Chapter 1

Structures, Functions, and Processes in Cells

Chapter 1 • Lesson 1

Macromolecules and Cellular Processes

Key Terms • cell • macromolecule • monomer • polymer • carbohydrate • protein • amino acid • enzyme • lipid • nucleic acid • nucleotide

Getting the Idea

All living things, including you, depend on the processes that occur within cells. These processes are related to the structures of large molecules found within cells, and the interactions among these structures.

Macromolecules, Monomers, and Polymers

A **cell** is the smallest unit that can carry out all the functions of life. Most of the processes that take place within cells involve large molecules that form when smaller molecules are joined by chemical bonds. These very large molecules are called **macromolecules.** Living things need four main kinds of macromolecules: carbohydrates, proteins, lipids, and nucleic acids.

The basic unit of macromolecules is a small molecule called a **monomer**. A chain of repeating monomers forms a **polymer.** Some polymers consist of the same monomer repeated in the chain. In other polymers, the repeated sequence consists of two or more different monomers. Macromolecules are formed from large numbers of polymers.

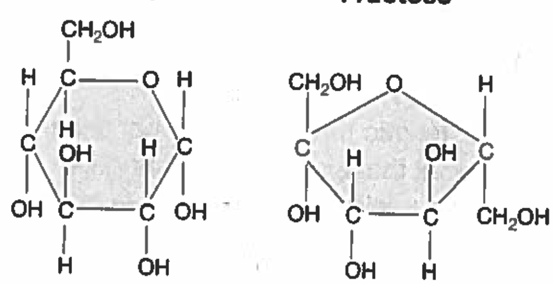
Carbohydrates

Carbohydrates are organic macromolecules composed of carbon, hydrogen, and oxygen atoms, usually in a ratio of 1:2:1. Sugars, starch, cellulose, and glycogen are examples of carbohydrates. Carbohydrates are the primary sources of energy for most organisms.

The sugar glucose is the main source of energy for cells. Plants produce glucose by photosynthesis. Plants store excess glucose in the form of starch in fruits, seeds, and other parts. Animals obtain glucose from plants, directly or indirectly. Animals store glucose in the form of glycogen. Cellulose makes up most of the cell walls that support plants and is important in many animals' diets. Glucose is a simple sugar—the simplest type of carbohydrate. Fructose is another simple sugar.

A carbohydrate can be a single simple sugar, or it can be two or more simple sugars bonded together. The word *saccharide* means "sugar." This is paired with the prefix *mono-* (one), *oligo-* (few), or *poly-* (many) to describe the number of molecules in the sugar. Monosaccharides, oligosaccharides, and polysaccharides are three categories of carbohydrates. A monosaccharide is made up of a single simple sugar.

Glucose and fructose are monosaccharides. The structures of these molecules are shown below.

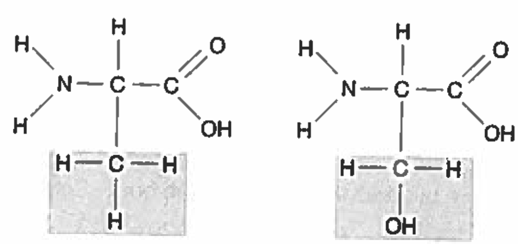


A short chain of two or more sugars is an oligosaccharide. Sucrose, the table sugar added to tea or sprinkled on cereal, is an oligosaccharide. Sucrose ($C_{12}H_{22}O_{11}$) is composed of one glucose molecule and one fructose molecule. Long chains of monosaccharides form polysaccharides. Cellulose and glycogen are polysaccharides made up of chains of glucose. Starch is also made up of glucose molecules, in chains and branches.

Carbohydrate molecules contain many carbon-hydrogen bonds. Organisms get most of their energy by breaking these bonds. Foods containing only or mostly carbohydrates are broken down quickly to provide useable chemical energy in cells.

Proteins

Proteins are complex polymers composed mainly of carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur. Proteins are made up of chains of smaller building blocks called amino acids. An **amino acid** is a carbon compound that contains at least one amino group (NH_2) and one carboxyl group (COOH) bonded to one or more other elements that form a side chain. The composition of the side chain is different in each amino acid. The side chains are the features that distinguish one amino acid from another. In the diagrams of two amino acids shown below, the side chains are shaded.



There are many different amino acids, but cells use only 20 of these to build proteins. These 20 amino acids can join together in a tremendous number of combinations. The amino group of each amino acid forms a bond called a peptide bond with the carboxyl group of the next amino acid.

Many animals eat proteins as a source of amino acids. The animals use the amino acids to build new proteins. Proteins are broken down into amino acids during digestion. Like sugars, these amino acids are absorbed by the intestine and carried by the blood to the cells where they are needed. The cells use the amino acids to build other proteins. Proteins are also a source of energy, but they break down more slowly than carbohydrates.

Each protein molecule has a characteristic three-dimensional shape that is determined by the arrangement of its amino acids. Recall that side chains distinguish amino acids from one another. Side chains also determine how amino acids bond and fold in proteins. A protein's shape determines its function. Proteins serve a variety of essential functions in organisms.

Some proteins are structural. They serve as the building materials for living things and hold organisms together. Collagen, for example, forms bones, tendons, ligaments, and cartilage. Other proteins are functional and take part in transporting materials or in chemical reactions. Hemoglobin is an iron-rich protein found in the red blood cells of most vertebrates. It bonds with and transports oxygen to the cells of these organisms.

Other functional proteins include some hormones and enzymes. A hormone is a substance produced by a cell or organ in one part of the body that affects the function of cells or organs in other parts of the body. Insulin, for example, is a hormone made in the pancreas that controls carbohydrate and fat metabolism. It does this by directing other cells to remove glucose from the blood and store it as glycogen in the liver and muscles. **Enzymes** are functional proteins that take part in chemical reactions. An enzyme is a protein that enables or speeds chemical reactions in cells. In the human body, proteins are required for most cellular processes.

This table summarizes some functions of proteins in humans and other animals.

Functions of Proteins

Function	Explanation
Catalyst	Enzymes catalyze, or speed up, most chemical reactions, including digestion. Enzymes are reusable proteins that are not changed by the reactions they catalyze.
Storage	Various small molecules are joined with proteins for storage.
Transport	Specialized proteins help transport substances through cell membranes.
Messenger	Hormones are used as signals within the body. Some proteins transmit nerve impulses.
Structure	Proteins such as collagen provide structure and support for the body. Proteins are a part of the structure of cell membranes.
Movement	Contractile proteins, such as those in muscle fibers, play an important role in movement.
Immunity	Antibodies bind to and help destroy foreign substances.
Regulation	Feedback mechanisms involving protein synthesis help maintain consistent internal conditions inside the cell.

Scientific arguments use evidence to support a claim. While everyday arguments may be based on opinions, scientific arguments must be based on facts and observations.

Refer to the text and to the diagrams of amino acids in this lesson. The diagrams show two of the 20 different amino acids used to build proteins in the body: alanine and serine.

What evidence supports the argument that the structure of amino acids allows them to form proteins with widely varied shapes? How might this be related to the many functions of proteins?

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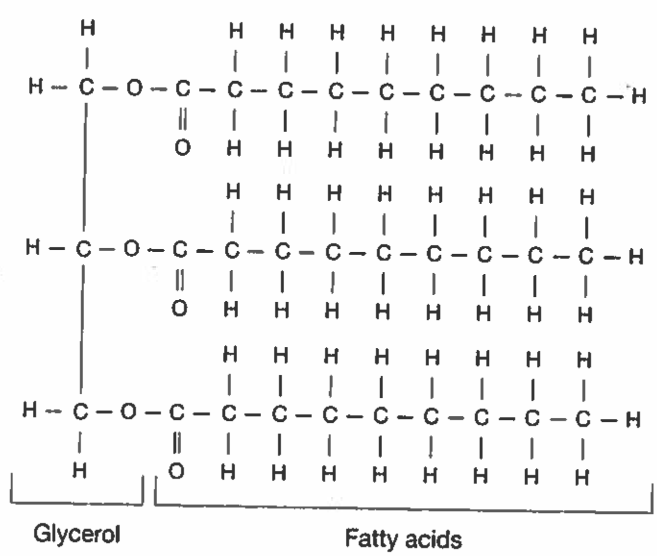
Lipids

Lipids are organic macromolecules composed of hydrogen, carbon, and oxygen. Lipids differ from carbohydrates in two main ways. First, lipids have more carbon-hydrogen bonds and fewer oxygen atoms than carbohydrates. This means that lipids store more energy per gram. Second, lipids do not dissolve in water. Many lipids are made up of a glycerol molecule combined with three fatty acids. Fatty acids are long chains of carbon, hydrogen, and oxygen. A lipid molecule is shown below.



Fats, oils, and waxes are types of lipids. In animals, most lipids are fats. In plants, lipids are usually oils. Both animals and plants produce waxes. Waxes are made up of long-chain fatty acids attached to an alcohol molecule (an organic compound with an -OH functional group).

Lipids have two main functions. First, they insulate and waterproof the organism. For example, cutin and other waxes coat the leaves of some plants to help prevent water loss.

Second, lipids are used for long-term energy storage. In humans and some other animals, fats are digested into glycerol and fatty acids. These components are absorbed through the intestine and transported by the bloodstream to cells, where they are used or stored. Stored fats are a source of energy. Cells use stored fats for energy when carbohydrates are unavailable.

Lipids also play important structural roles. Cells, for example, are enclosed by membranes composed mostly of lipids. On a larger scale, the human body uses fats in a variety of ways. For example, lipids insulate some nerve fibers and protect internal organs. Fats also store some essential nutrients that humans must obtain from their food.

Recall that scientific arguments are supported by evidence. Analyze the diagram that shows the structure of a lipid. What evidence supports the argument that lipids are used to store energy in an organism? Why are lipids better suited than carbohydrates for long-term energy storage?

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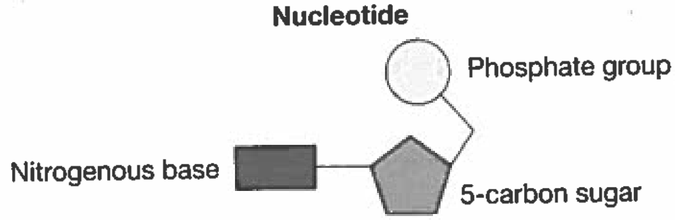
Nucleic Acids

Organic macromolecules in the fourth group are not used as sources of energy, but they are essential to life. **Nucleic acids** are large, complex molecules made up of smaller molecules containing carbon, hydrogen, oxygen, nitrogen, and phosphorus atoms. Nucleic acids store and transmit genetic (hereditary) information.

The smaller units that join together to form a nucleic acid are called **nucleotides.** The order of the nucleotides in a nucleic acid can be thought of as a code. A nucleotide is made up of three units: a five-carbon, or *pentose*, sugar; a nitrogen-containing, or *nitrogenous*, base; and a phosphate group. A single nucleotide is shown below.

Nucleotide



The two most important nucleic acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Each of these nucleic acids is named for the pentose sugar it contains. DNA contains deoxyribose, and RNA contains ribose. You will learn more about DNA and RNA in later lessons in this book.

Lesson Review

1. Which compounds interact to form proteins?
   - A. nucleic acids
   - B. amino acids
   - C. simple sugars
   - D. fatty acids

2. Which statement describes a property shared by lipids and carbohydrates?
   - A. Both dissolve in water.
   - B. Both are sources of energy for a cell.
   - C. Both have the same number of oxygen atoms.
   - D. Both have the same number of carbon-hydrogen bonds.

3. Scientists isolate an organic macromolecule that plays a role in digestion. When this polymer is not present, the rate of one of the chemical reactions required for digestion increases greatly. Which category of macromolecule are these scientists most likely studying?
   - A. carbohydrate
   - B. lipid
   - C. nucleic acid
   - D. protein

4. What structural difference explains why lipids provide more energy to a cell than an equal mass of proteins or carbohydrates?
   - A. Lipids have more carbon-hydrogen bonds per gram than proteins or carbohydrates.
   - B. Lipids have more nitrogenous bases per gram than proteins or carbohydrates.
   - C. Lipids have more amino acids per gram than proteins or carbohydrates.
   - D. Lipids have more simple sugars per gram than proteins or carbohydrates.

Standard:
SB1.a

Cell Structures and Organelles

Key Terms • cell membrane • selectively permeable • homeostasis • cytoplasm • eukaryote • prokaryote • nucleus • ribosome • endoplasmic reticulum • Golgi body • mitochondria • lysosome • cell wall • chloroplast • vacuole

Getting the Idea

All living things are made up of one or more cells. If an organism has only one cell, that cell must perform all the processes needed to keep it alive. If an organism is made up of more than one cell, each cell still performs most of the basic processes of life. Specialized structures within a cell enable it to do this.

The Basic Parts of Cells

All cells have a membrane that separates the inside of the cell from the outside environment. The **cell membrane** is a thin, flexible layer that surrounds the cell. This membrane supports and protects the cell and gives it shape.

The cell membrane is **selectively permeable**, meaning that only some types of substances can pass through it. Openings in the cell membrane allow the cell to control which substances enter and leave as the cell. The cell membrane helps the cell maintain homeostasis. **Homeostasis** is the regulation of the internal conditions of a cell or organism despite changes in external conditions.

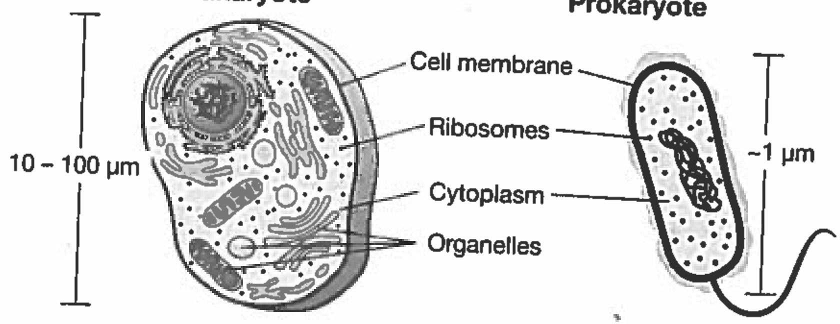
Inside the cell membrane is the **cytoplasm,** a thick, jelly-like material that holds the cell's internal structures. Cytoplasm allows the internal structures to move within the cell.

Prokaryotic Cells and Eukaryotic Cells

Cells are divided into two categories: prokaryotic cells and eukaryotic cells. Cells of **eukaryotes** have a distinct control center and other cell structures, called organelles. These structures are all surrounded by membranes. Organelles are specialized for different functions, such as making proteins and removing the cell's wastes. In eukaryotes, the organelles carry out most of the functions that sustain life.

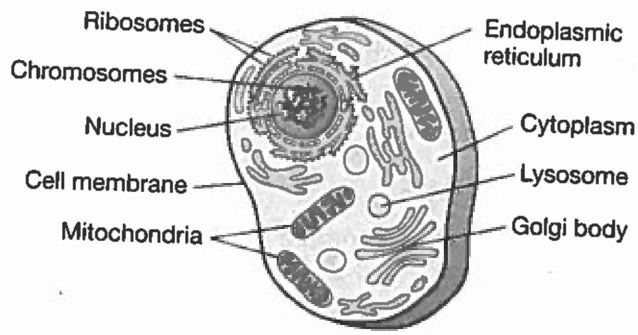
Many eukaryotic organisms are multicellular. A multicellular organism is made up of many cells that work together as a system. Plants, animals, protists, and fungi are all eukaryotes. All plants and animals, and some protists and fungi, are multicellular.

Prokaryotic cells do not have membrane-bound organelles. In **prokaryotes,** most of the cell processes occur in the cytoplasm. Prokaryotic cells are much smaller and simpler than eukaryotic cells. Nearly all prokaryotic organisms are unicellular. A unicellular organism consists of a single cell. Bacteria and archaea are prokaryotes. The following diagram summarizes the similarities and differences of eukaryotic and prokaryotic cells.



Structures and Organelles of the Eukaryotic Cell

The animal cell diagram below shows the structures and organelles found in most eukaryotic cells. You can refer to it as you read about the various organelles and structures.



Nucleus

The largest structure in most eukaryotic cells is the nucleus. The **nucleus** directs and controls most cellular activities. It is enclosed by a structure called the *nuclear membrane*, or *nuclear envelope*. This membrane controls the passage of materials between the nucleus and the cytoplasm. The nucleus contains deoxyribonucleic acid, or DNA. The DNA molecules control protein production and cell functions. DNA also stores the genetic information that is passed from parent to offspring during reproduction. Prokaryotic cells lack nuclei, but they do contain DNA. Their DNA is found in the cytoplasm.

Ribosomes

Numerous tiny structures called ribosomes are scattered throughout the cytoplasm of a cell. **Ribosomes** assemble a variety of proteins that are used throughout the cell. Some ribosomes are attached to other structures in the cell. Unlike most other organelles, free-floating ribosomes are not enclosed in membranes. Prokaryotes also have ribosomes.

Endoplasmic Reticulum (ER)

The **endoplasmic reticulum (ER)** is a network of membranes and sacs that surrounds the nuclear membrane. It transports molecules from one part of the cell to another. There are two types of ER. Rough endoplasmic reticulum, or rough ER, is dotted with ribosomes. It is most common in cells that make large amounts of protein. Smooth endoplasmic reticulum, or smooth ER, lacks ribosomes. Smooth ER helps regulate some cell processes. For example, smooth ER is most common in cells, such as animal liver cells, that break down toxic substances. Smooth ER can also synthesize membranes.

Golgi Bodies

Rough ER packages proteins in sacs called *vesicles,* which float through the cytoplasm to the Golgi bodies. **Golgi bodies** are systems of membranes that modify proteins and lipids according to where and how they will be used in a cell. The Golgi bodies repackage the finished molecules in new vesicles for transport. Some proteins and lipids travel to other parts of the cell. Others move to the cell membrane for release to other parts of the organism.

Mitochondria

Mitochondria (singular: *mitochondrion*) carry out cellular respiration. Cellular respiration is a process by which living things obtain energy from food. You will learn more about this process in Lesson 4. Cells that need a lot of energy, such as muscle cells, have many more mitochondria than cells with lower energy needs.

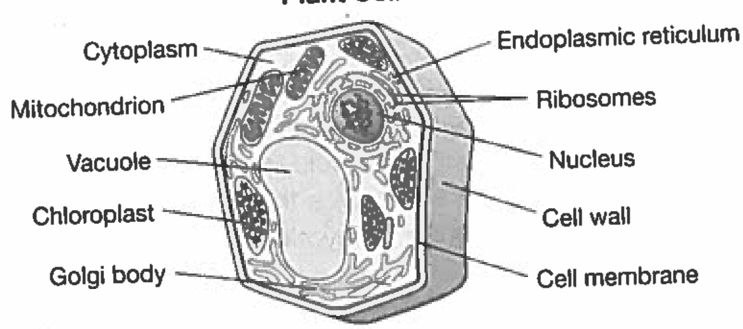
Lysosomes

Lysosomes are small, spherical organelles that use enzymes to digest (break down) complex molecules. Lysosomes also break down worn-out organelles. Lysosomes are common in cells of animals and fungi but are rare in plant cells.

Structures Found in Plant Cells

The organelles discussed so far (except lysosomes) are found in most eukaryotic cells. The cells of some eukaryotes, particularly plants, have structures that are not found in other types of eukaryotic cells. Some of these structures are shown in the plant cell diagram below.

Plant Cell



Cell Wall

A **cell wall** is a rigid structure that surrounds the cell membrane and gives the cell added protection and support. Cell walls are thicker than cell membranes, but, like cell membranes, they help control the passage of materials into and out of the cell. Plant cell walls are composed of cellulose. All prokaryotic cells, as well as those of fungi and some protists, have cell walls.

Chloroplasts

Plant cells contain **chloroplasts**. These organelles capture energy from the sun using a green pigment called chlorophyll. Chloroplasts carry out photosynthesis. In this process, the energy from sunlight is used to produce sugar (glucose) from water and carbon dioxide. Some protists, such as algae, also have chloroplasts. Some bacteria carry out photosynthesis. Their chlorophyll is scattered throughout the cytoplasm. Photosynthesis is explained in Lesson 4.

Vacuoles

Plant cells have a large, central vacuole. A **vacuole** is an organelle that stores water and other important materials, including salts, proteins, and carbohydrates. In plants, a liquid-filled vacuole creates pressure that helps the cell support heavy structures of the plant, such as leaves and flowers. Some animal cells have smaller vacuoles that store substances and transport them within the cell. The cells of some protists also contain vacuoles that store either useful materials or wastes.

Scientific explanations are developed using evidence and reasoning. A good explanation includes scientific information or principles.

Work with a partner. Each partner will select one cell structure or organelle mentioned in this lesson. Then, with your partner, discuss the functions of the two structures or organelles. Develop a scientific explanation for how these structures or organelles interact to carry out cell processes and help the cell maintain homeostasis.

Comparing Structures Found in Different Kinds of Cells

The table below summarizes the functions of the main components of prokaryotic cells and two types of eukaryotic cells.

Cell Components and Functions in Different Organisms

Cell Component	Function	Prokaryotes (Bacteria and Archaea)	Eukaryotes	
			Plants	Animals
Cell membrane	Control of materials entering and leaving the cell	Present	Present	Present
Cell wall	Support for the cell	Present	Present	Absent
Chloroplasts	Photosynthesis	Absent	Present	Absent
Cytoplasm	Site of biochemical reactions	Present	Present	Present
Endoplasmic reticulum	Transports molecules from one part of the cell to another	Absent	Present	Present
Golgi bodies	Modify and repackage proteins and lipids for transport	Absent	Present	Present
Lysosomes	Digestion	Absent	Rare	Present
Mitochondria	Cellular respiration	Absent	Present	Present
Nucleus	Control of most cell activities; location of most DNA	Absent	Present	Present
Ribosomes	Protein synthesis	Present	Present	Present
Vacuoles	Storage; transport; support	Absent	One large	Several small

Lesson Review

1. Human heart cells require a constant release of energy to function continuously. Which structure would be numerous in such cells to meet this demand?

   A. Golgi bodies

   B. nuclei

   C. mitochondria

   D. smooth endoplasmic reticulum

2. Which statement **best** compares the roles of organelles in making proteins?

   A. Vesicles modify proteins, while the Golgi bodies manufactures proteins.

   B. Rough ER transports proteins, while the cell membrane modifies proteins.

   C. Chromosomes modify proteins, while the nuclear membrane produces proteins.

   D. Ribosomes produce proteins, while the nucleus contains protein blueprints.

3. Which statement **best** distinguishes the roles of chloroplasts and mitochondria in maintaining homeostasis in a cell?

   A. Chloroplasts regulate movement of materials in plant cells; mitochondria regulate movement of materials in animal cells.

   B. Chloroplasts produce glucose molecules; mitochondria break down glucose molecules.

   C. Chloroplasts break down proteins; mitochondria generate new proteins.

   D. Chloroplasts store water and wastes; mitochondria provide support for the cell.

4. Which statement **best** justifies the comparison of a cell's nucleus to a person's brain?

   A. Both store information and control activities.

   B. Both are encased in a hard, protective covering.

   C. Both are involved in producing energy-containing molecules.

   D. Both are directly involved in transporting wastes so they do not build up.

Standard:
SB1.d

Cellular Transport

Key Terms • diffusion • concentration gradient • passive transport • facilitated transport • osmosis • hypertonic • hypotonic • isotonic • hypothesis • active transport • endocytosis • exocytosis

Getting the Idea

The cell membrane is a barrier between a cell and its environment. However, the cell is not completely closed off from the outside world. The cell membrane regulates the passage of materials into and out of the cell. To survive, a cell must maintain a careful balance in this flow of materials.

Homeostasis

Organisms must react to changes in their internal and external environments. Organisms need nutrients and other materials. They must also remove waste materials. Similarly, a cell must have structures and processes that enable it to react to changes in its conditions. These processes are necessary in the cells of both multicellular and unicellular organisms.

Recall that homeostasis is the regulation of the internal conditions of a cell or organism despite changes in external conditions. To function, each cell needs materials from its surroundings. For example, cellular respiration uses glucose and oxygen to produce energy. A cell must also get rid of wastes. Cellular respiration produces carbon dioxide molecules that a cell must release. A cell must control the passage of these materials to maintain homeostasis. If a cell fails to maintain homeostasis, it may not survive.

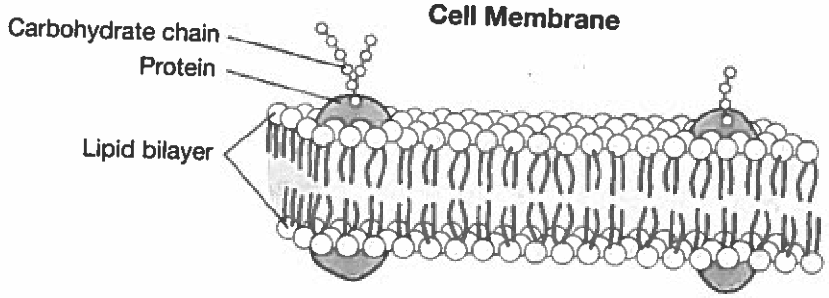
Cell Membrane

The cell membrane serves as a boundary between the intracellular and extracellular environments. The cell membrane helps maintain homeostasis by regulating which materials can cross it. A membrane is permeable to substances that can pass through it and impermeable to those that cannot. Recall that cell membranes are selectively permeable. That is, they allow only some substances to pass through them. For example, the cell membrane is impermeable to certain water-soluble substances. In multicellular organisms, the cell membranes of different cell types can allow different substances to pass in and out of the cell. This allows cells to carry out different functions.

Recall from Lesson 1 that the cell membrane is made up mostly of lipids. These are arranged in two layers, called the lipid bilayer. The cell membrane includes protein molecules embedded in the lipid bilayer. Many of these proteins are attached to carbohydrates.

The diagram below shows the basic structure of the cell membrane.

Cell Membrane



The structure of the cell membrane allows select materials to enter and leave the cell by several different transport processes. These processes are discussed below.

Passive Transport

Diffusion

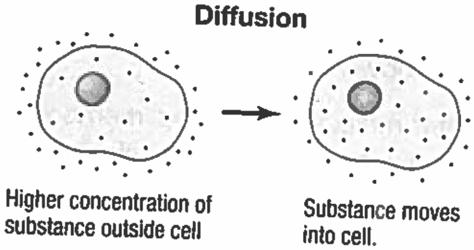
One way materials enter and leave a cell is by diffusion. **Diffusion** is the movement of particles from an area of higher concentration to an area of lower concentration. In cells, diffusion can occur across a membrane. For example, oxygen and carbon dioxide can enter and leave the cell by diffusion across the cell membrane. A difference in concentration on opposite sides of a membrane is called a **concentration gradient.**

Particles in solutions, such as those on both sides of a cell membrane, are in constant motion. The particles collide with each other and tend to spread out randomly. Diffusion depends on the random movements of particles, so it does not require a cell to use energy. The movement of materials into or out of a cell without an expenditure of energy is called **passive transport.**

Particles continue to diffuse into or out of a cell until the concentration of particles is the same on both sides of the cell membrane. When this state of equilibrium is reached, particles continue to diffuse across the cell membrane in both directions. However, about the same numbers of particles move in each direction.

The diagram below illustrates the process of diffusion. The particles of a substance are represented by dots. The densities of the dots show the relative concentrations of the particles.

Diffusion

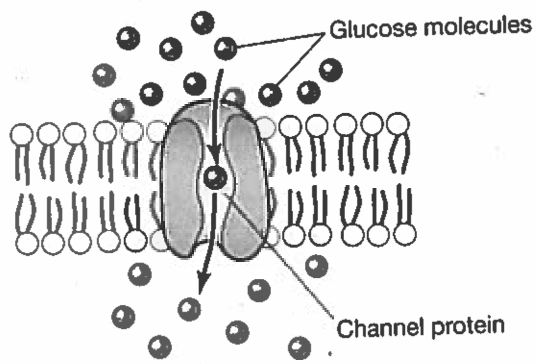


Facilitated Transport

The cell membrane is impermeable to some types of molecules due to their size or structure. These molecules move through the cell membrane only by facilitated transport. **Facilitated transport,** or facilitated diffusion, is the movement of substances across a cell membrane with the aid of the proteins in the cell membrane. Facilitated transport is another form of passive transport. In other words, it does not use the cell's energy.

Some of the protein molecules embedded in the lipid bilayer are called channel proteins. A channel protein allows certain molecules to pass based on their size and electric charge. Each channel protein lets a specific type of molecule enter or leave the cell. For example, channel proteins in red blood cells allow only glucose molecules to cross the membrane. Although the channel protein helps glucose move across the cell membrane, the process is still a type of passive transport. The particles move only with the concentration gradient, as shown in the diagram below.

Facilitated Transport

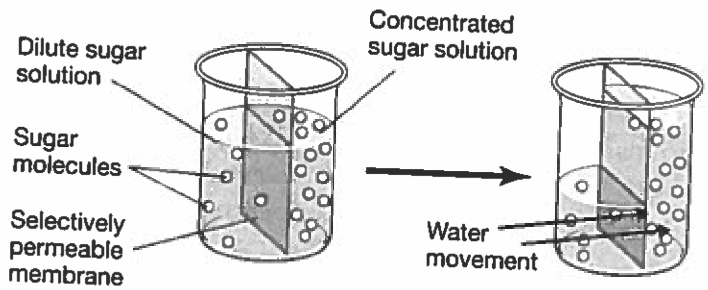


Osmosis

Cells are made up mostly of water. Water is an excellent solvent. A *solvent* is a substance in which other substances, or *solutes*, dissolve to form a solution. Many different compounds dissolve in water. In fact, cytoplasm is made up mostly of substances dissolved in water. Both the cytoplasm inside the cell and the cell's surroundings are fluid environments. The fact that they are both fluids allows for the passage of materials through the cell membrane. Because the cytoplasm is made up mostly of substances dissolved in water, regulation of the movement of water is essential for the cell's survival. Water molecules pass through selectively permeable membranes by a type of diffusion known as osmosis.

Osmosis is the movement of water molecules across a membrane from a less concentrated solution into a more concentrated solution. During osmosis, water can move into or out of the cell. Osmosis continues until there is an equal concentration of solutes on both sides of the membrane. The process of osmosis does not use the cell's energy.

The process of osmosis is modeled below.



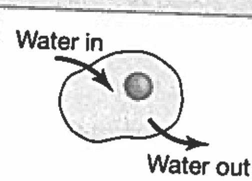
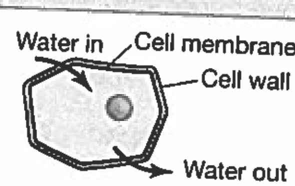
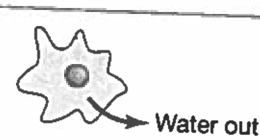
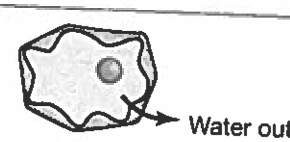
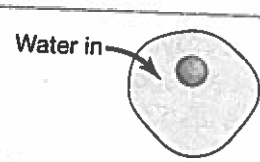
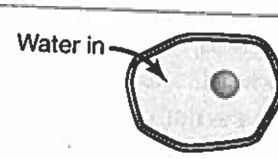
A difference in solute concentrations makes osmosis possible. When the concentration of solutes is higher outside a cell than inside, the solution outside the cell is **hypertonic**. When a cell is placed in a hypertonic solution, water moves out of the cell. If the concentration gradient is large enough, a cell can shrivel and die.

When the concentration of solutes is lower outside a cell than inside, the solution outside the cell is **hypotonic**. When a cell is placed in a hypotonic solution, water moves into the cell. This causes the cell to swell. If the concentration gradient is large enough, the cell can burst.

Solutions with equal concentrations of solutes on both sides of a membrane are **isotonic**. A cell in an isotonic solution is at equilibrium. Equal amounts of water move into and out of the cell.

The rigid cell wall of plant cells enables them to survive in a greater range of hypertonic or hypotonic conditions than animal cells. The table below shows the different effects of osmosis on animal and plant cells.

The Effect of Osmosis on Cells

Solution	Animal Cell	Plant Cell
Isotonic: The concentration of solutes is the same inside and outside the cell.		
Hypertonic: Solution has a higher solute concentration than the cell.		
Hypotonic: Solution has a lower solute concentration than the cell.		

A scientific investigation begins with a testable question. This is a question that can be addressed and answered by carrying out an investigation or controlled experiment. Scientists often formulate testable questions after making an observation about a natural or designed system.

For example, scientists have observed that cells live in a wide variety of environments, so they must respond in various ways to maintain homeostasis. *Elodea* is a freshwater plant that lives in lakes, rivers, and ponds. Suppose you want to investigate osmosis in *Elodea* cells. The first step is to ask a scientific question—one that can be tested by experimentation or observation.

Think of a scientific question you might ask about transport in *Elodea*. Record your question.

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The next step is to develop a **hypothesis**—a proposed answer to a scientific question. A hypothesis should be testable and should also try to explain the expected outcome. Write a hypothesis for your *Elodea* investigation.

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Active Transport

During diffusion, materials move with the gradient, from an area of higher concentration to an area of lower concentration. This movement does not require a cell to expend energy. In some situations, however, a cell must move materials against the concentration gradient. This process is called **active transport**.

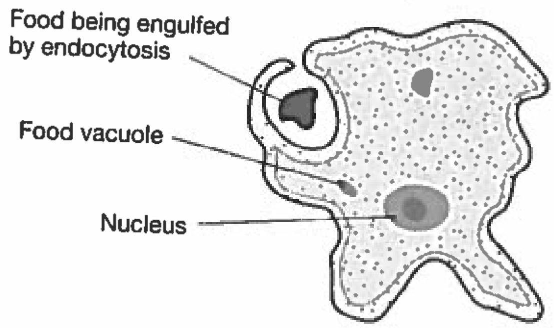
Like facilitated transport, active transport involves proteins embedded in the cell membrane. The proteins used in active transport are called carrier proteins. In active transport, a carrier protein does not provide an open pathway through the membrane. Instead, the protein binds to a molecule on one side of the membrane and releases it on the other. This process requires the cell to expend energy.

Some carrier proteins can transport ions and molecules either passively or actively. Other carrier proteins, called pumps, always use energy. One example is the sodium-potassium pump. Sodium ions are pumped out of the cell, and potassium ions are pumped into the cell, by specific carrier proteins. Calcium ions are also pumped into and out of the cell by active transport. In humans and some other animals, the active transport of calcium is necessary for muscle contraction. Cells also use active transport to remove wastes.

Endocytosis and Exocytosis

Some molecules are too large to move through the cell membrane, even with the aid of proteins. These large molecules are transported by the movement of the cell membrane itself. **Endocytosis** is a process in which a cell surrounds and takes in material from its environment. The cell membrane folds and then forms a pocket enclosing the material. Then the pocket separates from the cell membrane and forms a vesicle—a membrane-bound sac—in the cytoplasm. The formation of this vesicle carries the material into the cell.

As shown below, organisms called amoebas use endocytosis to feed.



The opposite process is exocytosis. Cells use exocytosis to remove unwanted materials. During **exocytosis,** the membrane of a vacuole fuses with the cell membrane. The contents of the vacuole are then expelled from the cell. Some organisms, such as amoebas and paramecia, release excess water in this way. The process can also be used to transfer molecules to other cells. Both endocytosis and exocytosis require the use of cellular energy.

Lesson Review

1. Which is a way in which exocytosis differs from the pumping of calcium ions against a concentration gradient?

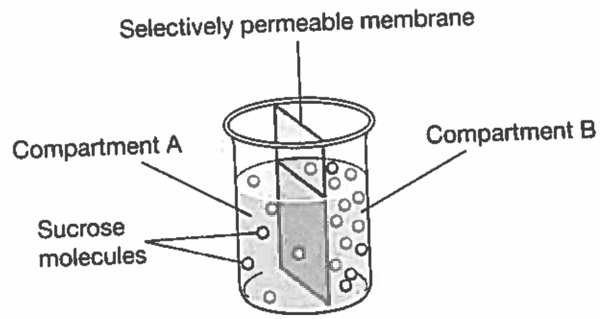
   A. Exocytosis is a form of passive transport.

   B. Exocytosis does not involve a carrier protein.

   C. Exocytosis occurs with the concentration gradient.

   D. Exocytosis requires an expenditure of energy by the cell.

2. A student set up the following investigation. An artificial membrane separates two fluid-filled compartments. This membrane is permeable to water but impermeable to sucrose. Both compartments initially hold the same amount of fluid, which consists of sucrose dissolved in water. The fluid in compartment A is a 20% sucrose solution. The fluid in compartment B is a 35% sucrose solution.



Which prediction is correct?

A. Water will move from compartment A to compartment B by osmosis.

B. Water will move from compartment B to compartment A by osmosis.

C. Sucrose will move from compartment A to compartment B by diffusion.

D. Sucrose will move from compartment B to compartment A by diffusion.

3. Which process is an example of facilitated transport?

A. The cell membrane wraps around a large molecule and forms a vesicle that takes the molecule into the cytoplasm.

B. A protein embedded in the cell membrane allows a specific type of protein to move to a region of lower concentration.

C. Waste materials from cellular processes are moved to a region of higher concentration outside the cell.

D. A carrier protein moves water across the cell membrane against the concentration gradient.

4. Which type of cellular transport requires a cell to use energy?

A. facilitated transport

B. active transport

C. diffusion

D. osmosis

Standards:
SB1.a, e

Energy and Matter within the Cell

Key Terms • ATP • phosphorylation • ATP-ADP cycle • photosynthesis • light reactions • Calvin cycle • cellular respiration • glycolysis • Krebs cycle • electron transport chain

Getting the Idea

Chemical energy is stored in the chemical bonds that hold carbohydrates and other organic compounds together. Plants (and some other organisms) convert the energy of sunlight into the chemical energy that is stored in these carbohydrates. Living things obtain the matter and energy they need for life processes by breaking down carbohydrates and other organic compounds.

Cells Need Matter and Energy

All cells need energy and matter to carry out their life processes. A single-celled alga, the cells of a houseplant, and those of a human use energy and matter to make new molecules such as enzymes and other proteins. Cells also use energy and matter to build and repair organelles and cell membranes. Some processes involved in maintaining homeostasis, such as the movement of materials into and out of a cell, also require energy. In animals, nerve cells use energy to transmit impulses that direct activities in other parts of the body. Some of these impulses are sent to muscle cells, which need energy for movement.

Recall that mitochondria in cells release the energy the cells need. When energy is needed somewhere in a cell, the chemical energy stored in glucose is released and used to produce adenosine triphosphate, or ATP. **ATP** is an organic molecule used for short-term energy storage and transport in the cell. Energy is transferred from glucose to ATP. Then the ATP delivers the energy to the places in the cell that need it.

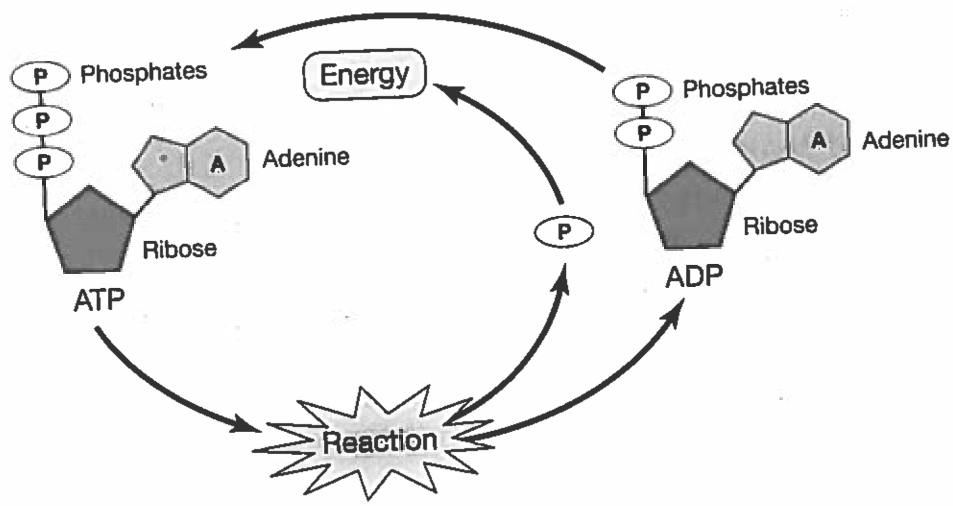
ATP and Energy

ATP is a nucleotide with two extra phosphate groups. Recall from Lesson 1 that nucleotides are smaller units that join to form a nucleic acid. Each nucleotide consists of a nitrogenous base, a sugar molecule, and a phosphate group. The phosphate group is made up of a molecule of phosphoric acid. The nitrogenous base in ATP is adenine. The sugar is ribose. A total of three phosphate groups are bound to the ribose in a chain. The phosphate tail of the ATP molecule holds the usable energy.

To release the stored energy, bonds between the phosphates in ATP are broken through hydrolysis. Hydrolysis is a chemical reaction in which a water molecule splits another molecule. In this case, the addition of water to ATP splits a bond connecting a phosphate group. In most cases, only the last phosphate is removed from the molecule to release energy. This leaves a molecule called adenosine diphosphate, or ADP, that contains two phosphates. ADP can be recombined with a free phosphate to form a new molecule of ATP. The process of combining ADP with free phosphates in a cell is called **phosphorylation**.

ATP cannot be stored for later use. Instead, ADP is constantly recombined with phosphates to form new molecules of ATP to support the work of the cell. This continuous process is called the **ATP-ADP cycle**. The ATP-ADP cycle is summarized in the diagram below.

ATP-ADP Cycle



The ATP-ADP cycle is like a rechargeable battery. The battery starts out filled with chemical energy. As the battery is used, it gives up some of this energy as a combination of electrical energy and heat. The depleted battery is then recharged by supplying it with more energy until it is ready to be used again. ATP is the higher-energy form in this cycle and is like the fully recharged battery. ADP is the lower-energy form, much like the used battery. When the phosphate bond is broken, stored energy in ATP is released, causing the ATP to become ADP. Energy is added when the ADP picks up a free phosphate, recharging itself and turning back into ATP.

For the ATP-ADP cycle to take place, chemical energy must first be stored in glucose and then released to produce ATP. This occurs through the related processes of photosynthesis and cellular respiration.

Photosynthesis

Photosynthesis is a chemical process through which energy from sunlight is used to convert carbon dioxide (CO_2) and water (H_2O) into a sugar called glucose ($C_6H_{12}O_6$) and oxygen gas (O_2). This chemical process occurs in a series of steps, which are summarized in this equation:

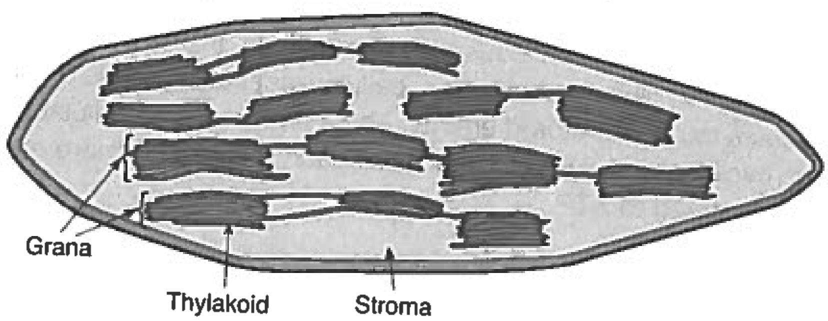
Energy + carbon dioxide + water → glucose + oxygen

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

Plants and some types of microorganisms, such as algae (*singular* alga), carry out photosynthesis. These organisms, which manufacture their own food molecules, are called autotrophs. Most autotrophs trap energy from the sun via photosynthesis.

Carbon dioxide and water are the reactants in photosynthesis. The process of photosynthesis converts these two inorganic compounds to glucose (an organic compound) and oxygen. Recall that photosynthesis occurs in organelles called chloroplasts. As shown below, a chloroplast has three main parts: *thylakoids*, which are membrane-bound sacs containing pigments; *grana*, which are stacks of thylakoids; and *stroma*, a surrounding fluid.

Interior of a Chloroplast



Photosynthesis occurs in two series of chemical reactions: light reactions and the Calvin cycle.

Light Reactions

The first series of reactions in photosynthesis, the **light reactions**, takes place in the thylakoids. Thylakoids contain a pigment called chlorophyll, which gives plants their green color. Chlorophyll absorbs energy from sunlight. This solar energy is used to break the bonds of water molecules, releasing hydrogen, oxygen, and electrons. Some of the solar energy is transferred to the electrons, which are used to produce the energy-storing molecule ATP. The hydrogen becomes part of a second energy-storing molecule, NADPH. Oxygen gas is released as a waste product.

Calvin Cycle

The second series of reactions in photosynthesis is called the **Calvin cycle**. ATP and NADPH provide the energy for the Calvin cycle. In these reactions, the hydrogen atoms stored in NADPH and carbon and oxygen atoms from carbon dioxide are assembled into a new molecule. This molecule is the simple sugar glucose, which stores chemical energy for the cell. The Calvin cycle is also referred to as the light-independent reactions or the dark reactions. As these terms suggest, no light is needed for these reactions, which take place in the stroma.

Most glucose molecules made by photosynthesis are reused to power the Calvin cycle and to make ATP. Other glucose molecules are transported to the rest of the plant. They may be used for energy, stored for later use, or converted to other organic molecules.

Cellular Respiration

Cellular respiration is a process in living things that breaks the chemical bonds of glucose to release energy. This energy is captured as chemical energy in the form of ATP. Cellular respiration is summarized in this equation:

Glucose	+	oxygen	→	carbon dioxide	+	water	+	energy
$C_6H_{12}O_6$	+	$6O_2$	→	$6CO_2$	+	$6H_2O$	+	ATP

Like photosynthesis, cellular respiration is a series of reactions. Instead of absorbing the energy from sunlight and storing it in glucose molecules, cellular respiration does the opposite: it breaks down glucose molecules to extract stored energy. The three stages of cellular respiration are glycolysis, the Krebs cycle, and electron transport. At each stage, a bit more energy in the glucose molecule is converted to ATP.

Glycolysis

Glycolysis is the first stage of cellular respiration. It releases a small amount of energy from glucose. Glycolysis occurs in a cell's cytoplasm and does not require oxygen. In glycolysis, enzymes break apart one molecule of glucose to form two molecules of pyruvic acid. Glycolysis also produces four molecules of ATP; however, the cell uses two molecules of ATP to start glycolysis. Therefore, the net energy gained from glycolysis is two ATP molecules.

The Krebs Cycle

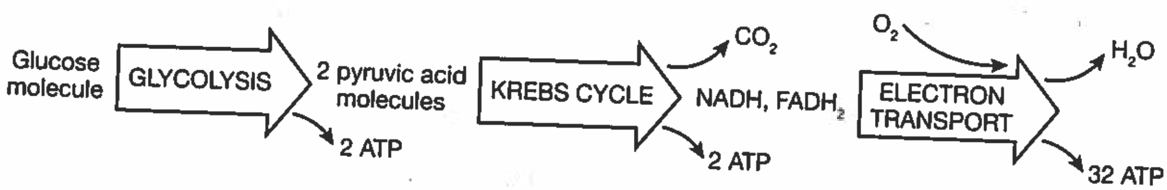
At the end of glycolysis, most of the energy from the original glucose molecule is stored in the bonds of the pyruvic acid molecules. The second stage of cellular respiration, called the **Krebs cycle**, occurs in a cell's mitochondria. There, a series of reactions converts the pyruvic acid to carbon dioxide. The Krebs cycle is the source of the carbon dioxide that animals exhale. The Krebs cycle also produces high-energy electrons. Hydrogen atoms transfer these electrons to two carrier molecules, FAD and NAD. The molecules $FADH_2$ and NADH form in this way. The $FADH_2$ and NADH molecules are the energy-carrying molecules that enter the next stage of respiration, electron transport. In addition, each molecule of pyruvic acid releases one molecule of ATP.

Electron Transport

Electron transport is a series of reactions that produces ATP from the NADH and $FADH_2$ molecules made in the Krebs cycle. In most cells, electron transport reactions depend on a series of proteins located on the inner membranes of the mitochondria. These proteins are called the **electron transport chain.**

During electron transport, the high-energy electrons of NADH and $FADH_2$ pass from one protein to another. They lose some of their energy at each step in the process. An enzyme at the end of the electron transport chain combines the electrons with hydrogen and oxygen to form water. The energy released by this process allows still another enzyme to produce ATP. In all, the electron transport chain produces 32 molecules of ATP.

Cellular respiration produces a total of 36 ATP molecules from each glucose molecule: 2 from glycolysis, 2 from the Krebs cycle, and 32 from electron transport. The process of cellular respiration is summarized in the diagram below. Compare this diagram to the equation for respiration shown previously.



Recall that scientific questions are those that can be tested through investigation. Consider the processes of photosynthesis and cellular respiration. On the lines below record at least two scientific questions about each process.

Photosynthesis

Cellular Respiration

Look back at the equations for photosynthesis and cellular respiration. Notice that the products of one equation are the reactants of the other. The two processes keep matter flowing in a continuous cycle to sustain life on Earth. You will learn more about cycles of matter and the flow of energy in later lessons in this book.

Recall that scientific explanations are based on facts and evidence. Use the information from the lesson to write a short explanation about the roles of photosynthesis and cellular respiration in the cycling of matter and flow of energy in a single-celled alga.

Lesson Review

1. Which substance is a product of cellular respiration?
   - A. ADP
   - B. glucose
   - C. oxygen
   - D. water

2. Which is the correct sequence of events in cellular respiration?
   - A. electron transport → Krebs cycle → glycolysis
   - B. glycolysis → Krebs cycle → electron transport
   - C. Krebs cycle → electron transport → glycolysis
   - D. Krebs cycle → glycolysis → electron transport

3. Which of these happens during the Calvin cycle?
   - A. the release of oxygen
   - B. the formation of glucose
   - C. the absorption of solar energy
   - D. the splitting of water molecules

4. Which is both a reactant of photosynthesis and a product of cellular respiration?
   - A. glucose
   - B. oxygen
   - C. sunlight
   - D. water

Standard:
SB2.a

Chapter 1 • Lesson 5

DNA and RNA

Key Terms • genetics • DNA (deoxyribonucleic acid) • chromosome • RNA (ribonucleic acid) • DNA replication • gene • transcription • messenger RNA (mRNA) • amino acid • codon • translation • ribosomal RNA (rRNA) • transfer RNA (tRNA) • anticodon

Getting the Idea

The nuclei of most of your cells contain coded instructions used for life processes. The macromolecules that store and transmit this coded information are essential for life. Although these macromolecules control many functions, in some ways these molecules are very simple. The code they contain, which directs so many life processes, is written in a language that uses only four letters.

Genetics and DNA

Genetics is the branch of biology concerned with inheritance—the passing of characteristics, or traits, from parent to offspring. Organisms inherit most of their traits from their parents. The genetic information that determines these traits is contained in nucleic acids.

Recall that nucleic acids are organic macromolecules made up of smaller units called nucleotides. Each nucleotide consists of a five-carbon sugar molecule bonded to a nitrogenous base and a phosphate group. Cells contain two types of nucleic acids—DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). Each nucleic acid is named for the sugar it contains: deoxyribose is DNA, and ribose is RNA. DNA and RNA both contain five-carbon sugar molecules. The carbon atoms of both sugars are arranged in a ring.

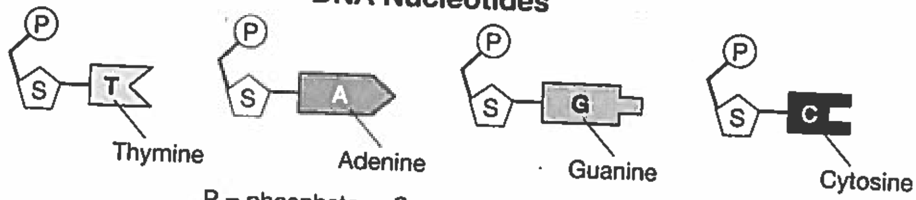
DNA (deoxyribonucleic acid) is the nucleic acid that carries the cell's genetic information. It contains instructions for cellular activity and for making proteins. In eukaryotic cells, most of the DNA is in the nucleus, where it is coiled into structures called chromosomes. **Chromosomes** are threadlike structures found in the nucleus, made up of tightly coiled DNA. Prokaryotic cells do not have nuclei, so DNA floats freely in the cytoplasm. Some of this DNA may be in the form of a circular ring called a plasmid.

The Structure of DNA

Each molecule of DNA is made up of linked nucleotides. The nucleotides have the same sugar and phosphate molecules, but their nitrogenous bases differ. Each nucleotide includes one of four nitrogenous bases. The four bases in DNA are adenine, thymine, guanine, and cytosine.

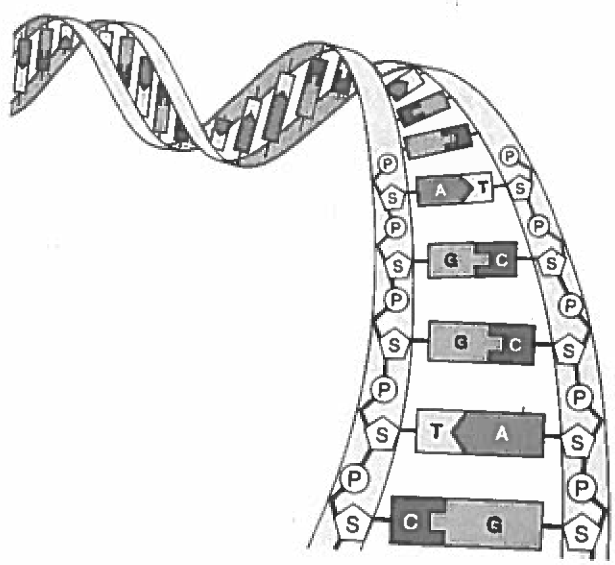
Below is a diagram of the four nucleic acids. Scientists often refer to each base by the first letter in its name. Thus, A = adenine, T = thymine, G = guanine, and C = cytosine.

DNA Nucleotides



P = phosphate S = sugar (deoxyribose)

A molecule of DNA is shaped like a twisted ladder. This shape is called a double helix. The sides of the ladder are two strands that spiral around an imaginary axis. These strands are made up of alternating phosphate and sugar molecules that are joined together by chemical bonds. The rungs of the twisted ladder shape are composed of pairs of nitrogenous bases. The structure of a DNA molecule is shown in the diagram below.

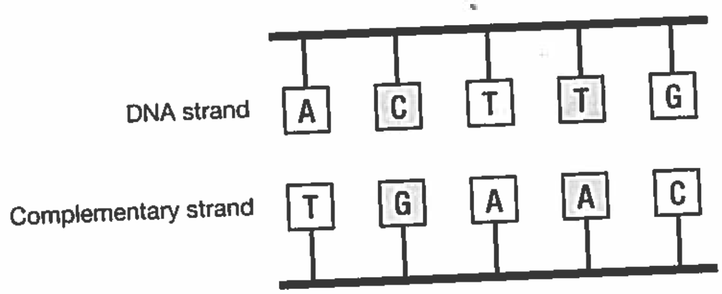


The bases in DNA always pair in the same way: adenine with thymine, A–T or T–A, and cytosine with guanine, C–G or G–C. The bases in each pair are known as complementary bases. They are held together by weak hydrogen bonds. The sequence of bases from rung to rung along the ladder stores the genetic information contained in the DNA molecule. Cells use the sequence of nucleotides in DNA as a set of instructions for making proteins. The proteins present during an organism's development and throughout its life are responsible for its traits. However, the proteins are not made directly by DNA. Instead, the nucleotide **RNA (ribonucleic acid)** copies the information in the DNA molecule and uses the information to control protein production.

DNA Replication

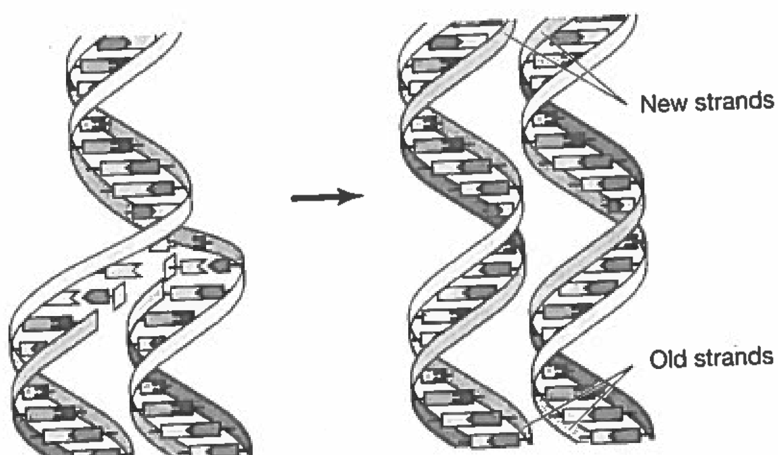
Cells are living structures. They must be able to reproduce, or make new cells like themselves. Before a cell reproduces, its DNA makes a copy of itself in a process called **DNA replication.**

In the first step of replication, the DNA molecule is unzipped down the middle by enzymes that break the weak hydrogen bonds between the pairs of bases. The nucleotides separate, breaking the DNA molecule into two halves, or strands. This leaves complementary sequences of bases exposed. For example, if one strand consists of the bases ACTTG, then its complementary strand has the bases TGAAC, as shown below.



The sequence of bases on each half is used to construct a duplicate DNA molecule. An enzyme in the cytoplasm uses free-floating materials to synthesize new nucleotides and form two new complimentary strands, one for each strand of the original DNA molecule. The enzyme moves the nucleotides in the proper positions so that A pairs with T and G pairs with C.

The result is two separate DNA molecules. Each is made up of half of the original DNA molecule bonded to a newly formed complementary half. The diagram below shows the process. The enzyme also checks the arrangement of bases in each new DNA strand and removes errors. This increases the chance that each new molecule is identical to the original molecule of DNA.



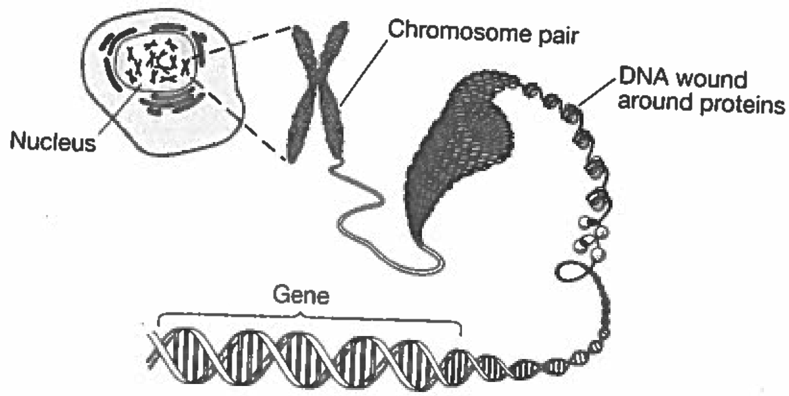
New nucleotides bond to each strand. Two DNA molecules are formed.

After replication, a cell is ready to reproduce. You will learn about cellular reproduction in the next chapter.

Chromosomes and Genes

A molecule of DNA can be quite long. The nucleus of a single human cell contains more than one meter of DNA. To fit inside the nucleus, long sections of DNA are tightly coiled into chromosomes. In eukaryotes, chromosomes are the structures that contain the genetic information that is passed down from one generation to the next.

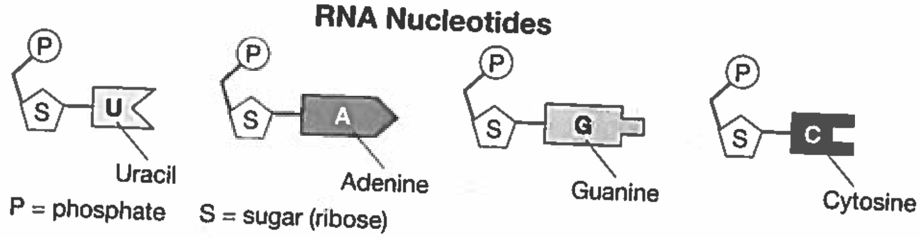
Every species has a characteristic number of chromosomes in its cells. Every chromosome contains the information for numerous traits. A trait is determined by one or more small sections of DNA called genes. A **gene** is a small section of DNA that encodes information for assembling one or more specific proteins. Each chromosome contains hundreds or thousands of genes. The diagram below shows the relationship among genes, chromosomes, and DNA.



The Structure of RNA

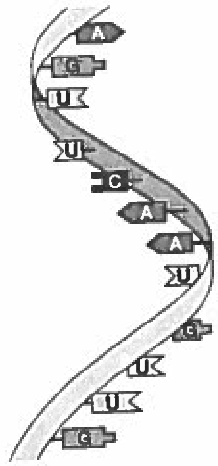
The nucleic acid RNA plays an important role in the assembly of proteins. The nucleotides that make up RNA are each composed of a sugar, a nitrogen base, and a phosphate group, similar to those in DNA.

RNA Nucleotides



RNA differs from DNA in three ways. First, the sugar in RNA is ribose instead of deoxyribose. Second, the RNA molecules contain the base uracil (U) instead of thymine (T). In RNA, uracil pairs with adenine in RNA or DNA. Third, the shapes of RNA and DNA are different. Recall that a DNA molecule is a double-stranded helix. RNA usually exists as one strand twisted into a single helix.

The structure of RNA is shown below.



Making Proteins

Protein synthesis is the process by which cells make proteins. Proteins are assembled on ribosomes, which are in the cytoplasm. However, the instructions for making proteins are in DNA in the nucleus. RNA carries the information needed to make proteins from the nucleus to the ribosomes. RNA molecules then direct and carry out the processes needed to make proteins. Protein synthesis occurs in two stages: transcription and translation, as shown in the diagram.

Transcription

The instructions in DNA are encoded in the sequence of nucleotide bases that make up a gene. In **transcription**, DNA serves as a template for making a complementary strand of RNA. The complementary strand of RNA is called **messenger RNA (mRNA)**.

Where a gene is located on a chromosome, the two DNA strands unwind and separate from each other. This exposes the bases on these single strands. An enzyme joins RNA nucleotides along one of the DNA strands, creating an RNA strand that is complementary. The RNA base uracil is used in place of thymine. Therefore, where the DNA base is adenine, uracil is joined to the RNA strand. The result is a single strand of mRNA containing nucleotides in the same sequence as the DNA strand it replaces.

Unlike DNA replication, in which the entire double helix separates, only a portion of the DNA separates during transcription. Once the mRNA strand is completed, the complementary bases of the DNA strands reconnect. Through the process of transcription, the genetic code for making a protein is passed from DNA to the mRNA molecule. Then the mRNA strand carries the instructions from the nucleus to the cytoplasm, where they will be translated into a protein.

The Genetic Code

Recall that the building blocks of proteins are small molecules called **amino acids**. Cells use 20 different amino acids to build proteins. However, the language of DNA and RNA contains only four nitrogenous bases. The bases are arranged in triplets, or groups of three, called codons. A **codon** is a sequence of three nitrogenous bases that codes for a particular amino acid. Because there are four bases, there are $4 \times 4 \times 4$, or 64, possible codons.

The genetic code is described as universal for nearly all living organisms. This is because the same sequences of bases encode the same amino acids in nearly all organisms. For example, a section of DNA that provides the instructions for the amino acid proline is the same in animals, plants, and other organisms. Although the code is universal, organisms can be very different from one another due to differences in the order of the nucleotides in DNA.

The chart below shows the genetic code, which specifies the codons for each amino acid. For the codon AGU, first find the "A" block in the column titled "First Base." That narrows your choices to those four rows. Next, move to the "G" column in the section called "Second Base." Finally, find the amino acid with the third base "U." The amino acid coded by AGU is serine.

The Genetic Code

First Base	Second Base				Third Base
	U	C	A	G	
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
U	Phenylalanine	Serine	Tyrosine	Cysteine	C
U	Leucine	Serine	(Stop)	(Stop)	A
U	Leucine	Serine	(Stop)	Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
C	Leucine	Proline	Histidine	Arginine	C
C	Leucine	Proline	Glutamine	Arginine	A
C	Leucine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
A	Isoleucine	Threonine	Asparagine	Serine	C
A	Isoleucine	Threonine	Lysine	Arginine	A
A	Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartic acid	Glycine	U
G	Valine	Alanine	Aspartic acid	Glycine	C
G	Valine	Alanine	Glutamic acid	Glycine	A
G	Valine	Alanine	Glutamic acid	Glycine	G

These amino acids combine in different sequences to form many different proteins. The order of the amino acids determines a protein's shape and function. The stop codons—UAA, UAG, and UGA—indicate that the end of the protein has been reached.

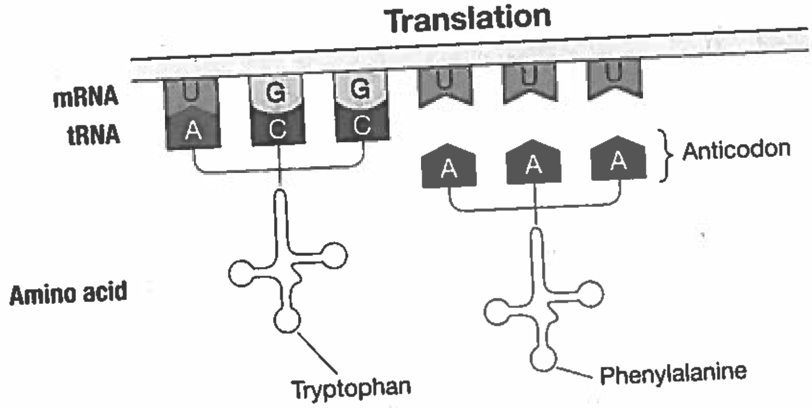
Translation

Translation converts the information in mRNA into a sequence of amino acids that makes up the specified protein. Translation begins after the mRNA moves from the nucleus into the cytoplasm, where it attaches to a ribosome. In the ribosome, **ribosomal RNA (rRNA)**, a form of RNA that makes up part of the structure of a ribosome, works with proteins to carry out translation.

A strand of mRNA attaches to a ribosome in a way that exposes a single codon. In the surrounding cytoplasm are molecules of **transfer RNA (tRNA)**. Each tRNA molecule carries a single amino acid on one end. Each tRNA molecule also has a specific sequence of exposed bases on the other end, called an anticodon. An **anticodon** is a set of three nitrogenous bases on a tRNA molecule that are complementary to a codon on an mRNA molecule. The sequence of bases in an anticodon is specific to the amino acid it carries.

The anticodon of the tRNA aligns and pairs with the exposed codon of the mRNA. The same base pairing rules apply: A with U, and G with C. Only a tRNA with the complementary anticodon can pair with the mRNA. When the tRNA is in this position, the ribosome can attach the amino acid the tRNA molecule carries to the growing chain of amino acids. The diagram below summarizes this process.

Translation



The process repeats, with the next amino acid being moved into place by a different tRNA molecule. The matching of codons on mRNA with anticodons on tRNA ensures that the amino acids join the chain in the correct order. The chain of amino acids is called a *polypeptide*. Once the amino acid carried by a tRNA molecule bonds to the growing polypeptide, it separates from the tRNA. The "used" tRNA molecule bonds with a free-floating amino acid in the cytoplasm and can be used again in translation.

The ribosome continues to attach amino acids to the chain until it reaches a stop codon in the mRNA strand. This tells the ribosome to release the polypeptide. When the polypeptide twists into a three-dimensional shape in the cytoplasm—sometimes in combination with other polypeptides—a complete protein is formed.

Protein Synthesis in Prokaryotes

Transcription and translation in prokaryotes differ slightly from those processes in eukaryotes. The DNA of prokaryotes floats in the cytoplasm because prokaryotes lack nuclei. Therefore, transcription and translation are not separated by a nuclear membrane. As in eukaryotes, a portion of the DNA molecule uncoils to allow a strand of mRNA to begin assembly. In prokaryotes, however, translation can begin sooner, even while transcription is still occurring. Since ribosomes are also present in the cytoplasm, a strand of mRNA can be forming and at the same time can be in contact with ribosomes and tRNA.

Gene Expression

The process by which the information carried in genes is used to make proteins is called gene expression. In most cases, all or most of the cells in an organism have the same DNA. However, not every gene in a cell is expressed. For example, the genes for a protein needed in skin cells are not expressed in liver cells.

A complex process determines whether a gene is turned on or off. If the gene is turned off, the protein it codes for is not produced. In addition, a cell does not always produce the same amounts and types of proteins. For example, a cell may respond to an injury by producing proteins to repair the injury.

There are many ways in which scientific information can be communicated. Providing a step-by-step explanation of a process is one way to communicate information.

Look at this DNA sequence.

TCT GAT AAG ATC

Write the mRNA sequence that would result from transcription.

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Write the anticodon sequence and the amino acid sequence that would result from translation.

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Explain how the structures of DNA and RNA are related to the expression of the information.

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Lesson Review

1. Suppose that a strand of DNA has the following sequence of bases: AAGTTC. What sequence of bases will the complementary strand of DNA have?

   A. GGCAAT

   B. GGTCCA

   C. TTACCG

   D. TTCAAG

2. In a DNA molecule, which molecules make up the sides of the double helix?

   A. single nucleotides

   B. pairs of nucleotides

   C. joined sugars and phosphates

   D. joined nitrogenous bases and phosphates

3. Which statement correctly distinguishes DNA and RNA?

   A. DNA contains uracil, and RNA does not.

   B. DNA contains nitrogenous bases, and RNA does not.

   C. RNA contains the sugar ribose, and DNA does not.

   D. RNA is arranged in a double helix, and DNA is not.

4. Transcription creates an mRNA molecule using DNA as a template. Where does this process occur in cells of eukaryotes?

   A. in the nucleus

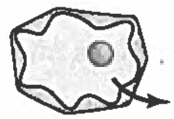
   B. in the cytoplasm

   C. in the ribosomes

   D. in the Golgi apparatus

Chapter 1 Review

1. A student drew the following diagram as part of a lab report.



Based on the diagram, which question was this student MOST LIKELY investigating?

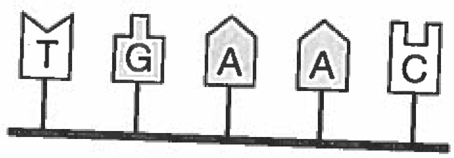
ⓐ How do freshwater plants react to salt water environments?

ⓑ How do animal cells react in an isotonic solution?

ⓒ How can wilted celery be made crisper?

ⓓ How do proteins affect the movement of water through a membrane?

2. The diagram shows a sequence of bases in a strand of DNA.



From left to right, what is the sequence of bases in the complementary strand of DNA?

ⓐ ACTTG

ⓑ TGAAC

ⓒ TGUUC

ⓓ UCTTG

3. Which statement correctly compares the roles of different types of organic molecules in the body?

ⓐ Carbohydrates provide insulation for the body, while nucleic acids provide long-term energy storage.

ⓑ Nucleic acids provide support and structure for the body, while carbohydrates provide insulation.

ⓒ Lipids provide long-term energy storage for the body, while carbohydrates provide quickly available energy.

ⓓ Proteins provide cushioning for organs, while lipids carry the body's genetic information.

4. Students planned an investigation using pea plants. They compared the rate of oxygen consumption in pea plants that were watered daily to the rate of oxygen consumption in pea plants that were not watered. Which question were these students MOST LIKELY investigating?

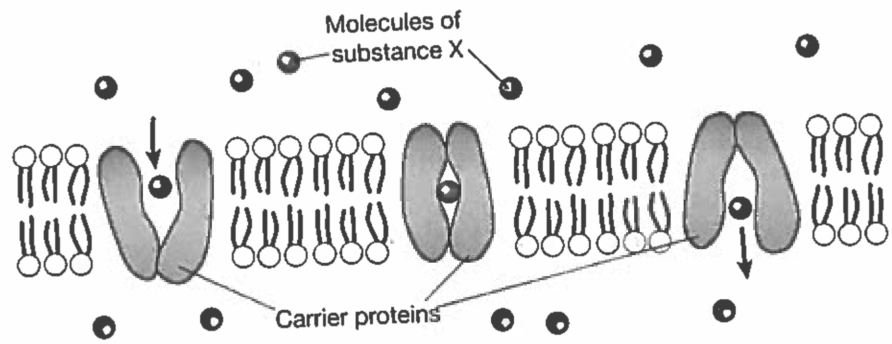
ⓐ Do pea plants carry out photosynthesis?

ⓑ Does the amount of water a plant receives affect photosynthesis?

ⓒ Is the rate of cellular respiration related to the amount of water a plant receives?

ⓓ Do pea plants carry out cellular respiration?

5. The diagram shows a selectively permeable membrane with embedded carrier proteins.



Part A

Which statement BEST describes how embedded proteins help a plasma membrane perform its function?

ⓐ They prevent waste materials from leaving a cell.

ⓑ They prevent water molecules from entering a cell.

ⓒ They allow certain kinds of molecules to enter or leave a cell.

ⓓ They allow substances dissolved in water to enter or leave a cell.

Part B

What information would you need to know to determine whether the diagram shows facilitated transport or active transport?

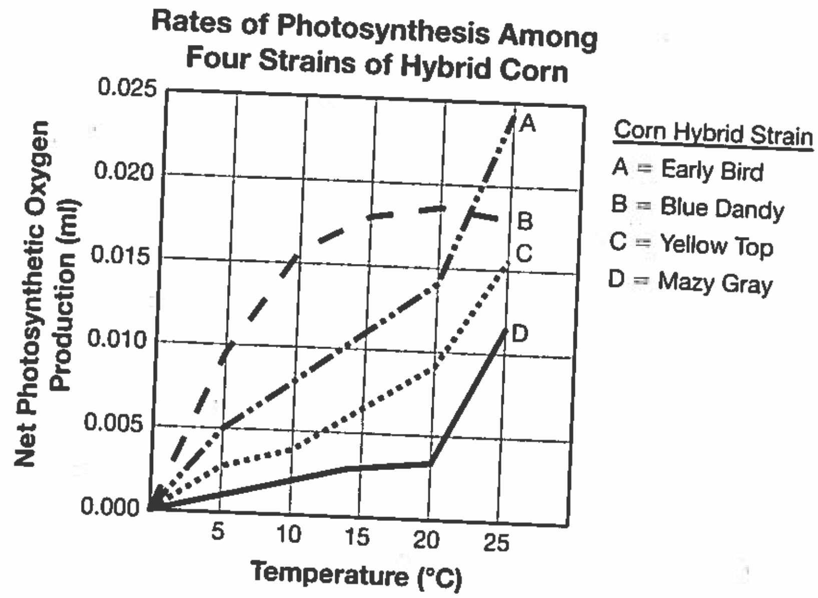
ⓐ the size of the molecules of substance X

ⓑ the type of lipids that make up the cell membrane

ⓒ the concentration of water on each side of the cell membrane

ⓓ the concentration of substance X on each side of the cell membrane

6. The graph shows data gathered in an investigation of the effect of temperature on the rate of photosynthesis.



What explanation is BEST supported by the data in the graph?

ⓐ For these plants, the rate of photosynthesis increases as temperature increases from 0 to 20°C.

ⓑ All types of corn plants photosynthesize at the fastest rate at 25°C.

ⓒ The rate of photosynthesis in these plants will continue to increase as temperatures increase above 25°C.

ⓓ In most types of corn, the rate of photosynthesis is unaffected by temperature.

7. Which DNA sequence produces an mRNA strand with the sequence AGUACA?

ⓐ CAGTAC

ⓑ GUACAG

ⓒ TCATGT

ⓓ UCAUGU

8. Which is the best snack for a runner to choose for quick energy during a race?

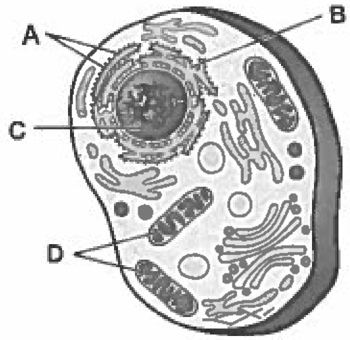
ⓐ a hard-boiled egg, because it is rich in amino acids

ⓑ a hamburger, because fats store long-term energy

ⓒ an apple, because it contains fructose, a monosaccharide

ⓓ a piece of cheese, because protein speeds chemical reactions

9. The diagram shows a cell.



Which organelles help the cell maintain homeostasis by releasing energy from stored food molecules to power cellular function?

ⓐ A and B

ⓑ C only

ⓒ D only

ⓓ B and C

10. If the cell membrane could not function properly, what would be the most immediate impact on a cell's ability to maintain homeostasis?

ⓐ The substances in the cytoplasm would change.

ⓑ Most mitochondria would stop functioning.

ⓒ The instructions for making proteins would be modified.

ⓓ Transport along the endoplasmic reticulum would slow down.

11. DNA replication results in two separate DNA molecules. How are the DNA molecules at the end of the process related to the DNA molecule at the beginning of the process?

ⓐ One strand of the original DNA molecule becomes one strand in each of the new DNA molecules, while each other strand is made from cytoplasmic nucleotides.

ⓑ Both strands of the original DNA molecule are stripped of their nitrogenous bases, and each strand of the new DNA molecules is made using cytoplasmic bases.

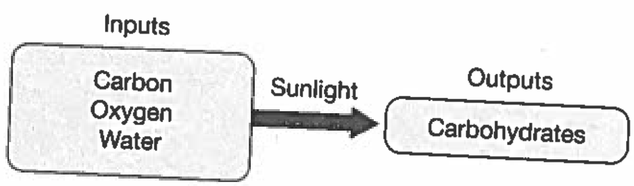
ⓒ Both strands of the original DNA molecule are broken down to their nucleotides, and each strand of the new DNA molecules is made from cytoplasmic nucleotides.

ⓓ Both strands of the original DNA molecule are in one of the new DNA molecules, and the other new DNA molecule is constructed from cytoplasmic nucleotides.

12. At the cellular level, lipids are the primary component of the cell membrane. Which statement would BEST support the argument that the structure of a lipid is related to this function?

ⓐ Lipids contain many hydrogen bonds.
ⓑ Lipids are insoluble.
ⓒ Lipids are constructed to store genetic information.
ⓓ Lipids are composed of amino acids.

13. A student investigated photosynthesis. In her lab report, she wanted to add a diagram summarizing the process. Which flow chart provides the BEST summary of photosynthesis?

ⓐ


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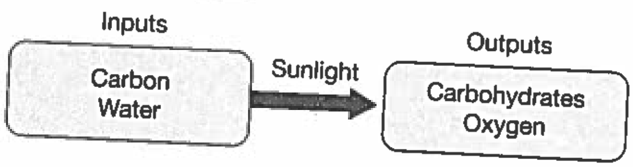

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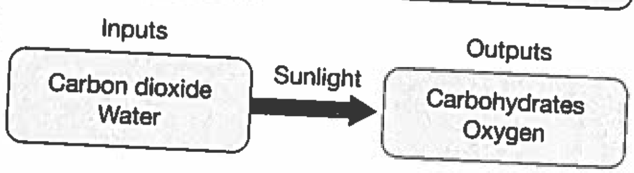

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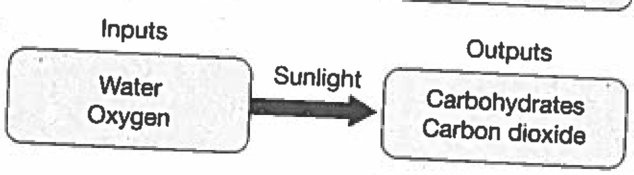

14. Which statement describes ALL prokaryotic and eukaryotic cells?

ⓐ Ribosomes are present in the cytoplasm.
ⓑ Materials are stored in vacuoles.
ⓒ Chloroplasts are used for photosynthesis.
ⓓ Cell walls provide shape and support.