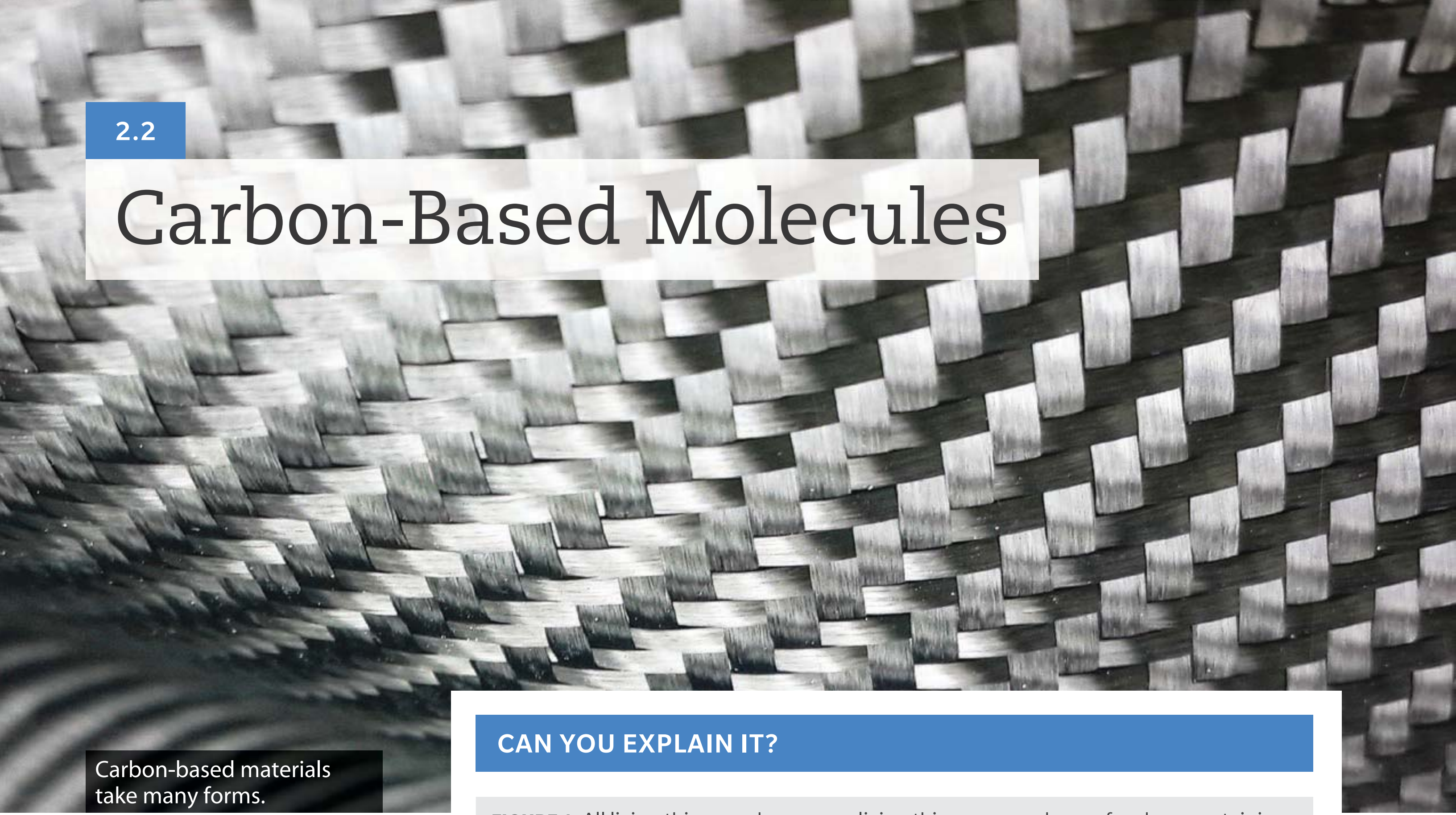


2.2

Carbon-Based Molecules

Carbon-based materials take many forms.

CAN YOU EXPLAIN IT?

FIGURE 1: All living things and many nonliving things are made up of carbon-containing compounds.

Gather Evidence As you explore the lesson, gather evidence for how the atoms in biomolecules are separated and rearranged to make new biomolecules.

The universe is made up of many different elements, but one of the most important elements in living things is carbon. It is often called the element of life because carbon atoms are the basis of biomolecules, molecules that make up living things. Carbon is also found in a number of nonliving things. Its properties allow it to form millions of different compounds with vastly different properties. Carbon atoms can arrange themselves into the molecules that make up your food and your clothes. Carbon-based materials are also used for many technical applications, such as electronic, optics, and even the rubber in tires.

Predict How can carbon be the central component of so many different types of molecules?

Properties of Carbon

Organic chemistry refers to the chemistry of carbon-based molecules, because living organisms are responsible for the production of nearly all naturally occurring carbon compounds. It was once believed that carbon-based compounds were only able to be produced in living things. Now, organic chemists know how to synthesize many different types of carbon-based compounds to make foods, materials, medicines, and much more.

Predict Why do you think carbon has an entire branch of chemistry devoted to its study?

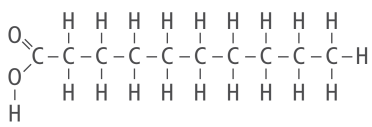
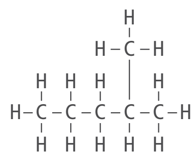
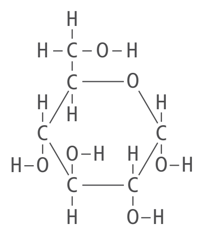
Despite the great number of carbon-based compounds that exist, those that compose all living things can be divided into four main groups: carbohydrates, lipids, proteins, and nucleic acids. Because of their relatively large size, these organic compounds are called macromolecules. Their structures and functions may differ in many ways, but they all share a common feature—they contain carbon.

Structure of Carbon-Based Molecules

Carbon atoms are the basis of most molecules that make up organisms and are involved in most processes that support life. The atomic structure of carbon gives it unique bonding properties. These properties allow it to form covalent bonds, or bonds that share pairs of electrons. Carbon has four available electrons to share with atoms of other elements to form covalent bonds. In organic molecules, carbon is most commonly bonded to the elements hydrogen, oxygen, nitrogen, and phosphorus.

Collaborate With a partner, compare the shapes of the molecules in Figure 2. What is similar? What differs?

FIGURE 2: Carbon-based molecules can have many different structures, including straight chains, branched chains, and rings.

Straight Chain	Branched Chain	Ring
		
CAPRIC ACID	**ISOHEXANE**	**GLUCOSE**
A fatty acid found in plant oils such as coconut oil and palm kernel oil, as well as in the milk of some mammals. This fatty acid has been shown to have antibacterial and anti-inflammatory properties.	A clear liquid used to make gasoline and glues, and as a solvent for extracting oils.	A simple sugar that is an important energy source for living organisms.

Analyze According to Figure 2, how many chemical bonds does carbon form? How is the number of bonds carbon can make related to its ability to form molecules with many different shapes?

In addition to forming single bonds, carbon atoms can also form double, or even triple, bonds. In structural formulas, double bonds are represented with two bars, and triple bonds are represented with three bars. As you can see in Figure 3, the carbon atom in carbon dioxide forms a double bond with each oxygen atom. In acetylene, each carbon forms one triple and one single bond. Both are carbon-based gases, but they have different chemical properties. For example, they have different densities, and carbon dioxide is odorless, while acetylene has a slight odor similar to garlic.

FIGURE 3: Carbon can form single, double, or triple bonds.

Carbon Dioxide (CO_2)	Acetylene (C_2H_2)
O=C=O	H–C≡C–H
A colorless, odorless gas that is naturally present in air (about 0.03 percent) and is used by plants in photosynthesis.	A colorless gas that burns with a bright flame and is used in welding. In its pure form, it has a sweet, garlic-like odor.

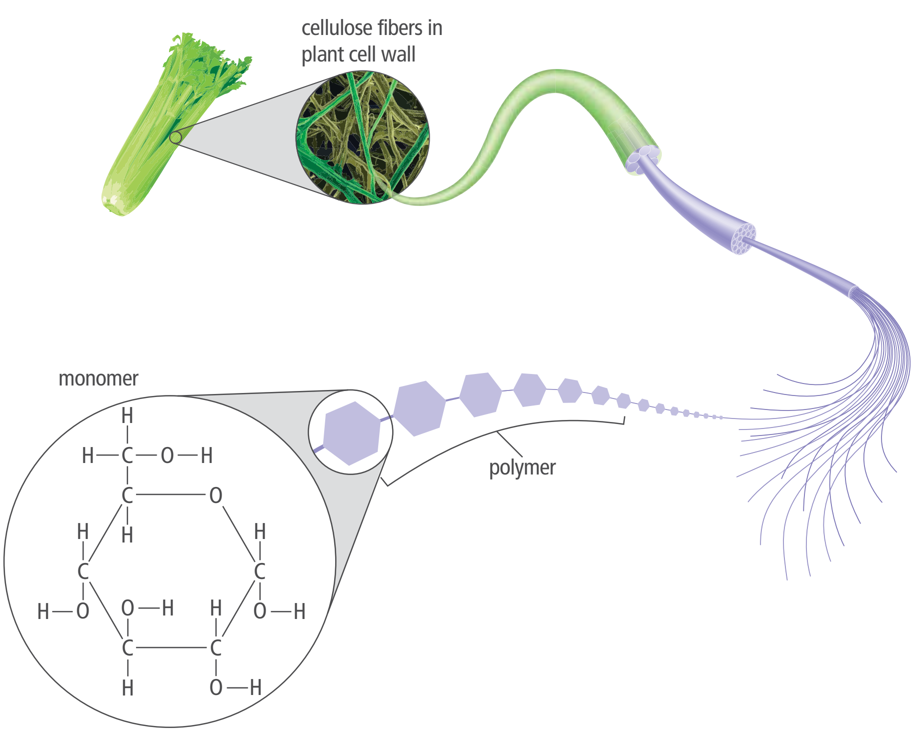
Predict Which do you think is the strongest type of covalent bond? A single, double, or triple bond? Explain your answer.

Monomers and Polymers

Looking back at Figure 2, you may note three characteristics of carbon atoms. One is that carbon can bond with itself or other atoms. The second is that the unique bonding in carbon molecules enables them to form a ring or a long-chain structure of repeating subunits. A polymer is a large molecule made of subunits called monomers. The monomers in a polymer may be the same, as they are in the cellulose molecule in Figure 4, or they may be different, as they are in proteins. The third characteristic of carbon atoms is they often bind to hydrogen atoms. In fact, many carbon compounds contain only carbon and hydrogen and are a class of compounds called hydrocarbons. The covalent bonds in hydrocarbons store a great amount of energy.

Language Arts Connection One polymer you may have heard of before is silk. Silk fibers, made by spiders and some worms, are very strong and durable. Now, researchers are trying to produce even stronger silk by feeding silkworms carbon-based materials such as carbon nanotubes. Scientists are hoping to use the enhanced silk for medical implants and wearable electronics. With a partner, research carbon-enhanced silk and discuss the ways this material might influence human society.

FIGURE 4: Cellulose is a polymer made of smaller subunits called glucose monomers.



Engineering

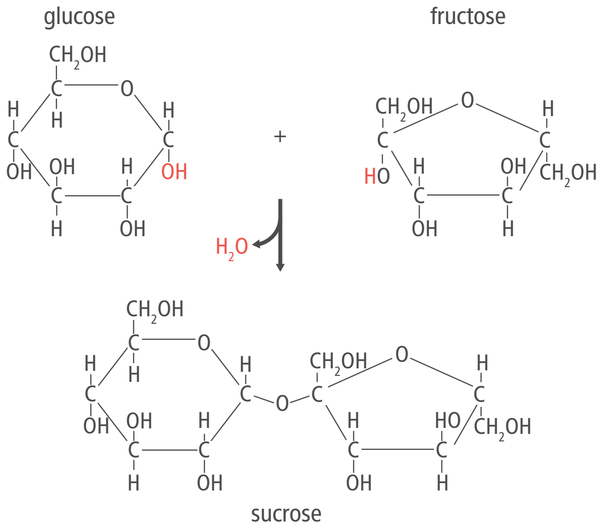
Making Polymers

Polymers may form through the process of dehydration synthesis. This process involves chemical reactions in which a molecule of water (H_2O) is released as one monomer bonds to another. One monomer provides a hydrogen ion (H^+) and the other provides a hydroxyl group (OH^-). Some polymers can be broken down in a reverse reaction, called hydrolysis. The bonds between the monomers are broken by the addition of water molecules.

In the human body, enzymes called hydrolases use hydrolysis to break apart polymers. In industry, dehydration synthesis can be used to make a wide variety of polymers, such as those in nylon and polyester fabrics.

Explain What might be some of the economic and environmental tradeoffs of producing clothes from human-made polymers, such as nylon and polyester, versus natural polymers, such as cotton?

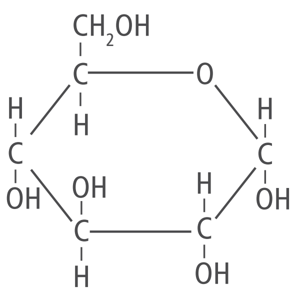
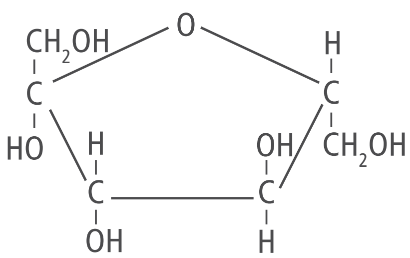
FIGURE 5: Glucose and fructose undergo dehydration to form sucrose, commonly known as table sugar.



Isomers

The molecular structures you've seen so far look flat, but molecules are actually three-dimensional (3D). The 3D placement of atoms and chemical bonds within organic molecules is central to understanding their chemistry. Molecules that share the same chemical formula but differ in the placement, or structure, of their atoms and/or chemical bonds are known as isomers. Because the atoms are connected in different ways, isomers have different physical and chemical properties. For example, glucose and fructose are energy sources for cell processes. However, fructose is not as easily metabolized as glucose. Isomers allow for greater variety of organic compounds with different properties.

FIGURE 6: The isomers glucose and fructose both have the chemical formula $C_6H_{12}O_6$.

Glucose	Fructose
	

Explain Compare and contrast the different types of carbon structures in terms of their structures, chemical formulas, and functions.

Structure and Function of Carbon-Based Molecules

The carbon-based macromolecules found in all organisms may be classified in four basic types: carbohydrates, lipids, proteins, and nucleic acids. These molecules, often called biomolecules, have different structures and functions, but all are formed around carbon chains and rings. Some organisms, like most green plants, make high-energy biomolecules through a process called photosynthesis. Other organisms obtain carbon-based molecules by eating food. All living things break down organic molecules and rearrange them to form new molecules necessary for life.

Carbohydrate Structure and Function

Analyze Which of the carbohydrates shown in Figure 7 are monomers, and which are polymers? Explain your answer.

Carbohydrates are composed of carbon, hydrogen, and oxygen. The most basic carbohydrates are simple sugars, or monosaccharides. Many simple sugars have either five or six carbon atoms. Glucose, one of the sugars made by plant cells during photosynthesis, is a six-carbon sugar. Simple sugars bind together to make larger carbohydrates called polysaccharides. A polysaccharide with two sugars joined together, such as sucrose, is called a disaccharide.

FIGURE 7: Glucose, sucrose, and cellulose are all carbohydrates.

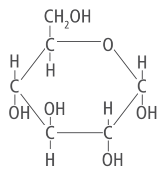
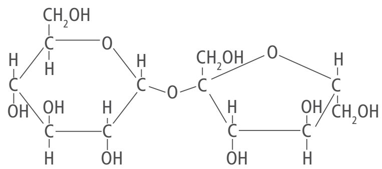
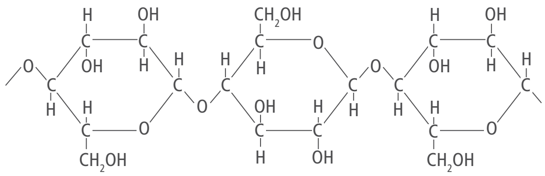
Monosaccharide	Disaccharide	Polysaccharide
		
GLUCOSE	**SUCROSE**	**CELLULOSE**
A simple sugar that is an important energy source in living organisms.	A simple sugar made of a glucose monomer bonded to a fructose monomer. Known as table sugar.	A complex carbohydrate with a straight, rigid structure that makes up the cell wall—a tough, outer layer of plant cells.

FIGURE 8: Carbohydrate-rich Foods

The energy contained in carbohydrate molecules can be released and used for essential cell processes. Carbohydrate-rich foods such as bread, pasta, vegetables, fruit, and sweeteners contain carbohydrate molecules that your body breaks down to release usable energy. Simple carbohydrates like glucose and sucrose can be quickly broken down and absorbed by your body. Complex carbohydrates are made up of longer chains of molecules and are broken down more slowly. Sources of complex carbohydrates include whole grains, potatoes, and vegetables. Complex carbohydrates are often rich in cellulose, or fiber, which is not broken down in your digestive system.

Predict Why does it take longer for your body to break down complex carbohydrates than simple carbohydrates? How is this related to their molecular structures?

Lipid Structure and Function

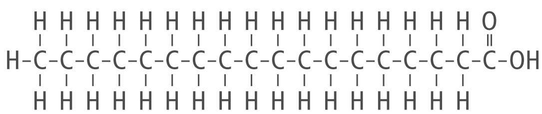
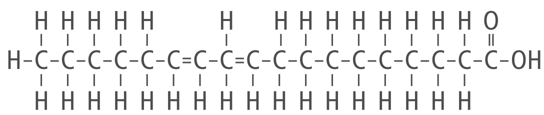
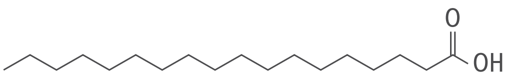
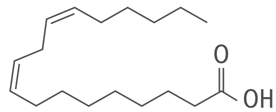
Lipids are similar to carbohydrates in that they contain many of the same elements. Unlike carbohydrates, lipids are nonpolar molecules. Thus, most lipids are insoluble in water because water molecules are polar. This is the origin of the phrase, “oil and water don’t mix, “ because lipids include many natural fats, oils, and waxes. Lipids also include phospholipids and steroids. Some lipids, such as fats and oils, are broken down as a source of usable energy for cells. Phospholipids are important for cell membrane structure. Waxes form protective coatings, and steroids act as chemical messengers.

The simplest lipids are fatty acids. More complex lipids often contain several fatty acids linked together. Fatty acids consist of long chain hydrocarbons containing two oxygen atoms at one end. Fatty acids are distinguished from one another by chain length and by the number of hydrogen atoms connected to each carbon atom. As shown in Figure 9, fatty acids are modeled in two different ways. The line drawings represent the same molecules as those above them, but the individual elements are not labeled. Each kink in the chain represents a carbon atom, including the ends.

FIGURE 9: Otters have a gland that secretes oil onto their fur.

Explain How does secreting oil onto their fur help otters maintain homeostasis?

FIGURE 10: Fatty acids can be saturated or unsaturated.

Saturated Fatty Acid	Unsaturated Fatty Acid
	
	
Saturated fatty acids are found mostly in foods from animals and some plants. They are usually solid at room temperature. There are no double bonds between the carbon atoms, so this molecule is “saturated” with hydrogen atoms. The saturated fatty acid shown here is stearic acid.	Unsaturated fatty acids are found mostly in oils from plants and are usually liquid at room temperature. There are double bonds between some carbon atoms, so this molecule is not saturated with hydrogen atoms, and it has a bent shape. The unsaturated fatty acid shown here is linoleic acid.

Collaborate With a partner, make a chart to compare and contrast these two sets of molecules: carbohydrates and lipids, and saturated and unsaturated fatty acids. Compare and contrast the elements that make them up, the arrangement of their atoms, and the types of bonds that hold the atoms together.

Fats and Oils

We often think of fats as something to avoid in our diets. However, fats and lipids serve many important roles in maintaining overall health. Fats contain 2.25 times as much energy per gram as carbohydrates, so fats are a major source of energy. They also play an important role in the absorption of some vitamins and minerals. Fats are needed to build and repair cell membranes and are an essential part of the myelin sheath that surrounds and protects nerves. Fats are also required for processes such as muscle movement, blood clotting, and inflammation.

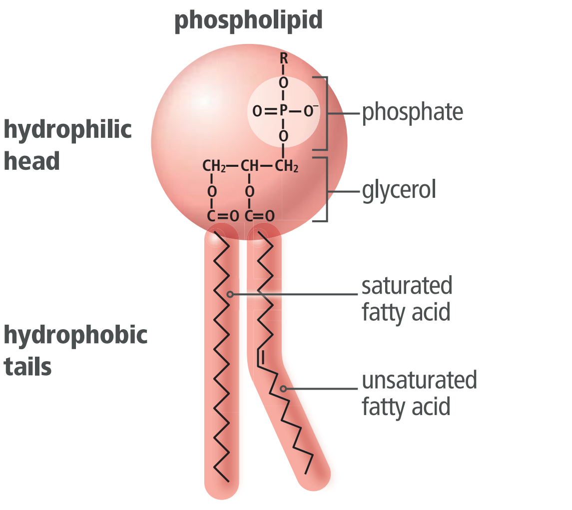
FIGURE 11: Foods Containing Fats and Oils

Image Credits: (t) ©neelsky/Shutterstock; (b) ©Lucas Sevilla Garcia/Shutterstock

Phospholipids

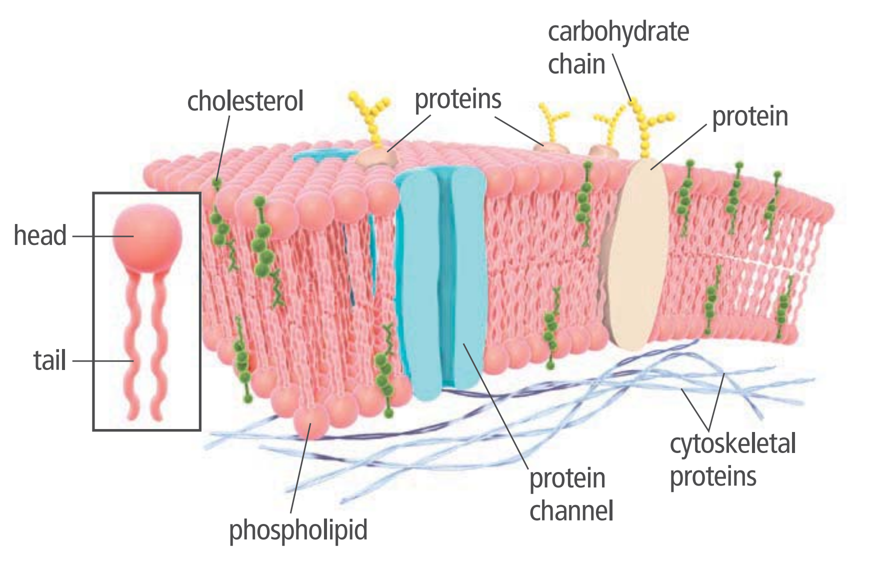
A phospholipid is a lipid that consists of glycerol, two fatty acids, and a phosphate group. The "head" of the phospholipid is made up of the glycerol backbone and the phosphate group. The fatty acids make up the "tails." The polar head of a phospholipid is soluble in water, or hydrophilic, which means "water loving." The nonpolar tails are insoluble in water, or hydrophobic, which means "water fearing." When phospholipids are placed in a watery environment, they arrange themselves in two layers. The hydrophilic phosphate heads face outside, and the hydrophobic tails face the inside, away from the water.

FIGURE 12: A phospholipid is made up of a hydrophilic head and hydrophobic tails. The head contains glycerol and a phosphate group. The fatty acids in the tails may be saturated or unsaturated.



Cell membranes are made up of a double layer of phospholipids. The polar heads face the outside of the membrane, and the nonpolar tails face the inside of the membrane. Since some of the molecules that need to pass through the membrane are polar, the nonpolar tails of the phospholipids would normally repel them. Proteins in the membrane create "passageways" that allow both polar and nonpolar molecules to pass from one side to the other.

FIGURE 13: Phospholipids are responsible for the dynamic nature of the cell membrane. The membrane also contains carbohydrates, cholesterol, and proteins.



Predict The hydrophobic tails of phospholipids keep water from passing directly through the cell membrane. How might this be beneficial for the maintenance of homeostasis in a cell?

Waxes

Waxes are distinguished from other lipids by very long carbon chains that are very hydrophobic. They resist water and are solid at a range of temperatures. Waxes form protective coatings for many living things, including plants, animals, fungi, and bacteria. Their properties also make waxes valuable commodities. Many products contain waxes, including makeup and foods.

Worker honey bees make wax out of carbohydrate molecules in honey. Bees consume the honey, and special glands in their abdomens convert the sugars in the honey into wax molecules. The wax then oozes out of the bee through small pores and forms flakes on the outside of the bee's body. Worker bees then chew the wax to make it soft and pliable, and finally incorporate it into the beehive structure. These bees are breaking down carbon-based molecules to make different molecules.

FIGURE 14: Waxes form protective coatings on leaves.

Analyze Waxes are a main component of the cuticle found on the upper surface of some plant leaves. Why might the leaves of these plants have a waxy cuticle?

Steroids

So far, the lipids you have examined have a mostly linear structure. Steroids, however, are a class of lipid that has a fused ring structure. All steroids have four linked carbon rings, and several of them have a short tail. Steroids contain both hydrophobic and hydrophilic regions, and they are insoluble in water.

Cholesterol is an example of a lipid with a fused ring structure. Your body needs a certain amount of cholesterol to function properly. Not all of the cholesterol in your body comes from your diet; your cells can make cholesterol from fatty acids. The ability to make cholesterol is important because it is an important part of cell membranes. Cholesterol is also the starting compound for steroid hormone production. Cholesterol-based steroids have many functions. Some regulate your body's response to stress. Others, such as testosterone and estrogen, control sexual development and the reproductive system.

FIGURE 15: A nutrition label shows how many milligrams of cholesterol are present in your food. Nutrition labels also show how many grams of carbohydrates, fats, and proteins are present.

Explain Excess cholesterol has been linked to heart disease, so the labels on some food products contain wording such as "cholesterol-free." Is it necessary to eat a completely cholesterol-free diet? Explain your answer.

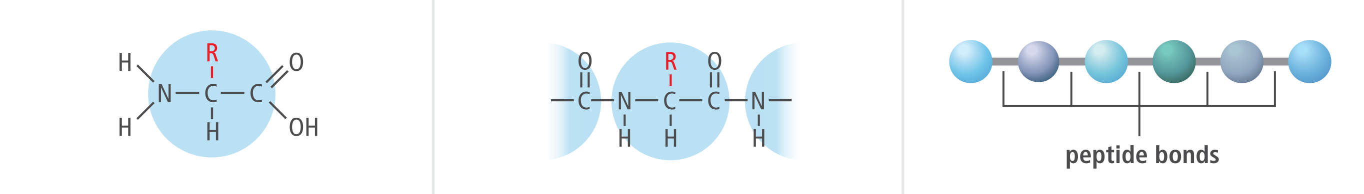
Image Credits: (t) ©Oleg Shpak/Alamy Images; (b) ©Spauln/E+/Getty Images

Protein Structure and Function

Analyze How do the terms polymer and monomer apply to the structure of protein molecules?

Proteins are often described as the building blocks of life. They play many essential roles in organisms. Many proteins function as enzymes, which help regulate chemical reactions within our bodies. The building blocks for proteins are amino acids. There are a number of different amino acids, but organisms use only 20 to build proteins. Our bodies can make 12 of these standard amino acids. The others come from foods you eat, such as meats, beans, and nuts.

FIGURE 16: Proteins are made up of amino acids linked together in a chain called a polypeptide.



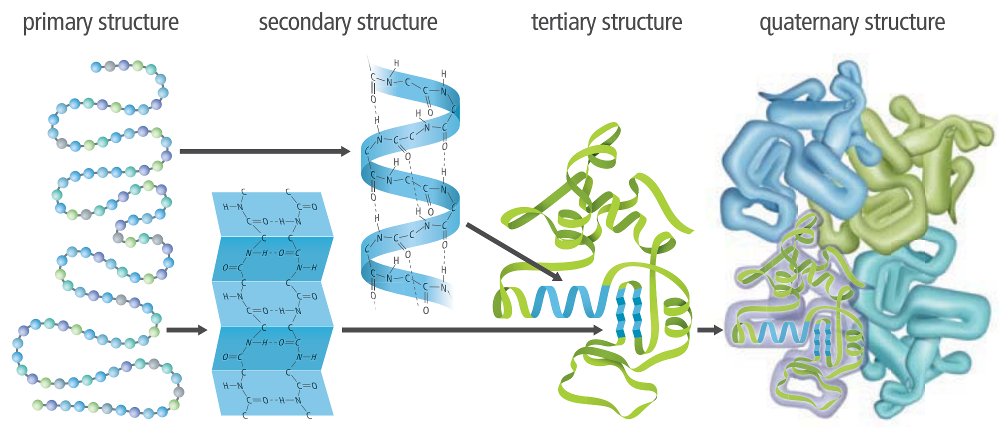
Amino acids have a carbon atom bonded to a hydrogen atom, an amino group (NH_2), and a carboxyl group (COOH). Different amino acids have different side groups (R).

Peptide bonds form between the amino group of one amino acid and the carboxyl group of another amino acid.

A polypeptide is a chain of precisely ordered amino acids linked by peptide bonds. A protein is made of one or more polypeptides.

Proteins differ in the number and order of amino acids. The specific sequence of amino acids determines a protein's structure and function. Proteins may have three, and sometimes four, levels of structure: primary, secondary, tertiary, and quaternary.

FIGURE 17: There are four possible levels of protein structure.



Predict Which would probably have the greatest effect on a protein's function—a change to the primary, secondary, or tertiary structure? Explain your answer.

The primary structure of a protein is the sequence of amino acids in the polypeptide. Hydrogen bonds between amino acids cause the chain to fold into zig-zag-shaped sheets and spirals, which make up the secondary structure. The tertiary structure is the 3D shape of the protein. Many proteins contain multiple polypeptide chains, or subunits, which combine to form the quaternary structure.

Remember that enzymes and other proteins are particularly sensitive to environmental changes. If pH or temperature exceed the normal ranges for a cell, the shape of its proteins may change, and their function may be disrupted. This process, called denaturation, only disrupts secondary, tertiary, and quaternary structures—the sequence of the protein remains unaffected.

Nucleic Acid Structure and Function

The unique sequence of amino acids in a protein is determined by the sequence of monomers in another biological polymer: nucleic acid. Nucleic acid polymers are made up of monomers called nucleotides. A nucleotide is composed of a sugar, a phosphate group, and a nitrogen-containing molecule, called a base. The sugar and phosphate nucleotides form the backbone of the DNA double helix. The nitrogenous bases form matching pairs held together by hydrogen bonds.

There are two general types of nucleic acids: DNA and RNA. Figure 19 shows the structure of each of these nucleotides and their nitrogenous bases. The names of the nitrogenous base also refer to the nucleotides that contain the bases.

FIGURE 19: DNA and RNA are both nucleic acids.

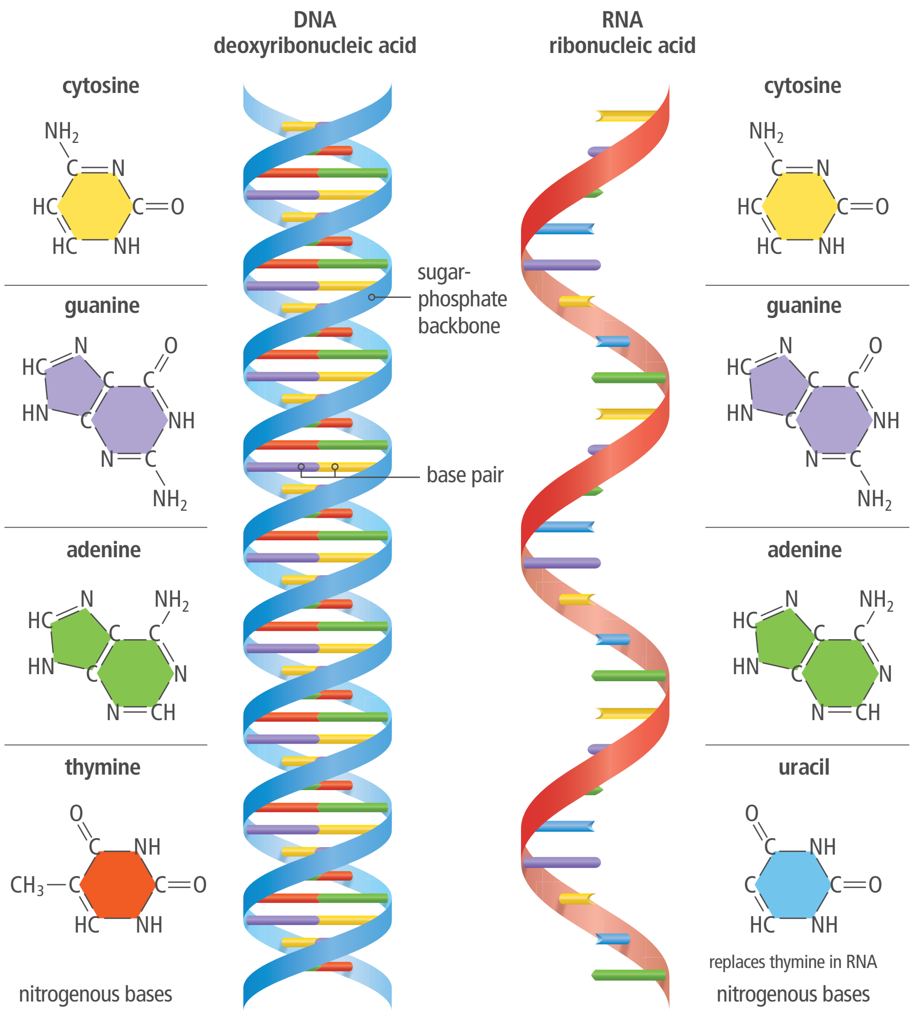
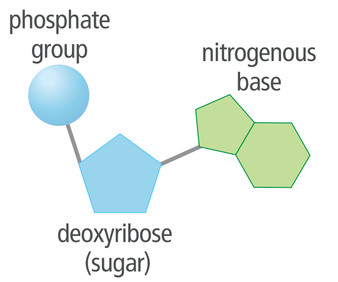


FIGURE 18: Nucleotide Model



Collaborate With a partner, compare and contrast RNA and DNA in terms of structure and nitrogenous bases.

Explore Online

Hands-On Lab

Modeling Biochemical Compounds Model a variety of biomolecules to better understand how atoms are arranged in these large molecules.

Explain Use evidence you have gathered to support or refute the claim that living things break down and rearrange carbon-based molecules. To organize your thoughts, make a graphic organizer to compare and contrast the four main types of biomolecules in these aspects: elemental makeup, overall structure, and main functions.

Chemical Energy

FIGURE 20: When an elk eats plants, energy in the plant molecules is released through a series of chemical reactions.

Model Draw a simple flow chart to show how energy is transferred from the sun to the elk's cells.

Your cells need energy to perform essential cell processes. This energy comes from food, but not directly. First, the food must be digested. Digestion breaks food into individual molecules, and some of these molecules store energy in their bonds. This chemical energy is only usable after biomolecules are broken down by a series of chemical reactions known as cellular respiration.

Chemical Energy and ATP

Cellular respiration transfers energy from organic molecules such as glucose to a molecule called ATP, or adenosine triphosphate. ATP is known as the energy currency of the cell. It provides the energy necessary for cell processes such as pumping molecules across the cell membrane and driving chemical reactions. ATP also provides energy for mechanical processes, such as the contraction of muscle cells.

Cellular respiration is complementary to another process called photosynthesis. In this process, organisms such as plants and algae absorb energy from sunlight and use it to help make high-energy sugars. When an animal such as an elk eats a plant, the plant matter is digested, and individual molecules are transported to cells. Cellular respiration converts energy from some of these molecules to a form cells can use.

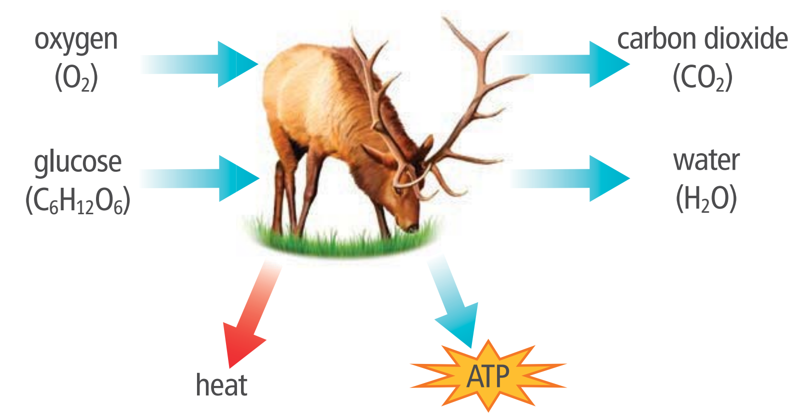
Energy and Matter

Cellular respiration is a multistep process that transfers chemical energy from glucose to ATP, which provides energy for cell processes. In addition to glucose, cellular respiration requires oxygen as a reactant. The products are ATP, carbon dioxide, and water. Heat is also released as a product of cellular respiration.

Collaborate With a partner, answer the following questions.

1. What is the energy input for cellular respiration, and what are the energy outputs?
2. According to this model, is cellular respiration an endothermic or exothermic process? Explain your answer.

FIGURE 21: Cellular Respiration



ATP is a molecule made up of subunits called adenine and ribose, as well as three phosphate groups. The bonds between the phosphate groups are high-energy bonds that store chemical energy in a form that cells can use.

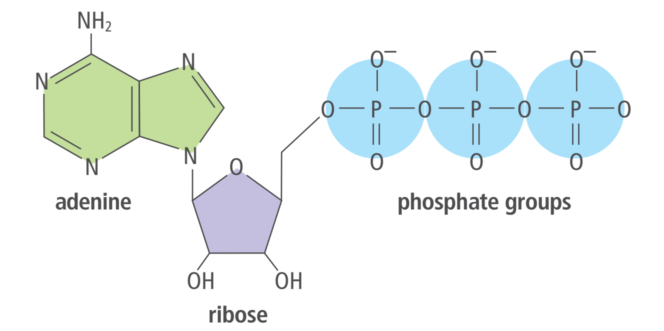


FIGURE 22: ATP is made up of adenine, ribose, and three phosphate groups. The "tri" in triphosphate signifies that there are three phosphate groups in this molecule.

ATP is generated when cells carry out cellular respiration. In this process, energy from the breakdown of biomolecules is used to add a phosphate group to adenosine diphosphate, or ADP. The energy carried by ATP is released when a bond between two phosphate groups is broken. A phosphate group is released, and ATP becomes ADP, a lower-energy molecule. The energy released can be used to power cell processes such as transporting materials, carrying out reactions, and producing new molecules.

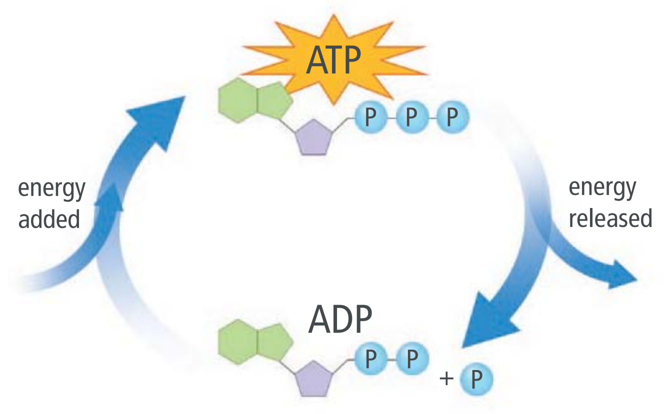


FIGURE 23: Cells use energy from the breakdown of carbon-based molecules to add a phosphate group to ADP. This forms ATP, a higher-energy molecule. When a phosphate group is removed from ATP, energy is released for cell processes.

Language Arts Connection Make an analogy to explain the role of ATP in storing energy and releasing energy for cell processes.

Analyzing Energy Content in Food

The energy in food is measured in Calories. One Calorie from food equals one kilocalorie, or 1000 calories. Proteins and carbohydrates have 4 Calories per gram, and fats have 9 Calories per gram. The number of Calories in food is indirectly related to the amount of ATP that can be produced from the food. The number of ATP molecules produced depends on the type of molecule that is broken down—carbohydrate, lipid, or protein.

Carbohydrates are the molecules most commonly broken down to make ATP, but they are not stored in large amounts in your body. The body uses fat for energy storage instead because it is more Calorie-dense and can yield greater amounts of ATP per unit mass. Proteins store about the same amount of energy as carbohydrates, but they are less likely to be broken down to make ATP. The amino acids in proteins are needed to build new proteins more than they are needed for energy.

Explain A common misconception is that proteins are a good source of energy. Explain which types of foods are the best energy sources and how this relates to the amount of ATP made by your cells.

The Cell Membrane

Collaborate Think about another system that controls inputs and outputs. Why is it necessary to control inputs and outputs in this system?

To maintain homeostasis, cells need to take in some substances while expelling others. But how do cells manage the import and export of materials? The cell membrane, or plasma membrane, has a specialized structure that allows the cell to control the passage of materials into and out of the cell. Different types of carbon-based molecules, including lipids, proteins, and carbohydrates, make up the cell membrane.

Cell Membrane Structure

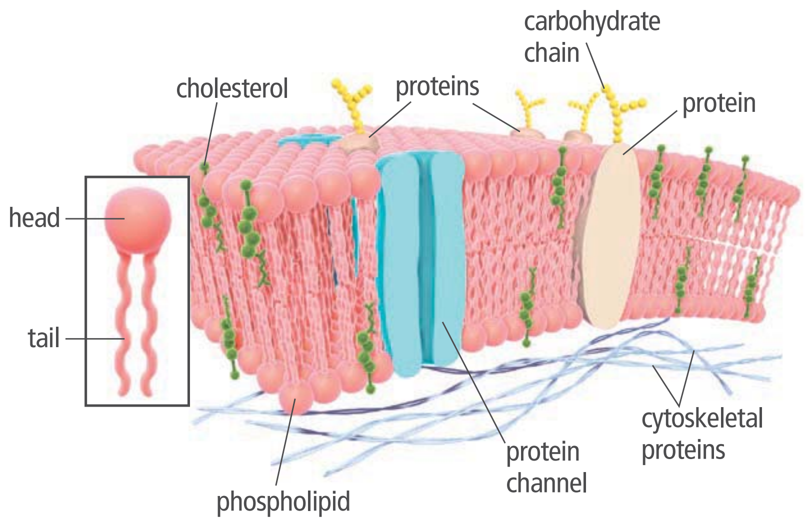
The cell membrane consists of a double layer of phospholipids. The hydrophilic heads of the phospholipids face the watery environment outside the membrane, and the hydrophobic tails face the inside of the membrane. However, the types of substances that could pass through the membrane, and their rates of passage, would be quite limited if the membrane was only composed of phospholipids. To solve this problem, the cell membrane also contains carbohydrates, proteins, and cholesterol.

Explore Online

Hands-On Lab

Modeling the Cell Membrane Make a model to investigate the properties of the cell membrane.

FIGURE 24: The cell membrane is made of two phospholipid layers embedded with other molecules, such as proteins, carbohydrates, and cholesterol.



A cell membrane needs multiple passageways for substances to enter and exit the cell. This task is accomplished by proteins. Some proteins embedded in the phospholipid bilayer transport materials across the membrane. Others, in the form of enzymes, speed up chemical reactions that take place on the membrane. Still others act as receptors for specific molecules, such as hormones.

Explain How do the structures within the cell membrane help the cell function within a larger system?

Carbohydrates on the cell membrane serve as identification tags, which allow cells to distinguish one type of cell from another. They also enable neighboring cells to adhere to each other. Cholesterol gives strength to the cell membrane by limiting the movement of the phospholipids, preventing the membrane from becoming too fluid. Cholesterol also protects the cell membrane at low temperatures by preventing it from becoming solid if the cell is exposed to cooler than normal temperatures.

The structure of the cell membrane gives it the property of selective permeability. This means it allows some, but not all, materials to cross. Selective permeability enables a cell to maintain stable conditions in spite of unpredictable, changing conditions outside the cell. Molecules and other materials cross the membrane in several ways. Some of these methods require the cell to expend energy; others do not. How a particular molecule crosses the membrane depends on the molecule's size, polarity, and concentration inside versus outside the cell.

Model Draw a model to illustrate the concept of a semipermeable membrane.

Passive Transport

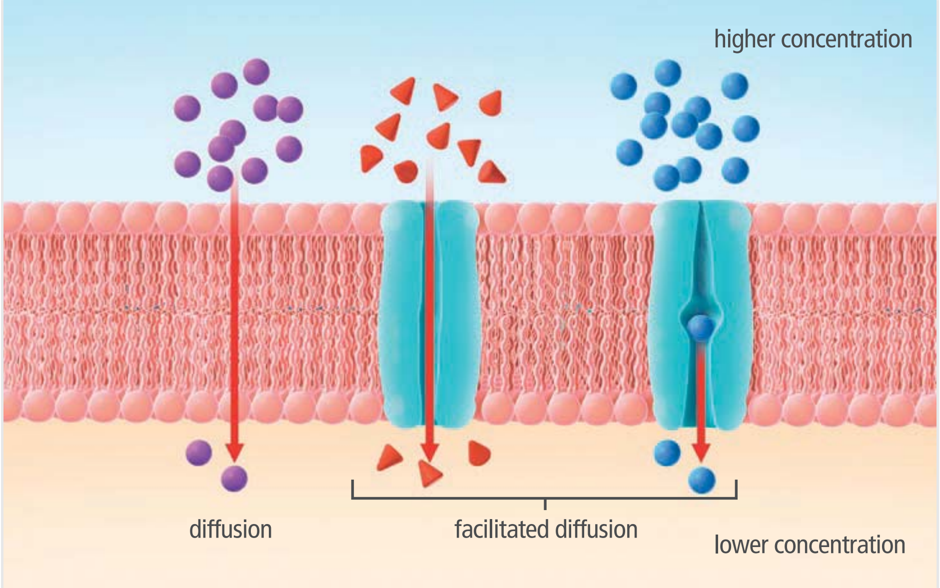
Cells almost continually import and export substances across the cell membrane. If they had to expend energy to move every molecule, cells would require an enormous amount of energy to stay alive. Fortunately, some molecules enter and exit a cell without energy input from the cell in a process called passive transport. This type of transport results from the diffusion of molecules across a membrane.

Diffusion

Diffusion is the movement of molecules in a fluid or gas from a region of higher concentration to a region of lower concentration. It results from the natural motion of particles, which causes molecules to collide and scatter. Concentration is the number of molecules of a substance in a given volume. A concentration gradient is the difference in the concentration of a substance from one location to another. Molecules diffuse down their concentration gradient—that is, from a region of higher concentration to a region of lower concentration.

FIGURE 25: Passive Transport

Explore Online



Analyze Compare and contrast the way molecules move in diffusion and facilitated diffusion. Discuss concentration and mode of transport across the membrane.

Some molecules cannot simply diffuse across a membrane. Facilitated diffusion is the diffusion of molecules across a membrane through transport proteins. Some proteins form openings, or pores, through which molecules can move. Other proteins bind to specific molecules to be transported on one side of the membrane. When the correct molecule binds, these proteins change their shape, and this allows the molecule to pass through the membrane to the other side. Each protein in the membrane is specific to a certain type of molecule or particle.

Hands-On Lab

MATERIALS

- beaker, medium (3)
- food coloring
- hot plate
- ice
- timer
- water

Heat and Diffusion

You can see diffusion in action when you add food coloring to water. In this lab, you will measure the rate of diffusion in water at three different temperatures.

Predict Which solution will have the greatest rate of diffusion: a hot, cold, or room-temperature one? Explain your answer.

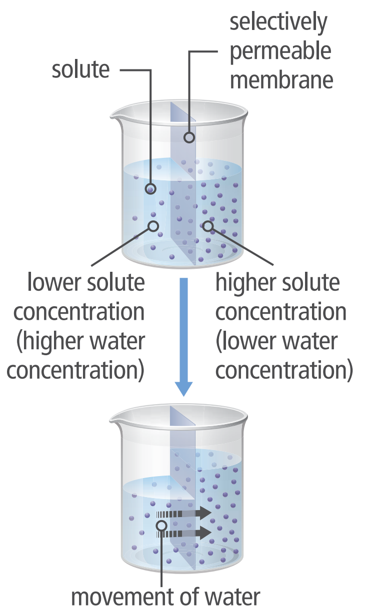
PROCEDURE

1. Place the same amount of water in three beakers.
2. Place Beaker 1 on the hot plate until it is warm, but not boiling. Place Beaker 2 in an ice bath or refrigerator. Leave Beaker 3 at room temperature.
3. With the timer ready, add one drop of food coloring in the room-temperature water. Record how long it takes the food coloring to evenly disperse throughout the solution. Repeat for the other two solutions.
4. Record your data in a data table.

ANALYZE

1. How could you tell that molecules were diffusing in this lab?
2. In which solution did diffusion occur most rapidly?
3. Explain your results in terms of the movement of water and food coloring molecules in each beaker. How did temperature affect this movement?

FIGURE 26: Osmosis is the movement of water toward areas of higher solute concentration.



Osmosis

Water molecules, of course, also diffuse. They move across a semipermeable membrane from an area of higher water concentration to an area of lower water concentration. They are also moving from an area of lower solution concentration to an area of higher solution concentration. This process is called osmosis. It is important to recognize that the higher the concentration of dissolved particles (solutes) in a solution, the lower the concentration of water molecules in the same solution. The membrane is only permeable to some solutes, so water must cross the membrane to equalize the concentrations of the two solutions.

Plants use osmosis to move water into the cells of their roots. Proteins in the cell membranes of root cells transport certain molecules into the cell. These molecules become more highly concentrated on the inside of the root cells than outside, and water follows the molecules into the cells. Water is always drawn toward areas of higher solute concentration.

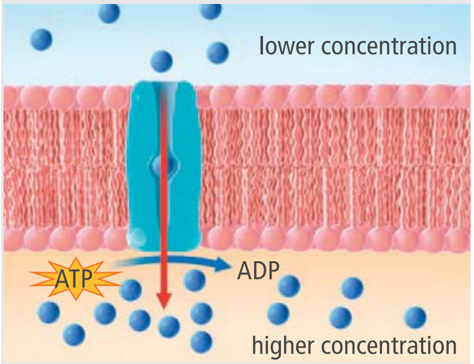
Model Red blood cells burst when placed in pure water. Draw a model explaining this phenomenon. Label semipermeable membrane, solute concentration, and movement of water on your model.

Active Transport

Sometimes a cell must move a substance against a concentration gradient in order to maintain homeostasis. Then it must use a process called active transport. Active transport drives molecules across a membrane from a region of lower concentration to a region of higher concentration using transport proteins. Unlike facilitated diffusion, the activity of transport proteins must be powered by chemical energy. An input of energy is necessary because the transport proteins have to overcome the natural tendency of substances to move with a concentration gradient. ATP often provides the energy for active transport.

Explore Online

FIGURE 27: Active Transport

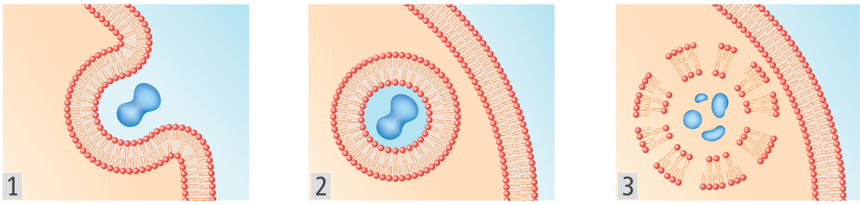


Analyze Make a table to compare passive and active transport in terms of energy, concentration, and the role of proteins in the membrane.

Endocytosis

A cell may also use energy to move large substances across the cell membrane using vesicles. Endocytosis is the process of taking liquids or fairly large molecules into a cell by engulfing them in a membrane. The cell membrane folds inward around the substance and pinches off inside the cell, forming a vesicle. The vesicle then fuses with a lysosome or similar vesicle. The vesicle membrane and content are broken down (if necessary) and released into the cell.

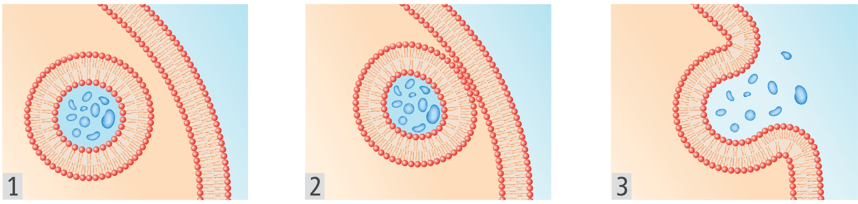
FIGURE 28: Endocytosis allows cells to take in materials.



Exocytosis

Exocytosis is the release of substances out of a cell by the fusion of a vesicle with the membrane. A vesicle forms around materials to be sent out of the cell. The vesicle then moves toward the cell's surface, where it fuses with the membrane and releases its contents.

FIGURE 29: Exocytosis allows cells to expel materials.



Predict Which would be more likely to carry out endocytosis: a white blood cell engulfing foreign materials or a cell that excretes hormones? Explain.

Explain Cystic fibrosis is a disease that occurs when a protein that normally transports ions across the cell membrane does not function properly. A change to the tertiary structure of the protein prevents it from transporting chloride ions out of cells. This leads to a lack of water outside the cells, which causes a sticky mucus to form in the lungs. Explain how diffusion and osmosis are related to the symptoms of cystic fibrosis.

Data Analysis

Food and Energy

Have you ever heard the saying, “You are what you eat?” In many ways, this is true! Living things are made up of different types of organic, or carbon-based, molecules. When we eat food, our digestive system breaks down the food into smaller molecules that can be used by the body. When digestion is complete, nutrients are absorbed by the body and transported by the circulatory system and lymphatic system to all the cells.

Once food enters the body, it can be broken down further to harness energy and form new types of molecules. For example, sugar molecules contain the elements necessary to produce many other types of organic molecules. These elements can be rearranged and combined with other elements through chemical reactions to form new products such as proteins, fats, and DNA.

The information on a food label, such as the one in Figure 30, can help you make good choices and compare the values of different foods. The label shown here is for cereal.

Serving size and number This measurement varies from one product to another. In this case, one serving equals $\frac{3}{4}$ of a cup of cereal.

Calories The numbers listed on the label are for one serving only. If you eat your cereal with milk, you will have a different number of Calories.

Nutrients to limit Americans usually consume too much saturated fat, trans fat, cholesterol, and sodium. Trans fat is a type of fat that can cause cell damage. A diet high in these nutrients is linked to obesity, which affects more and more Americans of all ages. Too much sodium can raise blood pressure by causing the body to retain water.

Nutrients to target Americans need to consume enough fiber, vitamins, and other nutrients each day. Notice that this product is low in Vitamin A and Vitamin C, but high in iron.

FIGURE 30: Nutrition labels contain information about the biomolecules in your food.

ANALYZE

Use the nutrition label shown in Figure 30 to complete the calculations necessary for Questions 1-6.

1. The label shows the calories in one serving of this food. If you were to eat two servings of this food, how many total calories would you consume?
2. If you were to eat two servings of this food, how many grams of carbohydrates would you consume?
3. Total carbohydrates is the sum of the simple sugars, starches, and dietary fiber in a product. Based on the label, what percentage of the total carbohydrates are in the form of fiber?
4. Carbohydrates contain 4 Calories per gram, fats contain 9 Calories per gram, and proteins contain 4 Calories per gram. Calculate the amount of caloric energy provided by each group of biomolecules in one serving of this food.
5. The label indicates that there are 0.3 grams of saturated fat in this product. What percentage of total fats is made up of unsaturated fats?
6. If a serving of this food is 29 grams, what percentage of the food is made up of carbohydrates?

The guidelines for what makes up a healthy diet have changed over time. You may have seen the food pyramid, which has carbohydrates at the base of the pyramid, and fats, oils, and sweetened foods at the top of the pyramid. More recently, a plate with four main sections for vegetables, proteins, grains, and fruits has been used as a model of a balanced diet. This is an example of how different fields of science work together to gather new information and update guidelines accordingly.

Language Arts Connection Research current nutritional guidelines using scientific and government sources. Consider the following when conducting your research:

- What is a balanced diet?
- How is a balanced diet modeled?
- How have nutritional guidelines changed over time?

Develop an informational pamphlet to share with your peers. Your pamphlet should contain the information you researched.

Informative/explanatory writing is a well-organized analysis of a topic. This type of writing tells how or why. Be sure to:

- Provide an introduction that clearly states the topic and engages readers.
- Organize your ideas to make important connections and distinctions.
- Include details that support your ideas.
- Provide a conclusion that supports your explanation.

FIGURE 31: Food has energy and nutrients your body can use.

PRACTICE

Track Your Nutrients

Record the foods you eat over the course of a week. Record the amount of carbohydrates, lipids, and proteins contained in the foods you eat for each meal. Are there any patterns in your eating habits?

MODELING BIOCHEMICAL COMPOUNDS | BUILDING BLOCKS OF PLANTS | INVESTIGATING OSMOSIS | **Go online to choose one of these other paths.**

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 32: Carbon is essential to life on Earth.

Carbon is often called the building block of life because carbon atoms are the central component of most molecules that make up living things. These molecules form the structure of living things and carry out most of the processes that keep organisms alive. Carbon is so important because its atomic structure gives it bonding properties that are unique among elements.

Carbon atoms can arrange themselves into the molecules that make up your food and your clothes. Carbon-based materials are also used for many technical applications, such as electronics, optics, and even the rubber in tires.

Explain How can carbon be the central component of so many different types of molecules? Write an explanation that answers these questions:

1. How do the properties of carbon allow it to form a variety of different molecules?
2. What evidence is there that chemical reactions in organisms' cells break apart and rearrange carbon-based molecules?
3. How is energy from biomolecules transferred to cell processes in living things?

CHECKPOINTS

Check Your Understanding

1. Suppose you are going to draw models of the four main biomolecules. Which statement describes how the models will be similar?
   - **a.** They will all be formed around carbon chains and rings.
   - **b.** They will all include a chain of amino acids.
   - **c.** They will all have hydrocarbon chains connected only by double bonds.
   - **d.** They will all include a sugar, a phosphate group, and a base.

2. Which of these evidence statements should you include in an explanation of the relationship among carbon, amino acids, and proteins? Select all correct answers.
   - **a.** Amino acids are polymers made up of proteins.
   - **b.** Proteins are polymers made up of amino acids.
   - **c.** Proteins and amino acids are polymers because they contain multiple carbon atoms.
   - **d.** Amino acids are monomers made up mostly of carbon, hydrogen, nitrogen, and oxygen.

3. Use these terms to complete the statement explaining how living things obtain and use the molecules necessary for life:

   ATP, glucose, cell processes, cellular respiration, photosynthesis

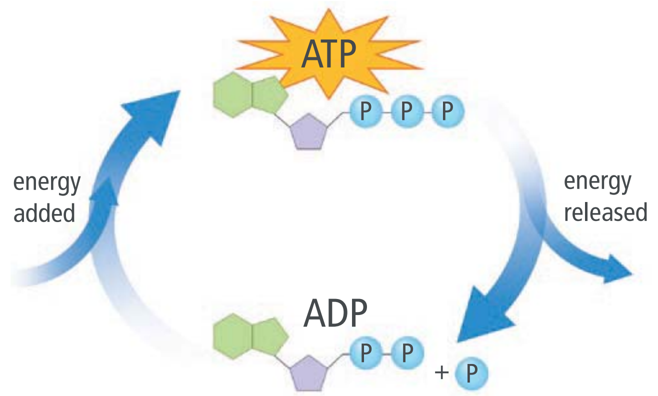
   Some living things, such as plants and algae, transfer energy from sunlight to _____ molecules. This process is known as _____. Virtually all living things transfer energy from these molecules to another molecule called _____, which provides the energy for _____. The process that produces this molecule is called _____.

4. Use these terms to complete the statement explaining how enzymes carry out chemical reactions in living things:

   bonds, shape, proteins, temperature

   Enzymes are _____ that help break chemical _____, as well as form new ones. Enzymes require specific environmental conditions related to _____ and pH to properly function. If these conditions are not met, the _____ of the enzyme may change. This could result in a nonfunctional enzyme that cannot carry out chemical reactions.

FIGURE 33: Formation and Breakdown of ATP



5. Use the model in Figure 33 to write an explanation for how ATP stores energy and how this energy is released for cell processes.

6. Which type of transport across the membrane requires ATP—facilitated diffusion or active transport? Explain your answer.

7. Draw a Venn diagram to compare and contrast carbohydrates and lipids. Include terms related to the molecular structures, functions, and energy content of these molecules.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

Organisms are made up of carbon-based molecules.

Carbon-based molecules are broken down and rearranged in organisms' cells to form new molecules and obtain energy.

Remember to include the following information to your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how the models in this lesson can be used to compare and contrast different types of carbon-based molecules.