flower organs are perfect and imperfect. Flowers that have both stamens and pistils are called perfect flowers. An imperfect flower has either functional stamens or pistils, not both.

The number of each flower organ varies from species to species. However, the number of flower organs distinguishes eudicots from monocots as shown in **Figure 21.** When the petal number for a flower is a multiple of four or five, the plant usually is a eudicot. The number of other organs—the sepals, pistils, and stamens—is often the same multiple of four or five. Monocots generally have flower organs in multiples of three.

Figure 21 Some plants can be identified as either a eudicot (left) or monocot (right) by their flowers.

Pollination mechanisms Different anthophyte species have flowers of distinctive sizes, shapes, colors, and petal arrangements. Many of these adaptations relate to pollination. Self-pollinating flowers can pollinate themselves or another flower on the same plant. Cross-pollinated flowers receive pollen from another plant. Some flowers must be cross-pollinated, often by animals.

As shown in **Figure 22** on the next page, many animal-pollinated flowers are brightly colored, have strong scents, or produce a sweet liquid called nectar. When small animals move between flowers searching for nectar, they can carry pollen from one flower to another flower. Flowers that lack showy or fragrant floral parts usually are wind-pollinated. They produce huge amounts of lightweight pollen. This helps to ensure that some pollen grains will land on the stigma of a flower of the same species. Also, the stamens of wind-pollinated flowers often hang below the petals, exposing them to the wind. The stigma of a wind-pollinated flower is often large, which helps to ensure that a pollen grain might land on it.

SCIENCE USAGE v. COMMON USAGE

stigma

Science usage: the tip of a flower's pistil where pollination occurs
The stigma of an iris's pistil has three parts. ***Common usage:*** a mark of shame or discredit
A criminal record often is a stigma for an individual trying to reenter society.

CCC CROSSCUTTING CONCEPTS

Systems and System Models Use evidence from the text to sketch a model of a typical flower. Label each part of the flower. Then write a few sentences that explain how each part you labeled helps the plant reproduce.

Figure 22 Visualizing Pollination

Flowers have several adaptations that ensure pollination. Pollen might be carried by the wind or by animals. While feeding, an animal can become covered with pollen and can transfer the pollen to the next flower it visits.

Wind disperses lightweight oak pollen that can cause allergic reactions for many people. Tassels hang down and can wave in the wind.

Hummingbirds are attracted to red flowers. The hummingbird's long beak reaches nectar at the base of this flower. Some yellow and orange pigments reflect light in ranges invisible to the human eye. Even so, the markings are highly visible to bees and other insects.

As night falls, heavy scents and pale colors make it easier for moths to locate certain flowers.

The carrion flower has a rancid odor that attracts fly and beetle pollinators.

Nectar producing flowers often attract insect pollinators as they seek food.

Flowering Plants

The flowering plants, division Anthophyta, form the largest and most diverse group of plants on Earth today. They provide much of the food eaten by humans. Anthophytes, also known as angiosperms, produce flowers and develop seeds that are part of a fruit.

Seed and fruit development

The sporophyte begins as a zygote, or a $2n$ cell. Numerous cell divisions produce a cluster of cells that eventually develops into an elongated embryo with one cotyledon in monocots or two cotyledons in eudicots. The $3n$ cell formed as a result of double fertilization undergoes cell divisions. A tissue called the **endosperm** (EN duh spurm) forms as a result of these divisions and provides nourishment for the embryo. Initially, these cell divisions occur rapidly without cell wall formation. As the endosperm matures, cell walls form. In some monocots, the endosperm is the major component of the seed and makes up most of the seed's mass. For example, the coconut palm is a monocot. The liquid inside a fresh coconut is liquid endosperm—cells without cell walls. In eudicots, the cotyledons absorb most of the endosperm tissue as the seed matures. Therefore, the cotyledons of eudicot seeds provide much of the nourishment for the embryo. Examples of eudicot and monocot seeds are shown in **Figure 23.**

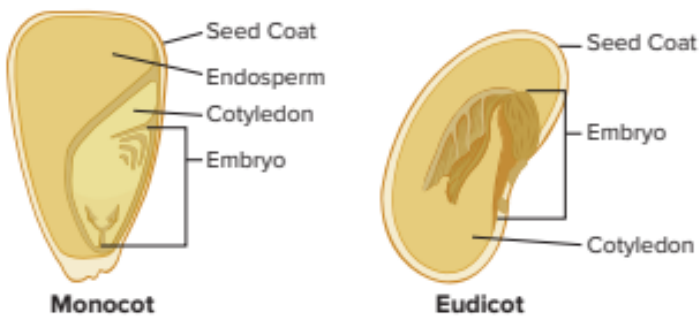

Figure 23 Seeds of monocots differ from those of eudicots.
Identify *the embryo's food source in each type of seed.*

As the endosperm matures, the outside layers of the ovule harden and form a protective tissue called the **seed coat.** You might notice the seed coats of beans or peas when you eat them. The seed coat is the thin, outer covering that often comes off or loosens as seeds are cooked.

Have you ever eaten a tomato or cucumber and noticed the number of seeds inside? Depending on the plant, the ovary can contain one ovule or hundreds. As the ovule develops into a seed, changes occur in the ovary that lead to the formation of a fruit.

Fruits form primarily from the ovary wall. In some cases, the fruit consists of the ovary wall and other flower organs. For example, the seeds of the apple are within the core that develops from the ovary. The juicy tissue that we eat develops from other flower parts.

Besides the apple, other fruits, such as peaches and oranges, are fleshy, while some are dry and hard, such as walnuts and grains. Study **Table 9** on the next page to learn about types of fruit.

Get It?
Compare and contrast the formation of a seed and a fruit.

Table 9 Types of Fruit

Fruit Type	Examples of Flower and Fruit		Description
Simple fleshy fruits			Simple fleshy fruits can contain one or more seeds. Apples, peaches, grapes, oranges, tomatoes, and pumpkins are simple fleshy fruits.
Aggregate fruits			Aggregate fruits form from flowers with multiple female organs that fuse as the fruits ripen. Strawberries, raspberries, and blackberries are examples of aggregate fruits.
Multiple fruits			Multiple fruits form from many flowers that fuse as the fruits ripen. Figs, pineapples, mulberries, and osage oranges are examples of multiple fruits.
Dry fruits			When mature, these fruits are dry. Examples of dry fruits include pods, nuts, and grains.

Seed dispersal

Fruits both protect and help to disperse seeds. Dispersal of seeds away from the parent plant eliminates the need for offspring to compete for resources with the parent plant. Fruits that are attractive to animals can be transported great distances away from the parent plant. Animals that gather and bury or store fruits usually do not recover all of them, so the seeds might sprout. Some of the animals, such as deer, bears, and birds, consume fruits. The seeds pass through their digestive tracts undamaged and then are deposited on the ground along with the animals' wastes. Some seeds have structural modifications that enable them to be transported by water, animals, or wind.

Seed germination

When the embryo in a seed starts to grow, the process is called **germination,** as shown in **Figure 24**. There are a number of factors that affect germination, including the presence of either water or oxygen (or both), and temperature. Most seeds have an optimum temperature for germination. For example, some seeds can germinate when soil is cool, but others need warmer soils.

Figure 24 Germination occurs when the embryo starts to grow.
Infer *why these seeds are at different stages of germination.*

Germination begins when a seed absorbs water, either as a liquid or gas. As cells take in water, the seed swells; this can break the seed coat. Water also transports materials to the growing regions of the seed.

Within the seed, digestive enzymes help start the breakdown of stored food. This broken-down food and oxygen are the raw materials for cellular respiration, which results in the release of energy for growth.

The first part of the embryo to appear outside the seed is a structure called the **radicle** that starts absorbing water and nutrients from its environment. The radicle, as shown in **Figure 25** on the next page, will develop into the plant's root. The **hypocotyl** is the region of the stem nearest the seed and, in many plants, it is the first part of the seedling to appear above the soil.

In some eudicots, as the hypocotyl grows, it pulls the cotyledons and the embryonic leaves out of the soil. Photosynthesis begins as soon as the seedling's cells that contain chloroplasts are above ground and exposed to light. In monocots, seedling growth is slightly different because the cotyledon usually stays in the ground when the stem emerges from the soil.

Get It?

Explain how the structures shown in **Figure 24** help plants to reproduce successfully on land.

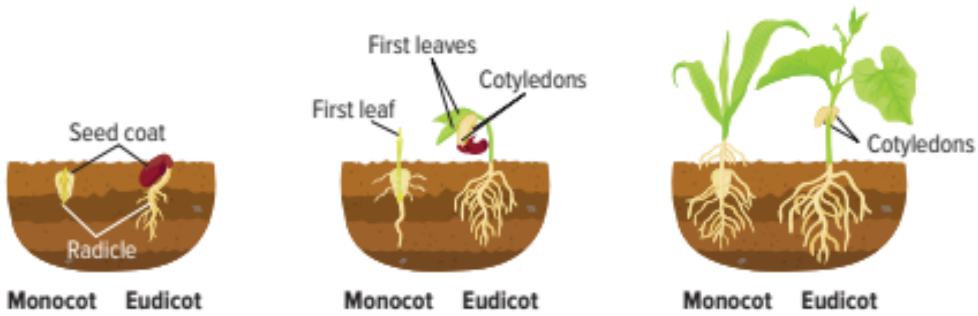

Figure 25 Seed germination differs in monocots and eudicots.

Some seeds can survive harsh environmental conditions, such as drought and cold. Other seeds germinate soon after dispersal and still others can germinate after long periods. Some maple seeds must germinate within two weeks after dispersal or they will not germinate at all. Most seeds produced at the end of a growing season enter **dormancy,** a period of little or no growth. Dormancy is an adaptation that increases the survival rate of seeds exposed to harsh conditions. The length of dormancy varies from species to species.

Check Your Progress

Summary

- Vegetative reproduction is asexual reproduction.
- The life cycles of plants involve the alternation of generations.
- A typical flower has sepals, petals, stamens, and pistils.
- Flowers can be perfect or imperfect, and complete or incomplete.
- Some flower modifications distinguish monocots from eudicots.
- Modifications make flowers more attractive to pollinators.
- Seeds provide nutrition and protection for the embryo, while fruits help protect and disperse seeds.
- Environmental conditions affect seed germination.

Demonstrate Understanding

1. **Describe** the stages of alternation of generations.
2. **Identify** advantages of vegetative reproduction.
3. **Explain** how each of the four organs of a typical flower work together to help a plant reproduce.
4. **Describe** traits of a typical monocot flower and a typical eudicot flower.

Explain Your Thinking

5. **Compare and contrast** the germination of monocot and eudicot seeds.
6. **Assess** the importance of pollinators for imperfect flowers.
7. **MATH Connection** As many as three million seeds can form inside an orchid pod. What is the percentage of germination, if all three million seeds are planted and 1,860,000 germinate?

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ENGINEERING & TECHNOLOGY

What might crop up on Mars?

Tending a vegetable garden on another planet may seem like a scene from a science fiction movie, but scientists hope to make "space farming" a reality in the near future. NASA scientists and engineers are developing new kinds of technology to study and grow plants in outer space.

More veggies, please!

Can you imagine eating prepackaged food for hundreds of days in a row? Until recently, that was the fate of astronauts aboard the *International Space Station (ISS)*. These astronauts can be in space for more than 300 days. The long missions pose a problem—lack of fresh food. The solution? Grow fruits and vegetables in outer space.

To accomplish this task, scientists developed the Vegetable Production System (Veggie), a plant growth system designed for use in outer space. Veggie provides the right amount of light and nutrients for seeds. It also provides a means to anchor plant roots in the microgravity of space.

Veggie's first salad greens were harvested in 2014, and soon its crops were deemed safe for the astronauts aboard the ISS. The salad was one small meal for humans, but a giant leap for humankind—this marked the first time that people ate fresh food not grown on Earth.

Would you eat space spinach? Scientists are using technology like this to simulate conditions on other planets.

Providing fresh food to the Earth-orbiting ISS is a major accomplishment. But NASA hopes to someday send crewed missions to Mars. The missions will involve years of space travel and exploration. What can be done to ensure that astronauts have a supply of fresh food?

Scientists are tackling that problem by recreating conditions found on Mars here on Earth. They are growing crops in artificial regolith, a rocky material that covers most of Mars. Preliminary results are promising, although astronauts would have to add fertilizers and remove some toxic chemicals for the food to be safe to eat.

Scientists hope that, by using new types of technology, they will be able to meet the challenge of growing plants in space.

COMMUNICATE SCIENTIFIC AND TECHNICAL INFORMATION

Conduct further research about the Veggie system used on the *ISS*. Create a manual about how the technology works.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 PLANT EVOLUTION AND DIVERSITY

- Algae were the ancestors of modern land plants.
- Plants alternate between a sporophyte and gametophyte generation.
- Nonvascular plants transport substances by diffusion and osmosis, are small, and grow near water.
- Seedless vascular plants are adapted to drier conditions, and have a dominate sporophyte generation.
- Vascular seed plants include nonflowering and flowering groups.
- Flowers are the reproductive organ in some seed plants.

- stomata
- vascular tissue
- vascular plant
- nonvascular plant
- seed
- strobilus
- cotyledon

Lesson 2 PLANT STRUCTURE AND FUNCTION

- The structure of plant cells and tissues are related to their function.
- There are several different types of plant tissues—meristematic, dermal, vascular, and ground tissues.
- The three main organs of a plant are roots, stems, and leaves.
- Nastic plant responses are not dependent on the direction of the stimulus; tropisms are responses to stimuli from a specific direction.

- epidermis
- guard cell
- xylem
- vessel element
- tracheid
- phloem
- sieve tube member
- companion cell
- ground tissue
- root cap
- cortex
- endodermis
- pericycle
- petiole
- palisade mesophyll
- spongy mesophyll
- transpiration
- nastic response
- tropism

Lesson 3 PLANT REPRODUCTION

- Vegetative reproduction is asexual reproduction.
- The life cycles of plants involve the alternation of generations.
- A typical flower has sepals, petals, stamens, and one or more pistils.
- Flowers can be perfect or imperfect, and complete or incomplete.
- Some flower modifications distinguish monocots from eudicots.
- Modifications make flowers more attractive to pollinators.
- Seeds provide nutrition and protection for the embryo, while fruits help protect and disperse seeds.
- Environmental conditions affect seed germination.

- vegetative reproduction
- sepal
- petal
- stamen
- pistil
- endosperm
- seed coat
- germination
- radicle
- hypocotyl
- dormancy

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

Why are these trees shaped this way?

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.

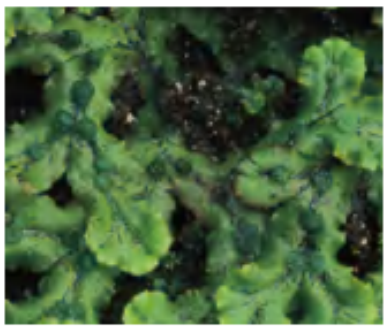
GO FURTHER

SEP Data Analysis Lab

How does *Nostoc* benefit a hornwort?

Cyanobacteria, usually species of *Nostoc*, form mutualistic relationships with a few liverworts and the majority of hornworts.

Data and Observations *Nostoc* colonies appear as dark spots within gametophyte tissue, as shown in the photo.



*Data obtained from: Costa, J-L., et al. 2001. Genetic diversity of Nostoc symbionts endophytically associated with two bryophyte species. *Appl. Envir. Microbiol.* 67: 4393–4396.

CER Analyze and Interpret Data

1. **Claim, Evidence, Reasoning** Hypothesize about the benefit(s) the cyanobacteria receive from the hornwort.
2. **Design** an experiment to test your hypothesis.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INTEGUMENTARY, SKELETAL, AND MUSCULAR SYSTEMS

ENCOUNTER THE PHENOMENON

How does the climber keep herself from falling off the cliff?

SEP Ask Questions

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

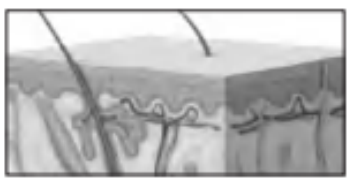
CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about how the climber keeps herself from falling off the cliff. Explain your reasoning.

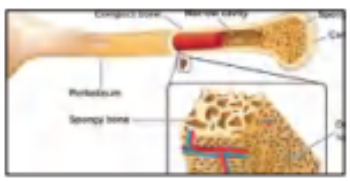
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

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 Integumentary System: How Skin Works



LESSON 2: Explore & Explain: The Skeletal System: How Bones Work

LESSON 1

THE INTEGUMENTARY SYSTEM

FOCUS QUESTION

What are the structures and functions of the integumentary system?

The Structure of Skin

The integumentary (ihn TEG yuh MEN tuh ree) system is the organ system that covers and protects the body. Skin is the main organ of the integumentary system and is composed of four types of tissues: epithelial tissue, connective tissue, muscle tissue, and nerve tissue. Epithelial tissue covers body surfaces, and connective tissue provides support and protection. Muscle tissue is involved in body movement. Nerve tissue forms the body's communication network.

The epidermis

Refer to **Figure 1**, which illustrates the two main layers of skin as seen through a microscope. The outer superficial layer of skin is the **epidermis.** The epidermis consists of epithelial cells and is about 10 to 30 cells thick, or about as thick as a sheet of paper. The outer layers of epidermal cells contain **keratin** (KER uh tun), a protein that waterproofs and protects the cells and tissues that lie underneath. These dead, outer cells are constantly shed. **Figure 2** on the next page shows that some of the dust in a house are dead skin cells. As much as an entire layer of skin cells can be lost each month.

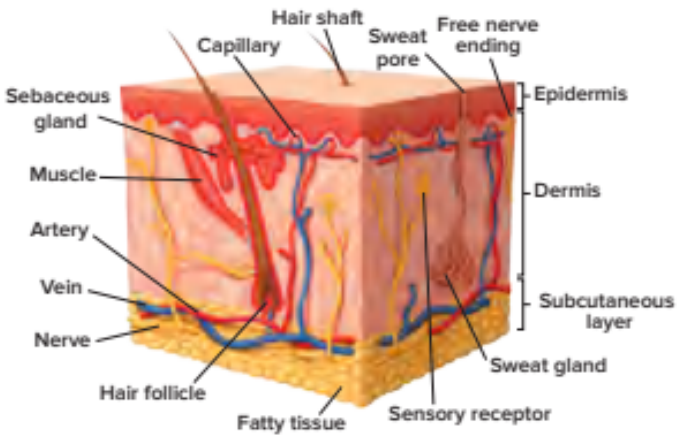


Figure 1 Skin is an organ because it consists of different types of tissues joined together for specific purposes.

Summarize *what types of tissues make up the skin.*

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: Examine Skin

Carry out an investigation to determine structures of skin.

Identify Cross Cutting Concepts

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

The inner layer of the epidermis contains cells that continually are dividing by mitosis to replace cells that are lost or die. Some cells in the inner layer of the epidermis provide protection from harmful ultraviolet radiation by making a pigment called melanin. **Melanin** is a pigment that absorbs light energy. This protects deeper cells from the damaging effects of ultraviolet rays of sunlight. The amount of melanin that is produced also influences the color of a person's skin. A suntan results when melanin is produced in response to exposure to the ultraviolet radiation in sunlight.

Color-Enhanced SEM Magnification:30×

Figure 2 The dust mite pictured here feed on dead skin cells—a major component of dust.

The dermis

Directly beneath the epidermis is the **dermis,** the second layer of skin. The thickness of the dermis varies but usually is 15–40 times thicker than the epidermis. The dermis consists of connective tissue, a type of tissue that prevents the skin from tearing and also enables the skin to return to its normal state after being stretched. This layer contains other structures including nerve cells, muscle fibers, sweat glands, oil glands, and hair follicles. Beneath the dermis is the subcutaneous layer, a layer of connective tissue that stores fat and helps the body retain heat.

Get It?

Describe the hierarchical structure and organization of the skin.

Hair and nails

Hair, fingernails, and toenails also are parts of the integumentary system. Both hair and nails contain keratin and develop from epithelial cells. Hair cells grow out of narrow cavities in the dermis called **hair follicles.** Cells at the base of a hair follicle divide and push cells away from the follicle, causing hair to grow.

Hair follicles usually have sebaceous or oil glands associated with them, as shown in **Figure 3**. **Sebaceous glands** lubricate skin and hair. When sebaceous glands produce too much oil, the follicles can become blocked. Oil, dirt, and bacteria can become trapped in the follicles and erupt and spread to surrounding areas. The trapped material can close the opening of a follicle, causing a whitehead, blackhead, or acne—an inflammation of the sebaceous glands.

Figure 3 Hairs grow out of hair follicles, structures found in the dermis.

Fingernails and toenails grow from specialized epithelial cells at the base of each nail. As cells at the base of a nail divide, older dead cells are compacted and pushed out. Nails grow about 0.5 to 1.2 mm per day. You might have heard that nails and hair continue to grow for several days after death. This is a myth; cells surrounding the nail and hair cells dehydrate causing the cells to shrink and pull away from nails and hair. This makes both appear longer.

Functions of the Integumentary System

Skin serves several important functions including regulation of body temperature, production of vitamin D, protection, and perception of one's surroundings.

Temperature regulation

What happens when a person is working outside on a hot summer day? In order to regulate body temperature, the person sweats. As sweat evaporates it absorbs body heat, thereby cooling the body. What happens to skin when a person gets cold or frightened? "Goose bumps" are caused by the contraction of muscle cells in the dermis. In other mammals, when these muscles contract, the hair (fur) stands on end.

Notice the frightened cat in **Figure 4**. The cat appears larger, perhaps as a way to scare off enemies. This also is a mechanism for trapping air, which insulates or warms the mammal. Humans do not have as much hair as most other mammals, but "goose bumps" are caused by the same type of muscles that make a cat's fur stand on end. Humans rely on fat in the subcutaneous layer instead of hair to keep warm.

Vitamin production

Skin also responds to exposure to ultraviolet light rays from the Sun by producing vitamin D. Vitamin D increases absorption of calcium into the bloodstream and is essential for proper bone formation. Many food products, such as milk and orange juice, are now fortified with vitamin D.

Figure 4 Muscles in the skin cause the hair of some mammals to stand on end, and cause "goose bumps" on human skin.

Relate *what environmental changes produce "goose bumps."*

Protection and senses

Intact skin prevents the entry of microorganisms and other foreign substances. Skin helps maintain body temperature by preventing excessive water loss. Melanin in the skin protects against ultraviolet rays. Information about changes in the environment, such as pain, pressure, and temperature changes, is relayed to the brain.

Get It?

Identify the functions of the skin and which layer of skin is associated with each function.

Damage to the Skin

Skin has the remarkable ability to repair itself. Without a repair mechanism, the body would be subject to invasion by microbes through breaks in the skin.

Cuts and scrapes

Sometimes, as in the case of a minor scrape, only the epidermis is injured. Cells deep in the epidermis divide to replace the lost or injured cells. When the injury is deep, blood vessels might be injured, resulting in bleeding. Blood flows out of the wound and a clot is formed.

Blood clots form a scab to close the wound, and cells beneath the scab multiply and fill in the wound. At the same time, infection-fighting white blood cells will help get rid of any bacteria that might have entered the wound.

Effects of the Sun and burns

As people age, the elasticity of their skin decreases and they start to get wrinkles. Exposure to ultraviolet rays from the Sun accelerates this process and can result in burning of the skin and other damage.

HEALTH Connection Burns, whether caused by the Sun, heat, or chemicals, usually are classified according to their severity. The types of burns are summarized in **Table 1**. First-degree burns generally are mild and involve only cells in the epidermis. A burn that blisters or leaves a scar is a second-degree burn and involves damage to both the epidermis and dermis. Third-degree burns are the most severe. Muscle tissue and nerve cells in both the epidermis and dermis might be destroyed, and skin function is lost. Healthy skin might have to be transplanted from another place on the body in order to restore the protective layer of the body.

Get It?

Contrast the three types of burns.

Table 1 Classification of Burns

Severity of burn	Damage	Effect
First-degree	Cells in the epidermis are injured and may die.	• Redness and swelling • Mild pain
Second-degree	Cells deeper in the epidermis die. Cells in the dermis are injured and may die.	• Blisters • Pain
Third-degree	Cells in the epidermis and dermis die. Nerve cells and muscle cells are injured.	• Skin function lost • Healthy skin needs to be transplanted • No pain because of nerve cell damage

ACADEMIC VOCABULARY

Function
action, purpose
One function of the skin is to protect the body.

STEM CAREER Connection

Dermatologist
Physicians that specialize in helping people take care of their skin are dermatologists. They treat skin conditions ranging from acne to skin cancer.

CCC CROSSCUTTING CONCEPTS

Systems and System Models Work with a partner to design a model of the integumentary system. Define the system and discuss how the model provides a tool for understanding the system.

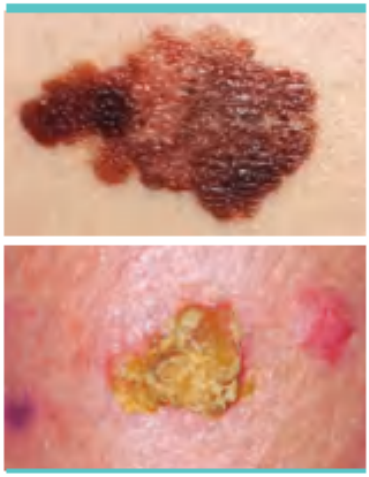


Figure 5 Warning signs of skin cancer include obvious changes to warts or moles, or moles that are irregularly shaped, varied in color, or larger than the diameter of a pencil.

Skin cancer

Exposure to ultraviolet radiation, whether it is from the Sun or from artificial sources such as tanning beds, is recognized as an important risk factor for the development of skin cancer. Ultraviolet radiation can damage the DNA in skin cells, causing those cells to grow and divide uncontrollably. When this happens, skin cancer results. Refer to **Figure 5** to see some warning signs of skin cancer.

Skin cancer is the most common cancer in the United States. There are two categories of skin cancer: melanoma and nonmelanoma. Melanoma is the deadliest form of skin cancer. Melanoma begins in melanocytes, the cells that produce the pigment melanin. Melanoma can spread to internal organs and the lymphatic system.

Ways to reduce your risk of developing skin cancer include avoiding prolonged exposure to the Sun, especially between 10 a.m. and 4 p.m. when the Sun's rays are the strongest. Other preventative measures include wearing protective clothing or sunscreen with a sun protection factor (SPF) of at least 15.

Check Your Progress

Summary

- The skin is the major organ of the integumentary system.
- Maintaining homeostasis is one function of the integumentary system.
- There are four types of tissue in the integumentary system.
- Hair, fingernails, and toenails develop from epithelial cells.
- Burns are classified according to the severity of the damage to skin tissues.

Demonstrate Understanding

1. **Relate** the components of cells in skin to their function.
2. **Summarize** the types of tissues in the integumentary system and their functions.
3. **Generalize** different ways the integumentary system helps a human survive.
4. **Sequence** the steps of skin repair in response to a cut.
5. **Compare** effects of first-degree, second-degree, and third-degree burns.

Explain Your Thinking

6. **Evaluate** the labels of two skin creams to compare how they claim to benefit the skin.
7. **MATH Connection** To determine how long an SPF will protect a person from burning in the Sun, multiply the amount of time the person can spend in the Sun before starting to burn by the SPF rating. If an individual who usually burns in 10 mins uses a product with an SPF of 15, how long will the protection last?

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LESSON 2

THE SKELETAL SYSTEM

FOCUS QUESTION

What are the structures and functions of the skeletal system?

Structure of the Skeletal System

Notice all the bones in the adult skeleton pictured in **Figure 6**. If you counted them, you would find that there are 206 bones. The human skeleton consists of two divisions—the axial skeleton and the appendicular skeleton. The **axial skeleton** includes the skull, the vertebral column, the ribs, and the sternum. The **appendicular skeleton** includes the bones of the shoulders, arms, hands, hips, legs, and feet.

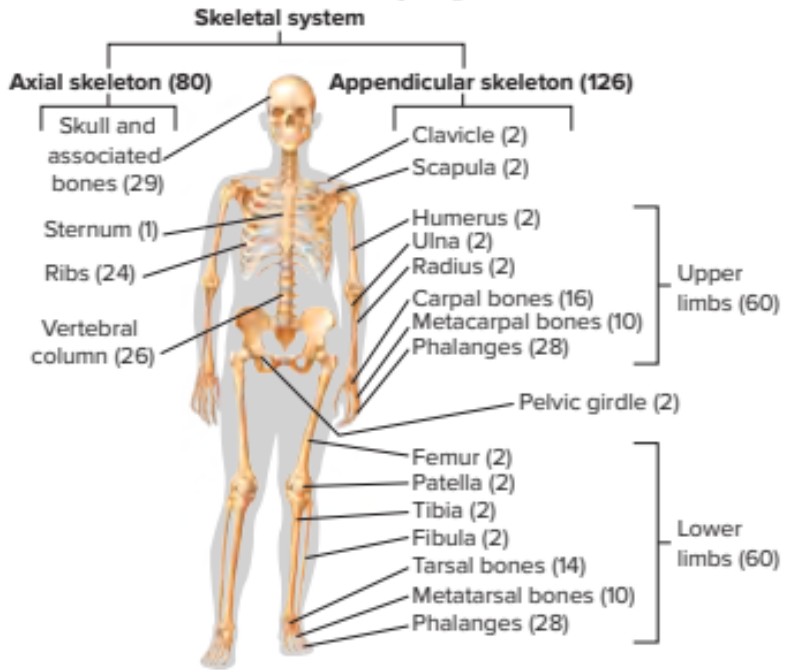

Figure 6 The axial skeleton includes the bones of the head, back, and chest. Bones in the appendicular skeleton are related to movement of the limbs.

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 skeletons help you solve a "crime"?
Plan and carry out an investigation to determine if the structure of a bone can tell which animal it came from.

Quick Investigation: Examine Bone Attachments
Carry out an investigation to determine structures of the skeletal system.

Compact and spongy bone

Bone is a connective tissue that has many shapes and sizes. Bones are classified as long, short, flat, or irregular. Refer to **Figure 6** on the previous page. Arm and leg bones are examples of long bones, and wrist bones are examples of short bones. Flat bones make up the skull. Facial bones and vertebrae are irregular bones.

The outer layers of all bones are composed of compact bone. **Compact bone** is dense and strong; it provides strength and protection. Running the length of compact bones are tube-like structures called osteons, or Haversian systems, which contain blood vessels and nerves. The blood vessels provide oxygen and nutrients to **osteocytes**—living bone cells. The centers of bones can differ greatly, as illustrated in **Figure 7**. As the name suggests, **spongy bone** is less dense and has many cavities that contain bone marrow. Spongy bone is found in the center of short or flat bones and at the end of long bones. Spongy bone is surrounded by compact bone and does not contain Haversian systems.

There are two types of bone marrow—red and yellow. Red and white blood cells and platelets are produced in **red bone marrow.** Red bone marrow is found in the humerus bone of the arm, the femur bone of the leg, the sternum and ribs, the vertebrae, and the pelvis. The cavities of an infant's bones are composed of red marrow. Children's bones have more red marrow than adult bones. **Yellow bone marrow,** found in many other bones, consists of stored fat. The body can convert yellow bone marrow to red bone marrow in cases of extreme blood loss or anemia.

Formation of bone

The skeletons of embryos are composed of cartilage. During fetal development, cells in fetal cartilage develop into bone-forming cells called **osteoblasts.** The formation of bone from osteoblasts is called **ossification.** Except for the tip of the nose, outer ears, discs between vertebrae, and the lining of movable joints, the human adult skeleton is all bone. Osteoblasts also are the cells responsible for the growth and repair of bones.

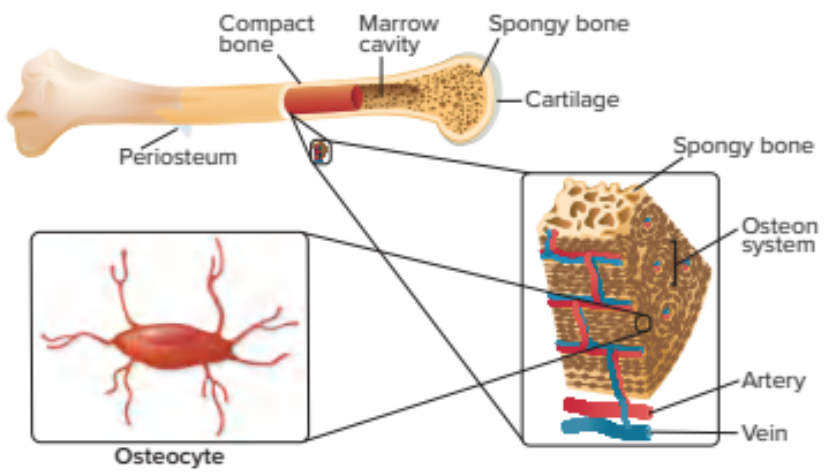

Figure 7 Bone is either compact bone or spongy bone.

Classify *how spongy bone and compact bone differ in location and function.*

Remodeling of bone

Bones constantly are being remodeled, which involves replacing old cells with new cells. This process is continual throughout life and is important in the growth of an individual. Cells called **osteoclasts** break down bone cells, which are then replaced by new bone tissue.

Repair of bone

Fractures are common bone injuries. When a bone breaks but does not come through the skin, it is called a simple fracture. A compound fracture is one in which the bone protrudes through the skin. When a bone is fractured, repair begins immediately. **Figure 8** illustrates the repair of a broken bone.

Fracture Upon injury, endorphins, chemicals produced in the brain that help to relieve pain, flood the area of the injury to reduce pain temporarily. The injured area becomes inflamed, or swollen. Within about eight hours, a blood clot forms between the broken ends of the bone and new bone begins to form. The release of endorphins and formation of the blood clot are examples of how feedback mechanisms help the body respond to changes in homeostasis. The tissues in the body send communication signals that help the body maintain homeostasis. The fracture repair begins with a soft callus, or mass, of cartilage forming at the location of the break. This tissue is weak, so the broken bone must remain in place.

Get It?
Describe the feedback mechanisms involved in responding to a broken bone.

Callus formation About three weeks later, osteoblasts form a callus made of spongy bone that surrounds the fracture. The spongy bone is then replaced by compact bone. Osteoclasts remove the spongy bone while osteoblasts produce stronger, compact bone. Splints, casts, and sometimes traction can ensure that the broken bone remains in place until the compact bone tissue has formed.

Remodeling Bones require different amounts of time to heal. Age, nutrition, location, and severity of the break are all factors. A lack of calcium in a person's diet will slow down bone repair. Bones of younger people usually heal more quickly than bones of older people. For example, a fracture might take only four to six weeks to be repaired in a toddler, but it might take six months in an adult.

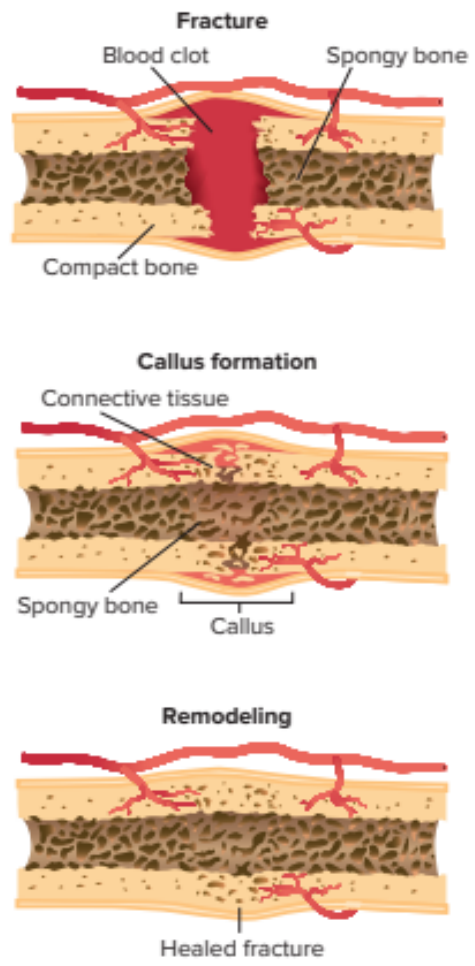

Figure 8 Bone repair requires several steps. First, a mass of clotted blood forms in the space between the broken bones. Then connective tissue fills the space of the broken bone. Eventually, osteoblasts produce new bone tissue.

Joints

Joints occur where two or more bones meet. They can be classified according to the movement they allow and the shapes of their parts. **Table 2** identifies five kinds of joints: ball-and-socket, pivot, hinge, gliding, and sutures. Study **Table 2** to identify the type of movement that each kind of joint allows and also the bones involved in each example.

Not all joints are movable. The joints between some skull bones, called sutures, are fixed. They are joined together by fibrous tissue. At birth, however, skull bones are not all fused together. This flexibility helps avoid damage to the brain during birth. They become fused by the time a baby is about three months old. Gliding joints, like those found in the wrists and ankles have limited movement. Other joints, such as the hinge joint of the elbow and knee, and the pivot joint in the lower arm and neck, allow back-and-forth movement and twisting. The ball-and-socket joints of the hips and shoulders have the widest range of motion.

The bones of joints are held together by tough bands of connective tissue called **ligaments.**

Table 2 Some Joints of the Skeletal System

Name of Joint	Ball-and-Socket	Pivot	Hinge	Gliding	Sutures
Example					
Description	In a ball-and-socket joint, the ball-like surface of one bone fits into a cuplike depression of another bone. The joints of the hips and shoulders are ball-and-socket joints. They allow a person to swing their arms and legs.	The primary movement at a pivot joint is rotation. One example of a pivot joint is the elbow joint, where two bones of the lower arm meet. This joint allows a person to twist the lower arm.	In a hinge joint, the convex surface of one bone fits into the concave surface of another bone. Elbows and knees are hinge joints. They allow back-and-forth movement like that of a door hinge.	Gliding joints allow side-to-side and back-and-forth movement. The joints in wrists and ankles are gliding joints. The joints of vertebrae also are gliding joints.	Sutures are joints in the skull that are not movable. There are 22 bones in an adult skull. All skull bones except the lower jaw bone are joined at sutures.

CCC CROSSCUTTING CONCEPTS

Systems and Systems Models Consider a model of part of the skeletal system. What system components does the model help you study? Write a paragraph describing the usefulness of the model.

Osteoarthritis

The ends of bones in movable joints, such as the knee, are covered by cartilage, which serves as a cushion and allows smooth movement of the joint. Osteoarthritis (ahs tee oh ar THRI tus) is a painful condition that affects joints and results from the deterioration of the cartilage. It is a very common condition in knees and hips and also affects the neck and back. Osteoarthritis affects about ten percent of Americans and the frequency increases with age. A young person who has a joint injury is at risk to develop osteoarthritis later in life.

Rheumatoid arthritis

Rheumatoid (roo MAH toyd) arthritis is another form of arthritis that affects joints. Rheumatoid arthritis is not the result of cartilage deterioration or of wear and tear on the joint. Affected joints lose strength and function and are inflamed, swollen, and painful. Joints can become deformed, as shown in **Figure 9**.

Figure 9 Rheumatoid arthritis can cause loss of strength and function and involves severe pain.

Compare *how rheumatoid arthritis differs from the more common osteoarthritis.*

Bursitis

Shoulders and knees also have fluid-filled sacs called bursae that surround these joints. Bursae decrease friction and act as a cushion between bones and tendons, which attach muscle to bone. Bursitis is an inflammation of the bursae and can reduce joint movement and cause pain and swelling. "Tennis elbow" is a form of bursitis. Treatment involves resting the affected joint.

Sprains

A sprain involves damage to the ligaments that hold joints together. It is caused when a joint is twisted or overstretched and usually causes the joint to swell and be tender and painful.

Functions of the Skeletal System

You might think that the only purpose of a skeleton is to serve as a framework to support the body. The bones of the legs, pelvis, and the vertebral column hold up the body. The mandible supports the teeth, and almost all bones support muscles. Many soft organs are directly or indirectly supported by nearby bones.

The skeletal system serves other functions besides support, as shown in **Table 3** on the next page. The skull protects the brain, vertebrae protect the spinal cord, and the rib cage protects the heart, lungs, and other organs.

The outer layers of bone tissue also protect the bone marrow found inside bones. In addition to forming red blood cells and white blood cells, red bone marrow forms platelets, which are involved in blood clotting. Red blood cells are produced at the rate of more than two million per second.

Until a person reaches about seven years of age, all bone marrow is red bone marrow. Then, fat tissue replaces some red marrow and gives the marrow a yellowish appearance, which gives it its name. Fat is an important source of energy.

Bones are reservoirs for the storage of minerals such as calcium and phosphorus. When blood calcium levels are too low, calcium is released from bones. When blood calcium levels are high, excess calcium is stored in bone tissue. Through this system of feedback and response, the skeletal system helps to maintain homeostasis in the body.

Bones that have muscles attached to them allow movement of the body. For example, as muscles pull on the bones of the arms and legs, they cause movement. Muscles that are attached to your ribs allow you to breathe normally.

Table 3 Functions of the Skeletal System

Function	Description
Support	• Legs, pelvis, and vertebral column hold up the body • Mandible supports the teeth • Almost all bones support muscles
Protection	• Skull protects the brain • Vertebrae protect the spinal column • Rib cage protects the heart, lungs, and other organs
Formation of blood cells	• Red bone marrow produces red blood cells, white blood cells, and platelets
Reservoir	• Stores calcium and phosphorus
Movement	• Attached muscles pull on bones of arms and legs • Diaphragm allows normal breathing

Check Your Progress

Summary

- The human skeleton consists of two divisions.
- Most bones are composed of two different types of tissue.
- Bones are being remodeled constantly.
- Bones work in conjunction with muscles.
- The skeleton has several important functions.

Demonstrate Understanding

1. **Identify** and describe the functions of the axial skeleton and the appendicular skeleton.
2. **Compare** the compositions of red bone marrow and yellow bone marrow.
3. **Compare** the body's mechanism for repairing a fractured bone with the original development of bone.
4. **Construct** a classification scheme for all of the bones shown in **Figure 6.**

Explain Your Thinking

5. **Consider** what the result might be if osteoblast and osteoclast cells did not function properly both in a developing fetus and in an adult.
6. **Distinguish** between compact and spongy bone based on appearance, location, and function.

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LESSON 3

THE MUSCULAR SYSTEM

FOCUS QUESTION

What are the structures and functions of the muscular system?

Three Types of Muscles

A muscle consists of groups of fibers or muscle cells that are bound together. These specialized cells help the body perform essential functions of life. **Figure 10** shows the three types of muscle. Muscles are classified according to their structure and function.

Smooth muscle

Many hollow internal organs such as the stomach, intestines, and bladder are lined with **smooth muscle.** Smooth muscle is called **involuntary muscle** because it is not controlled consciously. For example, food moves through the digestive tract because of the action of smooth muscles that line the esophagus, stomach, and intestines. Smooth muscle does not appear striated, and each cell has one nucleus.

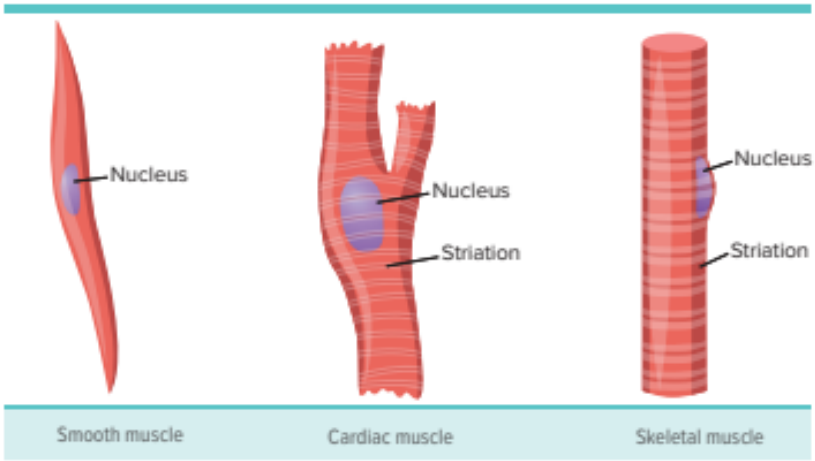


Figure 10 The three types of muscle cells are smooth muscle, cardiac muscle, and skeletal muscle.

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 can you last?

Plan and carry out an investigation to determine if the structures and functions of muscles work together on a task.

Virtual Investigation: Muscle Stimulation

Use a model to determine the effect of stimulation on muscles.

Cardiac muscle

The involuntary muscle present only in the heart is called **cardiac muscle.** Cardiac muscle cells are arranged in a network, or web, that allows the heart muscle to contract efficiently and rhythmically. This arrangement gives strength to the heart. Cardiac muscle is striped, or striated, with light and dark bands of cells with many nuclei. Cells usually have one nucleus and are connected by gap junctions.

Skeletal muscle

Most of the muscles in the body are skeletal muscles. **Skeletal muscles** are muscles attached to bones by tendons and when tightened, or contracted, cause movement. Skeletal muscles are **voluntary muscles** that are consciously controlled to move bones. **Tendons,** which are tough bands of connective tissue, connect muscles to bones. Under a microscope, skeletal muscles also appear striated.

Get It?
Describe how the three types of muscle cells support essential functions of life.

Skeletal Muscle Contraction

Most skeletal muscles are arranged in opposing, or antagonistic pairs. **Figure 11** illustrates muscles that you use to raise your arm and opposing muscles that you use to lower your arm. Skeletal muscle is arranged into fibers, which are fused muscle cells.Muscle fibers consist of many smaller units called **myofibrils.** Myofibrils consist of even smaller units, **myosin** and **actin,** which are protein filaments. Myofibrils are arranged in sections called sarcomeres. A **sarcomere** is the functional unit of a muscle and the part of the muscle that contracts as illustrated in **Figure 12** on the next page. The striations of skeletal muscles are a result of the sarcomeres, which run Z line to Z line. Z lines are where actin filaments attach within a myofibril. The overlap of actin and myosin filaments results in a dark band called the A band. The M line consists of only myosin filaments. The arrangement of the components of a sarcomere causes a muscle to shorten and then relax.

Sliding filament theory

The sliding filament theory is also illustrated in **Figure 12**. This theory states that once a nerve signal reaches a muscle, the actin filaments slide toward one another, causing the muscle to contract. Notice that the myosin filaments do not move. There are many skeletal muscles involved in a simple motion.

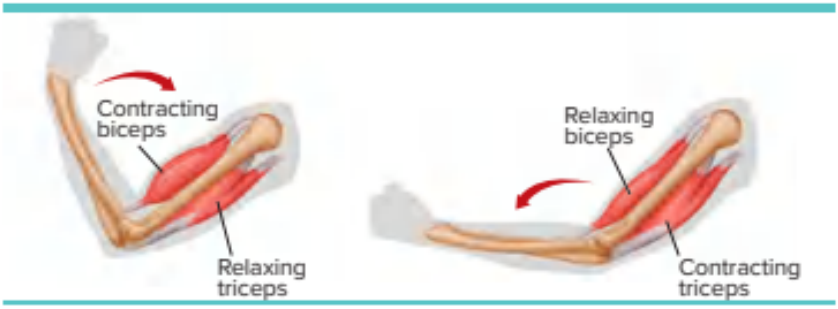
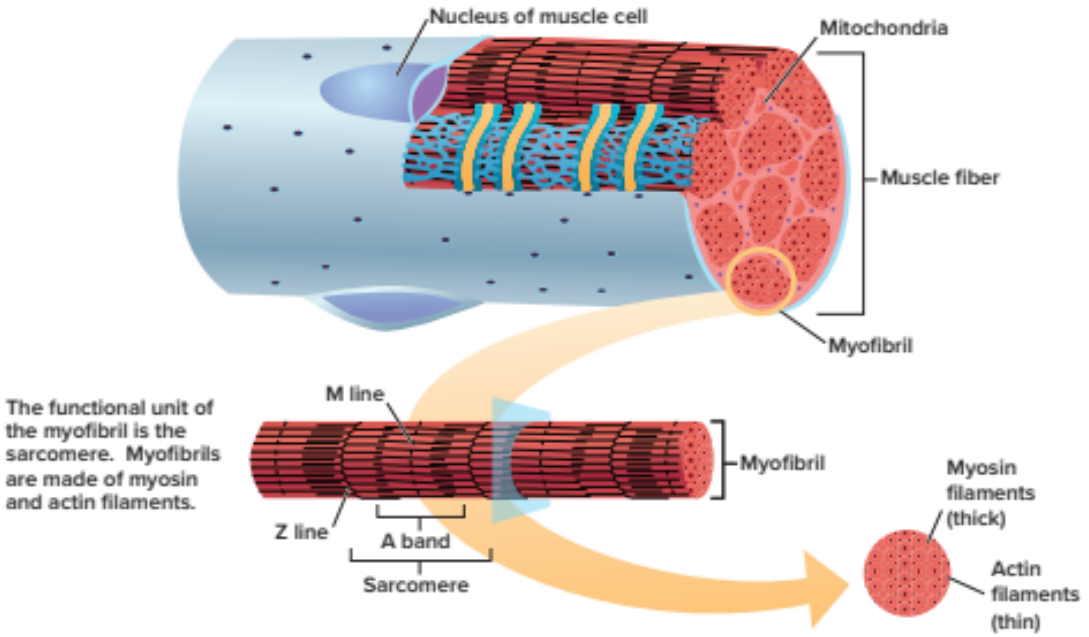


Figure 11 Skeletal muscles are arranged in antagonistic pairs.

Figure 12 Visualizing Muscle Contraction

A muscle fiber is made of myofibrils. The protein filaments actin and myosin form myofibrils.



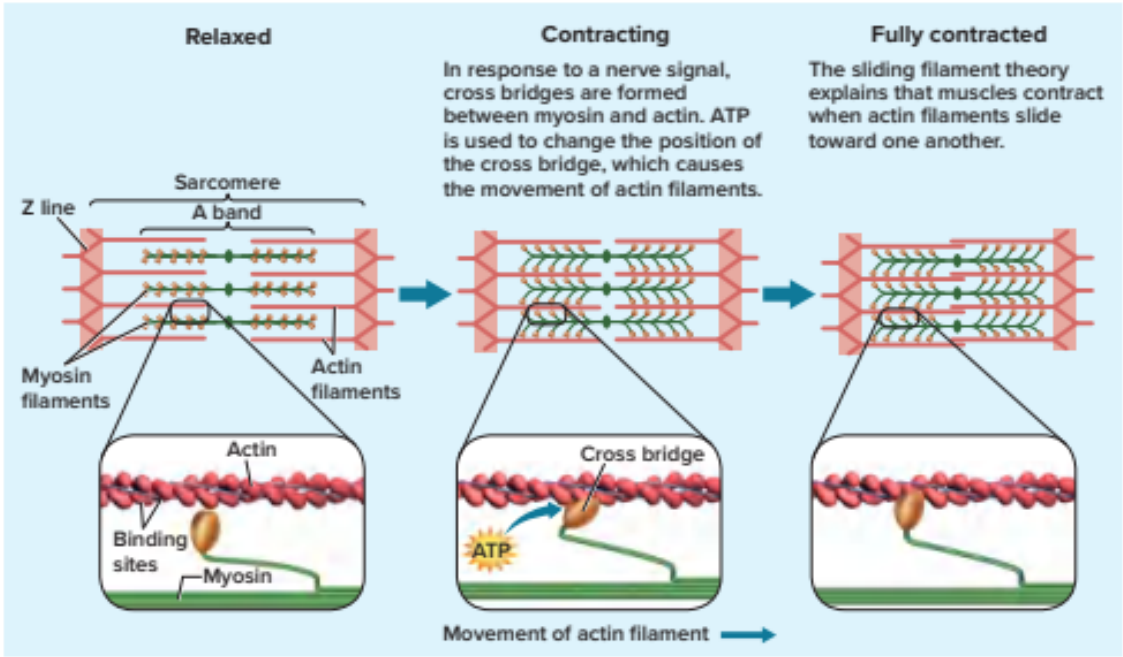


Figure 13 Crossing the finish line is a moment of intense energy.
Explain *why normal breathing is important after intense exercise.*

CHEMISTRY Connection When the nerve impulse reaches the muscle, calcium is released into the myofibrils causing the myosin and actin to attach to each other. The actin filaments are pulled toward the center of the sarcomere, resulting in muscle contraction. ATP is necessary for this step of muscle contraction. As the muscle relaxes, the filaments return into their original positions.

Energy for muscle contraction

All muscle cells metabolize aerobically and anaerobically. When sufficient oxygen is available, aerobic cellular respiration occurs in muscle cells. Recall that the cellular respiration process provides ATP for energy. After a period of intense exercise, muscles might not get enough oxygen to sustain cellular respiration, limiting the amount of ATP that is available. Muscles, like those of the athlete in **Figure 13**, then must rely on the anaerobic process of lactic acid fermentation for energy. During exercise, lactic acid builds up in muscle cells, causing fatigue. Excess lactic acid enters the bloodstream and this stimulates rapid breathing. After resting for a short time, adequate amounts of oxygen are restored and lactic acid is broken down.

You probably have seen a dead animal along the side of the road. When an animal dies, rigor mortis sets in. Rigor mortis is a state of prolonged muscular contraction. ATP is required to pump the calcium back out of the myofibrils, which causes the muscles to relax. In rigor mortis, the dead animal cannot produce ATP, so the calcium remains in the myofibrils and the muscle remains contracted. After 24 hours, cells and tissues begin degrading and the muscle fibers cannot remain contracted.

Get It?
Summarize how the integumentary, skeletal, and muscular systems work together to enable the runner in **Figure 13** to finish the race.

Skeletal Muscle Strength

Different people may have different types of athletic abilities. For example, many people do not develop the physiques of champion bodybuilders, no matter how often they work out in the weight room. In another case, a person might be the fastest sprinter on the track team, but she quickly becomes fatigued in a long-distance race. What might be the reason for these differences? The reason in both cases is the ratio of slow-twitch muscle fibers to fast-twitch muscle fibers. Both slow-twitch and fast-twitch fibers are present in every person's muscles, but the relative amounts of each may differ from person to person.

CCC CROSSCUTTING CONCEPTS
Structure and Function Create a poster to present a detailed examination of the properties and structure of skeletal muscles. Describe how understanding the structure of the muscles reveals their function.

STEM CAREER Connection
Massage Therapist
Athletes use massage therapy to help relax muscles and release lactic acid that builds up during training or competition. Massage therapists must have a thorough understanding of anatomy and physiology.

Slow-twitch muscles

Muscles vary in the speeds at which they contract. Slow-twitch muscles contract more slowly than fast-twitch muscle fibers. Slow-twitch muscle fibers have more endurance than fast-twitch muscle fibers. The body of the triathletes in **Figure 14** have many slow-twitch fibers. These kinds of muscle fibers function well in long-distance running or swimming because they resist fatigue more than fast-twitch muscle fibers. Slow-twitch muscle fibers have many mitochondria needed for cellular respiration. They also contain myoglobin, a respiratory molecule that stores oxygen and serves as an oxygen reserve. Myoglobin causes the muscles to have a dark appearance.

Fast-twitch muscles

Fast-twitch muscle fibers fatigue easily but provide great strength for rapid, short movements. Fast-twitch muscle fibers are adapted for strength. They function well in exercises requiring short bursts of energy such as sprinting or weightlifting, as illustrated in **Figure 14**. Fast-twitch fibers are lighter in color because they lack myoglobin. Because they have fewer mitochondria, they rely on anaerobic metabolism, which causes a buildup of lactic acid. This causes these muscles to fatigue easily.

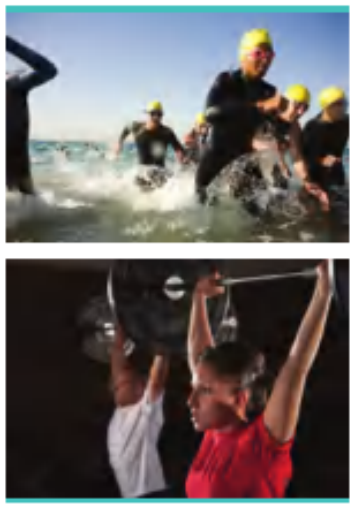


Figure 14 Triathletes have a high proportion of slow-twitch muscle fibers. Weight lifters have a high proportion of fast-twitch muscle fibers.

Check Your Progress

Summary

- There are three types of muscle tissue.
- Skeletal muscles are arranged in antagonistic pairs that work opposite to each other.
- Smooth muscles line many internal organs.
- Cardiac muscle is present only in the heart.
- All muscle cells metabolize both aerobically and anaerobically.

Demonstrate Understanding

1. **Construct** a chart that lists similarities and differences among the three types of muscles.
2. **Explain** why aerobic respiration occurs before lactic acid fermentation in most muscles.
3. **Compare** the role of mitochondria in slow-twitch and fast-twitch muscle fibers.

Explain Your Thinking

4. **Infer** Wild turkeys have a higher ratio of dark meat (muscle) to white meat than farm-raised turkeys. Why does this allow wild turkeys to fly longer distances than domesticated turkeys?
5. WRITING Connection **Write** an essay about how structure and function are related in the context of muscles.

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ENGINEERING & TECHNOLOGY

New Sunscreens on the Horizon

For thousands of years, people have been applying substances to their skin to protect themselves from the harmful effects of ultraviolet (UV) radiation in sunlight. Mass-produced modern sunscreens have been available since the mid-1900s, and the technology is constantly improving. Like many technological ideas, ideas for new sunscreen ingredients can emerge from inquiry into nature.

Many animals, including this American alligator, produce gadusol, which protects their skin from UV radiation.

Nature Inspires Sunscreen Technologies

Many animals are exposed to sunlight for hours each day without suffering UV damage or developing skin cancer. Researchers recently discovered that many fish, amphibians, reptiles, and birds produce a substance called gadusol that protects them from UV radiation.

Mammals do not produce gadusol. But researchers can use yeast to produce large quantities of it. The substance is being investigated as a potential sunscreen ingredient.

Humans produce melanin, a substance that protects our skin, eyes, and other tissues from UV radiation. Some researchers recently developed nanoparticles that mimic the behavior of the structures that produce and store melanin in cells. The nanoparticles were developed with the goal of helping people with conditions such as albinism but could one day find wider applications in sunscreens.

One problem with sunscreens is that they wear off or wash off and must be reapplied. Developed as a new type of dressing for wounds, DNA film sunscreen is a coating that can be applied to the skin. Researchers discovered that the strands of the DNA film separated, unraveled, and formed new bonds when exposed to UV radiation. The new structure absorbs and scatters UV radiation better than the original. Because its structure is integral to its UV-blocking function, the film would not work well as a sunscreen ingredient.

COMMUNICATE TECHNICAL INFORMATION

Conduct research to find out more about the DNA film sunscreen. Make a brochure to communicate to health professionals the benefits of the film as a wound dressing.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 THE INTEGUMENTARY SYSTEM

- The skin is the major organ of the integumentary system.
- Maintaining homeostasis is one function of the integumentary system.
- There are four types of tissue in the integumentary system.
- Hair, fingernails, and toenails develop from epithelial cells.
- Burns are classified according to the severity of the damage to skin tissues.

- epidermis
- keratin
- melanin
- dermis
- hair follicle
- sebaceous gland

Lesson 2 THE SKELETAL SYSTEM

- The human skeleton consists of two divisions.
- Most bones are composed of two different types of tissue.
- Bones are being remodeled constantly.
- Bones work in conjunction with muscles.
- The skeleton has several important functions.

- axial skeleton
- appendicular skeleton
- compact bone
- osteocyte
- spongy bone
- red bone marrow
- yellow bone marrow
- osteoblast
- ossification
- osteoclast
- ligament

Lesson 3 THE MUSCULAR SYSTEM

- There are three types of muscle tissue.
- Skeletal muscles are arranged in antagonistic pairs that work opposite to each other.
- Smooth muscles line many internal organs.
- Cardiac muscle is present only in the heart.
- All muscle cells metabolize both aerobically and anaerobically.

- smooth muscle
- involuntary muscle
- cardiac muscle
- skeletal muscle
- voluntary muscle
- tendon
- myofibril
- myosin
- actin
- sarcomere

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

How does the climber keep herself from falling off the cliff?

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 is the percentage of slow-twitch muscle related to action of a muscle?

The proportion of slow-twitch to fast-twitch muscle fibers can be determined by removing a small piece of a muscle and staining the cells with a dye called ATPase stain. Fast-twitch muscle fibers with a high amount of ATP activity stain dark brown.

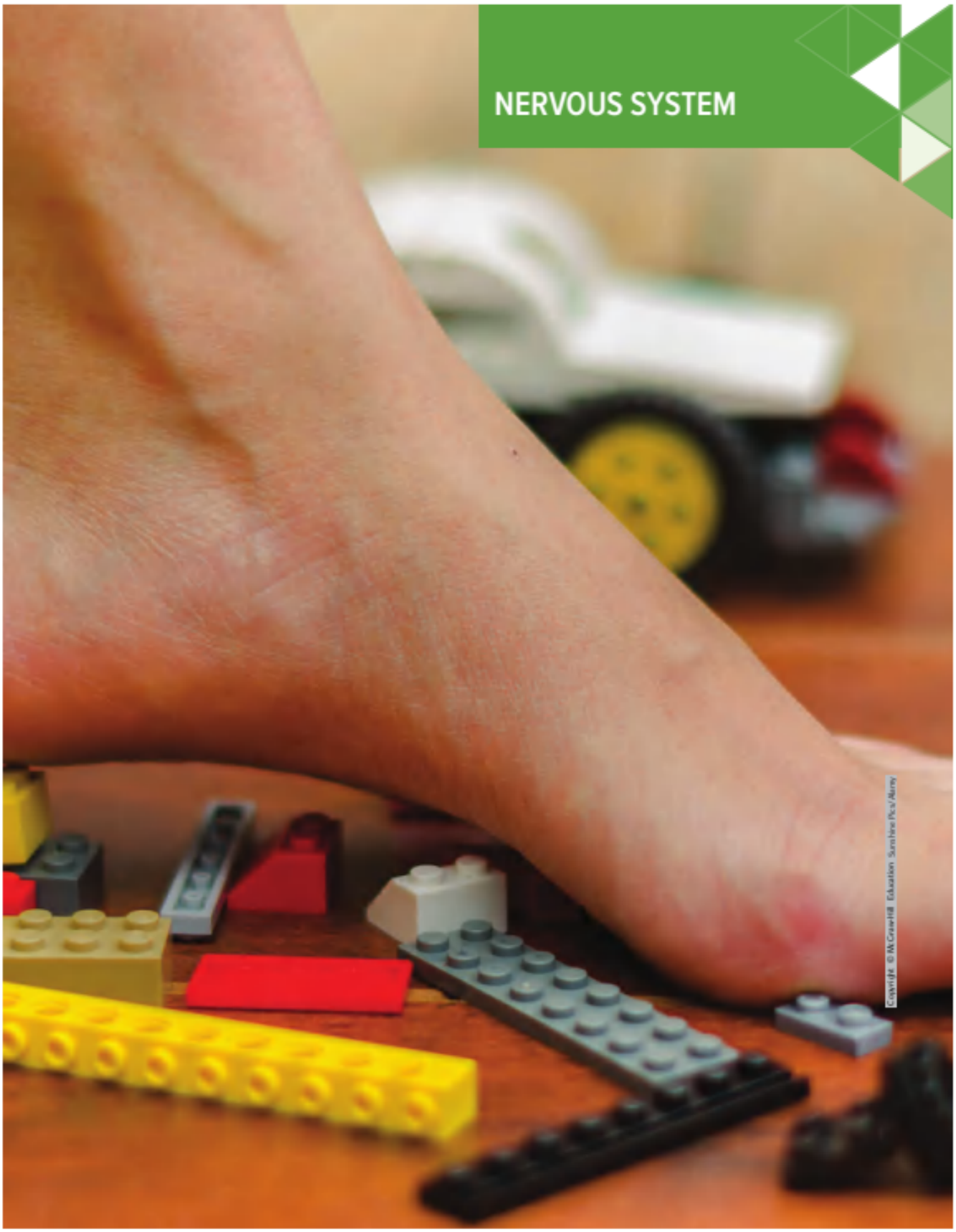
CER Analyze and Interpret Data

1. **Claim, Evidence, Reasoning** Explain why a muscle such as the soleus has more slow-twitch muscle fibers than a muscle such as the orbicularis oculi.
2. **Classify** muscles by giving examples of muscles that have a high proportion of fast-twitch muscle fibers.

Muscle	Action	Percent Slow Twitch
Soleus (leg)	Elevates the foot	87
Biceps femoris (leg)	Flexes the leg	67
Deltoid (Shoulder)	Lifts the arm	52
Sternocleidomastoideus (neck)	Moves the head	35
Orbicularis oculi (face)	Closes the eyelid	15

*Data adapted from: Lamb, D.R. 1984. *Physiology of Exercise* New York: Macmillan Co.

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.

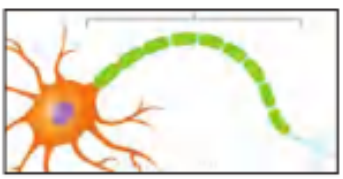
CER Claim, Evidence, Reasoning

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.

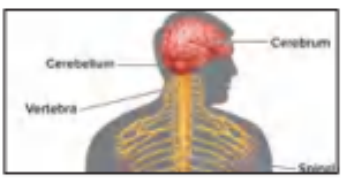
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

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.

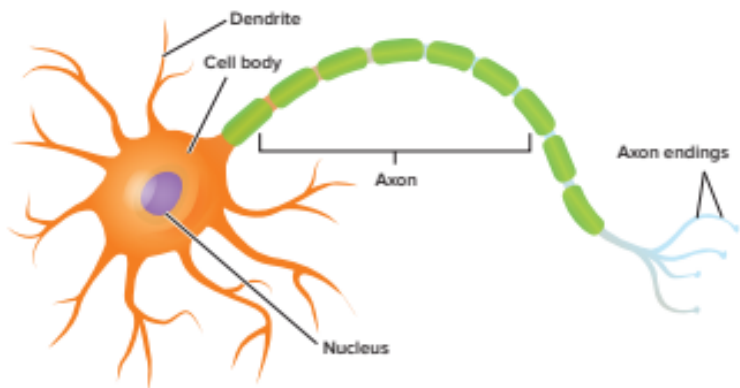


Figure 1 There are three main parts of a neuron: the dendrites, a cell body, and an axon. Neurons are highly specialized cells that are organized to form complex networks.

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.

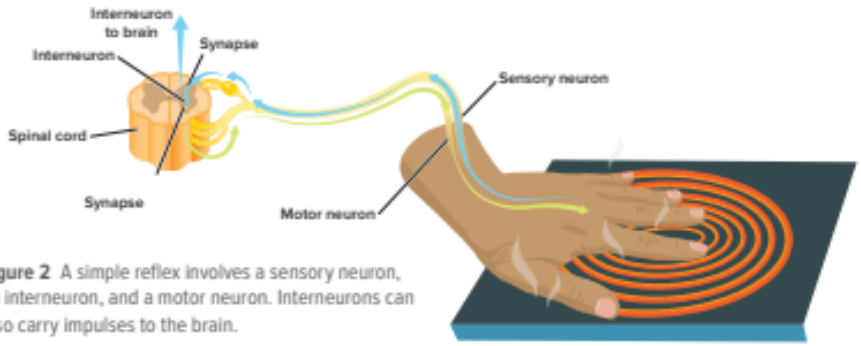


Figure 2 A simple reflex involves a sensory neuron, an interneuron, and a motor neuron. Interneurons can also carry impulses to the brain.

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.

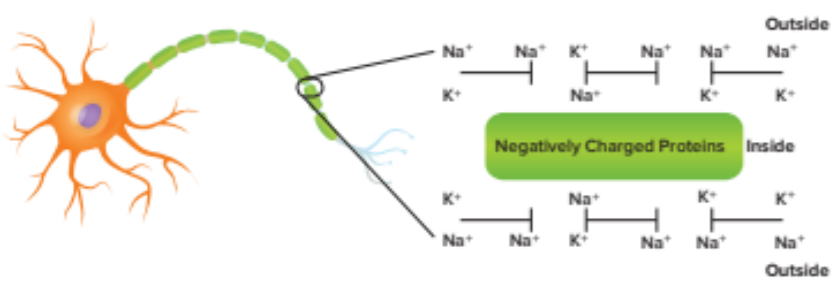


Figure 3 The distribution of Na^+ and K^+ ions, and the presence of negatively charged protein molecules in the cytoplasm, keep the inside of the cell more negatively charged than the outside when a neuron is at rest.

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.

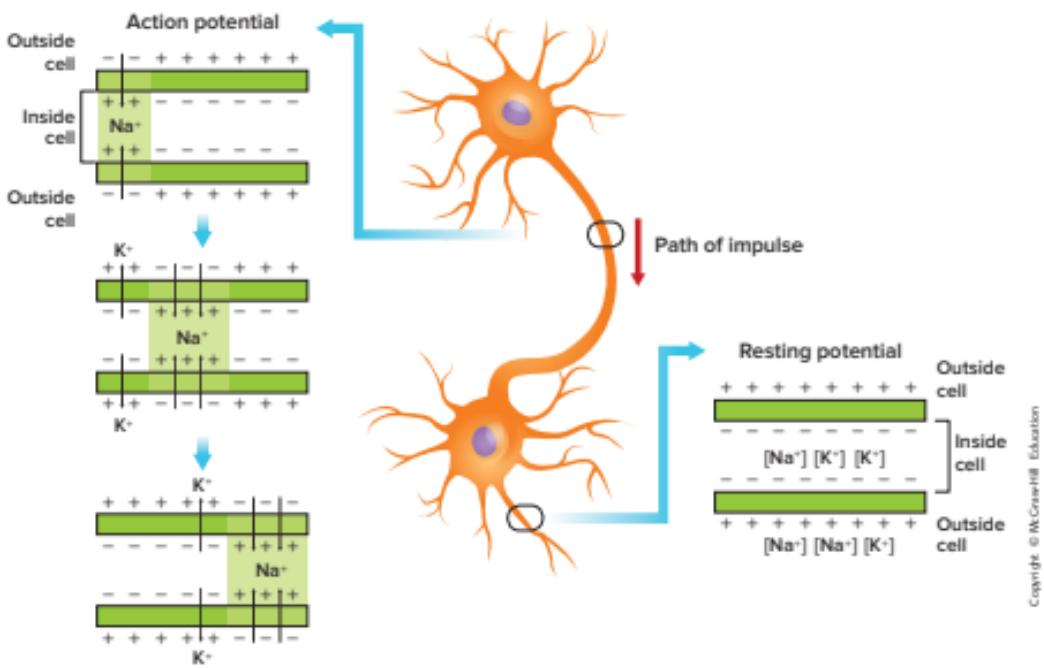


Figure 4 Follow as an action potential moves along an axon from left to right. Notice what happens to the Na^+ and K^+ and how this changes the relative electrical charges inside and outside the neuron.

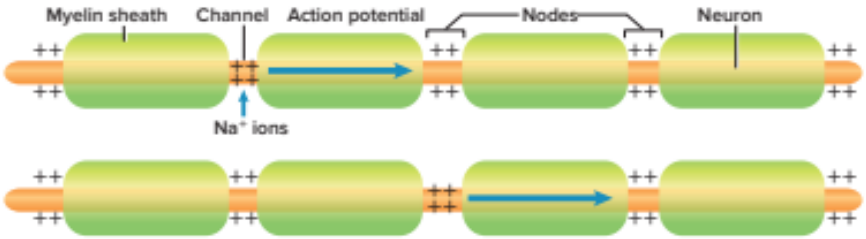


Figure 5 A nerve impulse moves from node to node along myelinated axons.
Explain *what happens at a node when an impulse moves along a myelinated axon.*

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

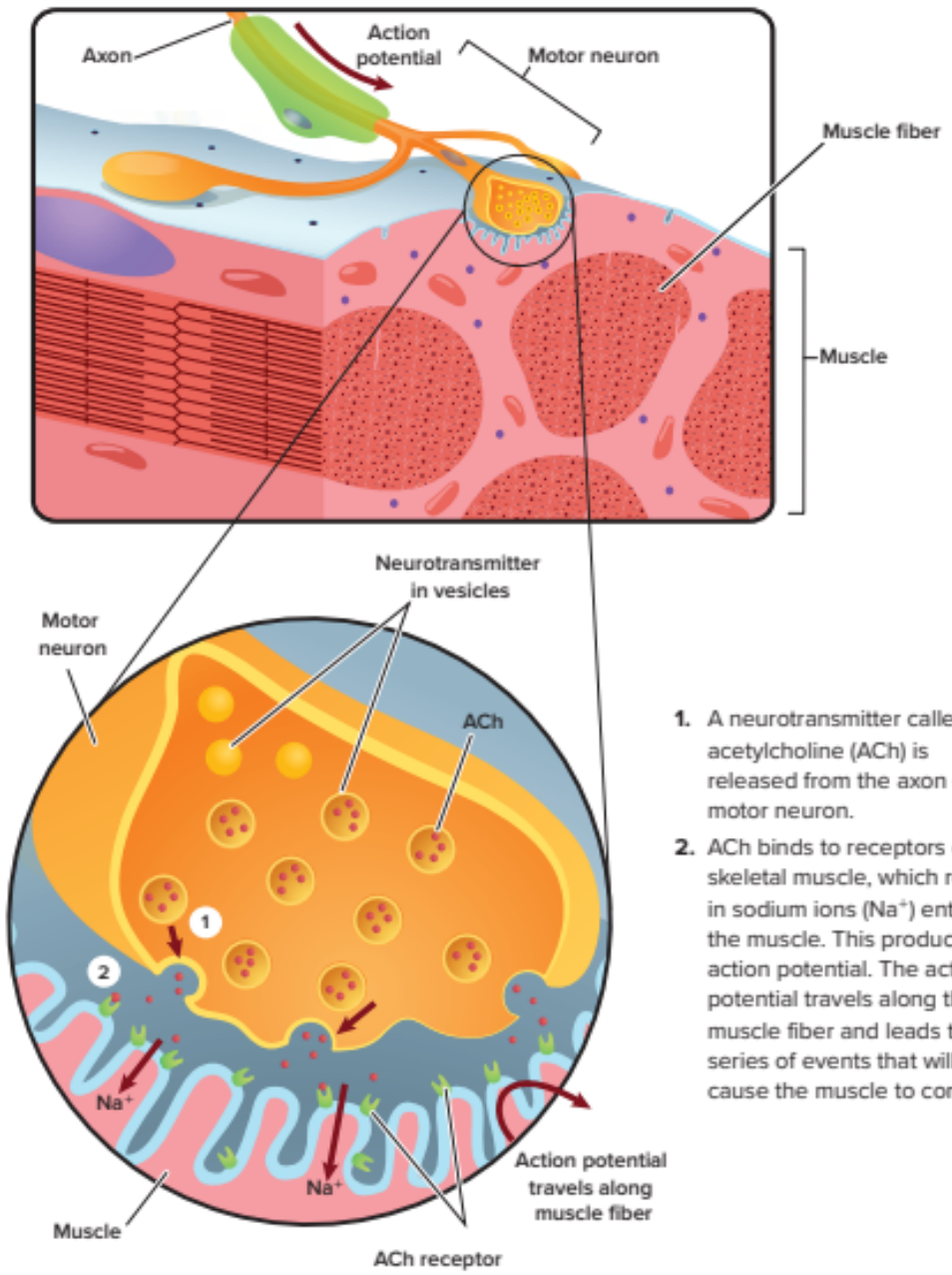
Large ships move through a harbor channel.

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.

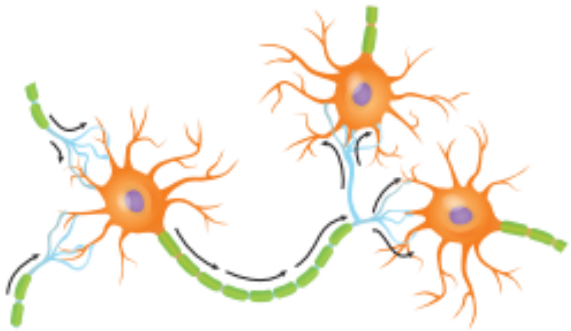


Figure 8 A single neuron can have multiple connections with other neurons.

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?

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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.

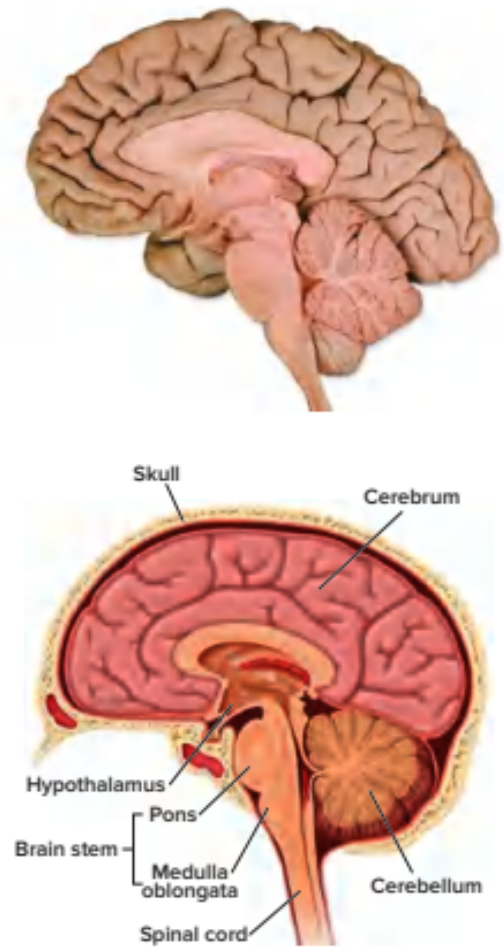

Figure 10 **Top:** A photograph of a human brain shows distinct sections. **Bottom:** The major sections of the brain are the cerebrum, the cerebellum, and the brain stem.

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.

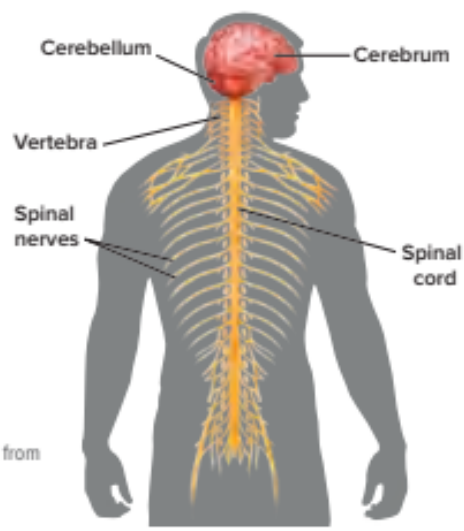

Figure 11 Thirty-one pairs of spinal nerves extend from the spinal cord.

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.

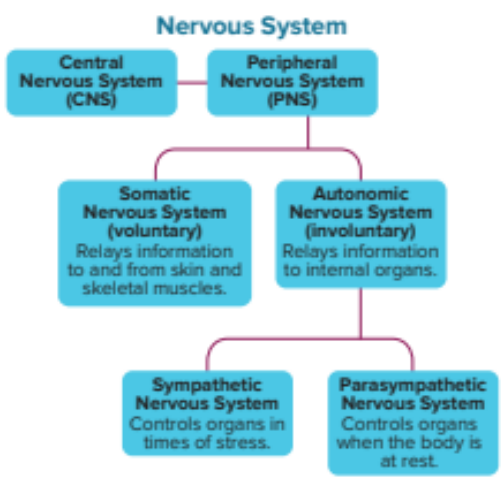

Figure 12 Each division of the nervous system functions in the control of the body and the communication within the body.

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.

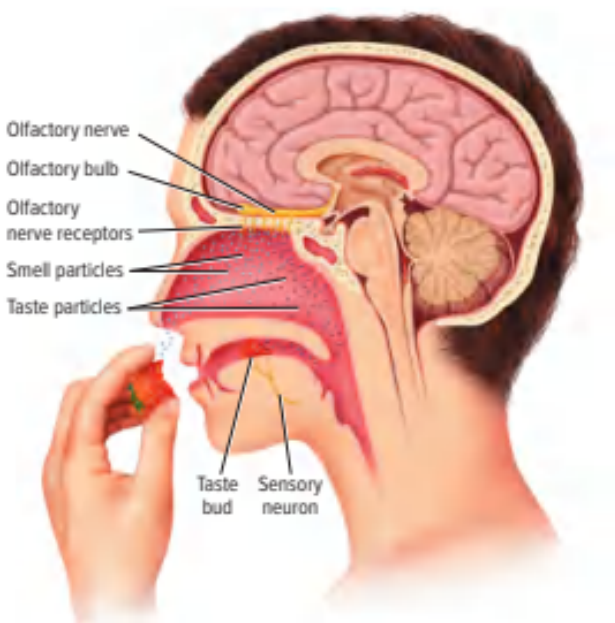

Figure 13 The receptors of taste and smell function together and are stimulated in similar ways. Food is often smelled as it is tasted.

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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: 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.

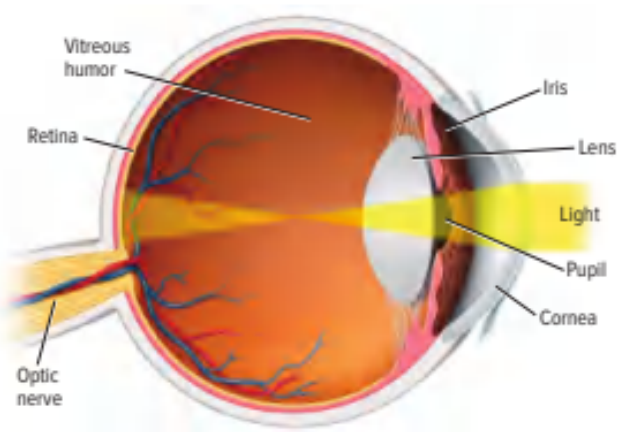

Figure 14 Light travels through the cornea and the pupil to the lens, which focuses the image on the retina. Rods and cones in the retina send information to the brain through the optic nerve.

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.

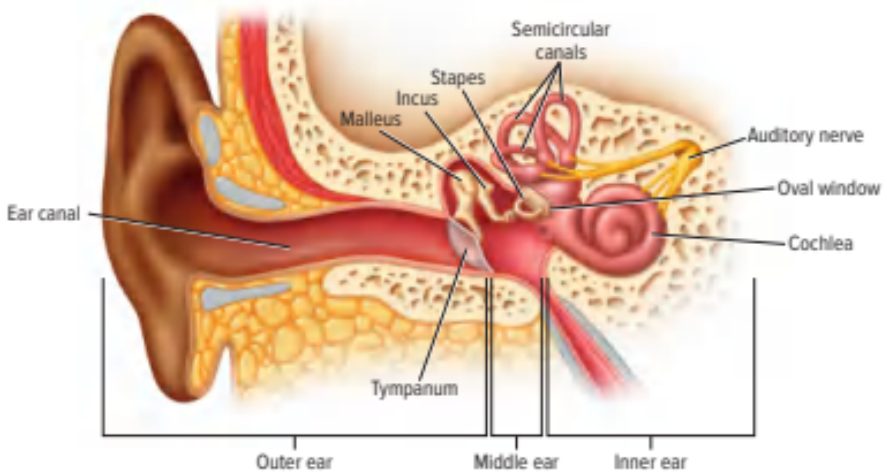

Figure 15 Sound waves cause the tympanum to vibrate, and the vibrations travel through the bones of the middle ear to the cochlea. Hair cells in the cochlea generate nerve impulses, which are sent to the brain through the auditory nerve.

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.

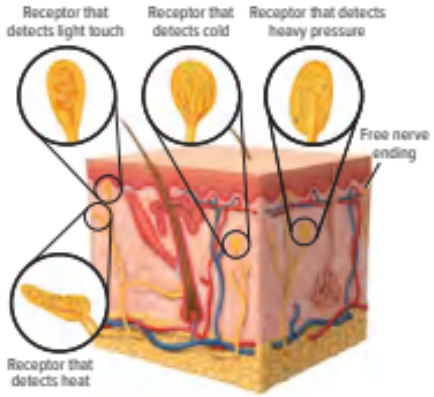

Figure 16 Many types of receptors are found in the skin. A person can tell if an object is hot or cold, sharp or smooth.

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

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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.

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.

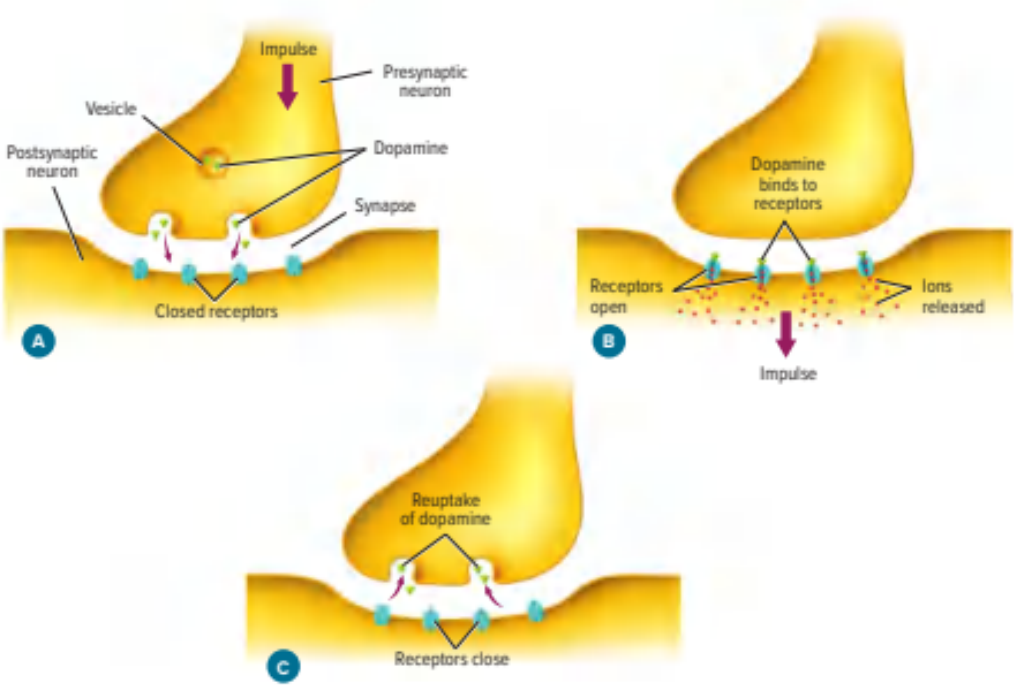

Figure 17 Dopamine crosses the gap from one neuron and binds to receiver sites, or receptors, on the membrane of another neuron. This occurs at a synapse.

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 families. 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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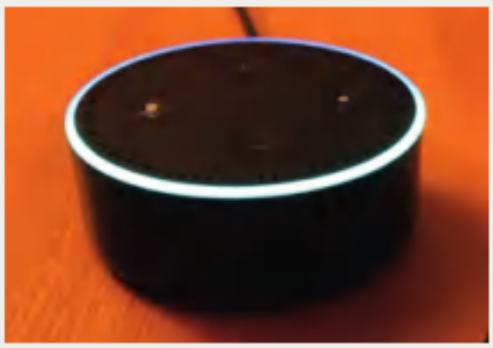
ENGINEERING & TECHNOLOGY

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

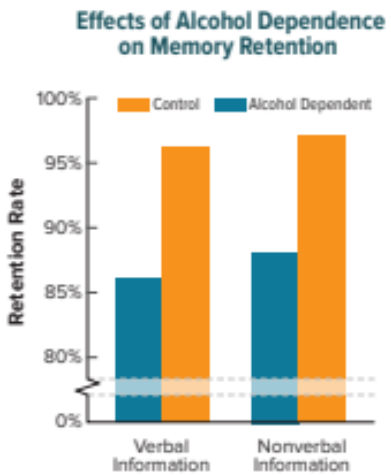
SEP Data Analysis Lab

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.



*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

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