SECTION 3

CELL ORGANELLES AND FEATURES

Eukaryotic cells have many membrane systems. These membranes divide cells into compartments that function together to keep a cell alive.

OBJECTIVES

- **Describe** the structure and function of a cell's plasma membrane.
- **Summarize** the role of the nucleus.
- **List** the major organelles found in the cytosol, and describe their roles.
- **Identify** the characteristics of mitochondria.
- **Describe** the structure and function of the cytoskeleton.

VOCABULARY

phospholipid bilayer
chromosome
nuclear envelope
nucleolus
ribosome
mitochondrion
endoplasmic reticulum
Golgi apparatus
lysosome
cytoskeleton
microtubule
microfilament
cilium
flagellum
centriole

PLASMA MEMBRANE

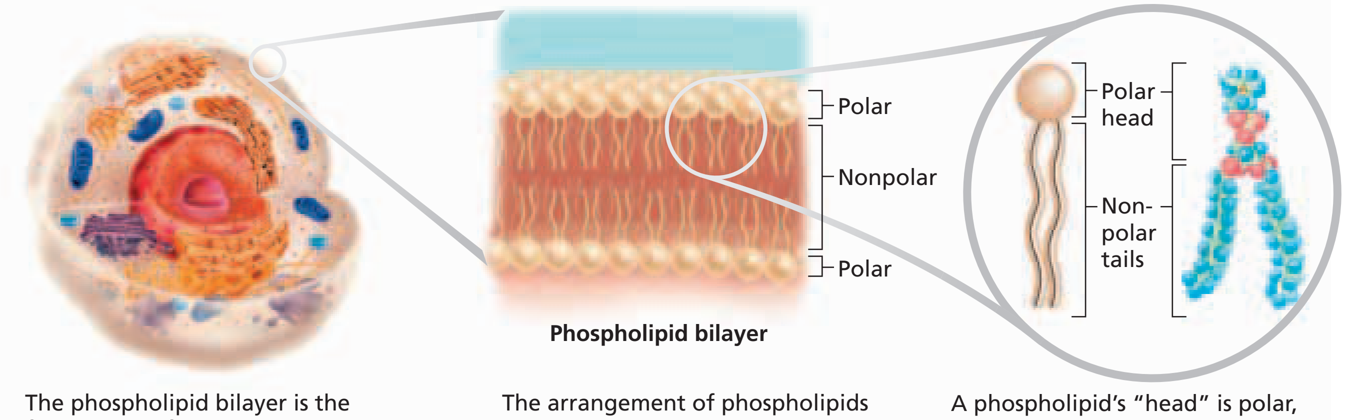
The plasma membrane (also called the *cell membrane*) has several functions. For example, it allows only certain molecules to enter or leave the cell. It separates internal metabolic reactions from the external environment. In addition, the plasma membrane allows the cell to excrete wastes and to interact with its environment.

Membrane Lipids

The plasma membrane, as well as the membranes of cell organelles, is made primarily of phospholipids. Phospholipids have a polar, hydrophilic ("water-loving") phosphate head and two nonpolar, hydrophobic ("water-fearing") fatty acid tails. Water molecules surround the plasma membrane. The phospholipids line up so that their heads point outward toward the water and their tails point inward, away from water. The result is a double layer called a **phospholipid bilayer,** as shown in Figure 4-10. The cell membranes of eukaryotes also contain lipids, called *sterols,* between the tails of the phospholipids. The major membrane sterol in animal cells is cholesterol. Sterols in the plasma membrane make the membrane more firm and prevent the membrane from freezing at low temperatures.

FIGURE 4-10

Cell membranes are made of a phospholipid bilayer. Each phospholipid molecule has a polar "head" and a two-part nonpolar "tail."



The phospholipid bilayer is the foundation of the cell membrane.

The arrangement of phospholipids in the bilayer makes the cell membrane selectively permeable.

A phospholipid's "head" is polar, and its two fatty acid "tails" are nonpolar.

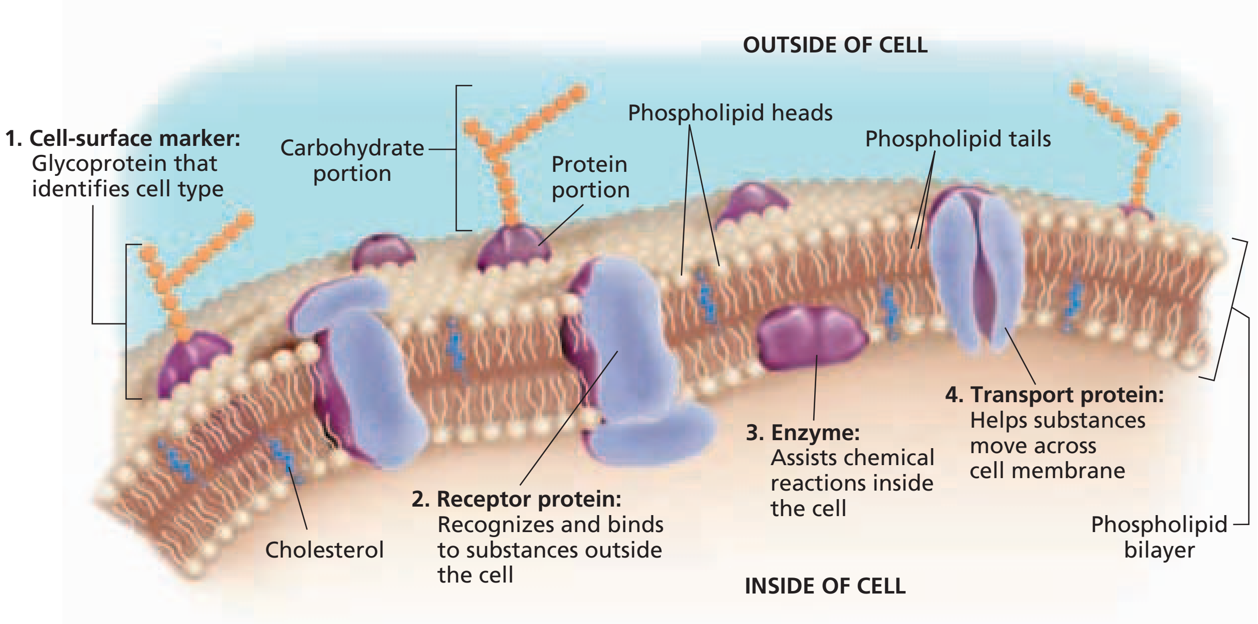


FIGURE 4-11

Cell membranes often contain proteins. Integral proteins include cell-surface markers, receptor proteins, and transport proteins. Enzymes are examples of peripheral proteins.

Membrane Proteins

Plasma membranes often contain specific proteins embedded within the lipid bilayer. These proteins are called *integral proteins*. Figure 4-11 shows that some integral proteins, such as cell surface markers, emerge from only one side of the membrane. Others, such as receptor proteins and transport proteins, extend across the plasma membrane and are exposed to both the cell's interior and exterior environments. Proteins that extend across the plasma membrane are able to detect environmental signals and transmit them to the inside of the cell. *Peripheral proteins,* such as the enzyme shown in Figure 4-11, lie on only one side of the membrane and are not embedded in it.

As Figure 4-11 shows, integral proteins exposed to the cell's external environment often have carbohydrates attached. These carbohydrates can act as labels on cell surfaces. Some labels help cells recognize each other and stick together. Viruses can use these labels as docks for entering and infecting cells.

Integral proteins play important roles in actively transporting molecules into the cell. Some act as channels or pores that allow certain substances to pass. Other integral proteins bind to a molecule on the outside of the cell and then transport it through the membrane. Still others act as sites where chemical messengers such as hormones can attach.

Fluid Mosaic Model

A cell's plasma membrane is surprisingly dynamic. Scientists describe the cell membrane as a fluid mosaic. The *fluid mosaic model* states that the phospholipid bilayer behaves like a fluid more than it behaves like a solid. The membrane's lipids and proteins can move laterally within the bilayer, like a boat on the ocean. As a result of such lateral movement, the pattern, or "mosaic," of lipids and proteins in the cell membrane constantly changes.

NUCLEUS

Most of the functions of a eukaryotic cell are controlled by the nucleus, shown in Figure 4-12. The nucleus is filled with a jellylike liquid called the *nucleoplasm,* which holds the contents of the nucleus and is similar in function to a cell's cytoplasm.

The nucleus houses and protects the cell's genetic information. The hereditary information that contains the instructions for the structure and function of the organism is coded in the organism's DNA, which is contained in the nucleus. When a cell is not dividing, the DNA is in the form of a threadlike material called *chromatin.* When a cell is about to divide, the chromatin condenses to form **chromosomes.** Chromosomes are structures in the nucleus made of DNA and protein.

The nucleus is the site where DNA is transcribed into ribonucleic acid (RNA). RNA moves through nuclear pores to the cytoplasm, where, depending on the type of RNA, it carries out its function.

Nuclear Envelope

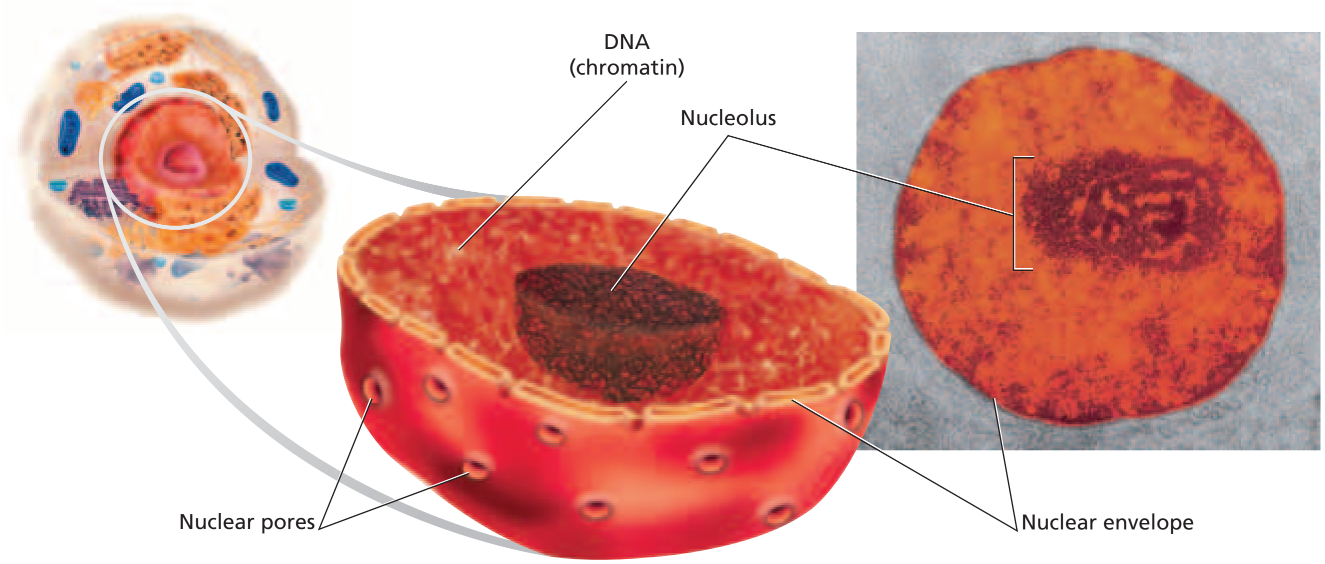
The nucleus is surrounded by a double membrane called the **nuclear envelope.** The nuclear envelope is made up of two phospholipid bilayers. Covering the surface of the nuclear envelope are tiny, protein-lined holes, which are called *nuclear pores*. The nuclear pores provide passageways for RNA and other materials to enter and leave the nucleus.

Nucleolus

Most nuclei contain at least one denser area, called the **nucleolus** (noo-KLEE-uh-luhs). The nucleolus (plural, *nucleoli*) is the site where DNA is concentrated when it is in the process of making ribosomal RNA. **Ribosomes** (RIE-buh-SOHMZ) are organelles made of protein and RNA that direct protein synthesis in the cytoplasm.

FIGURE 4-12

The nucleus of a cell is surrounded by a double membrane called the nuclear envelope. The nucleus stores the cell's DNA.



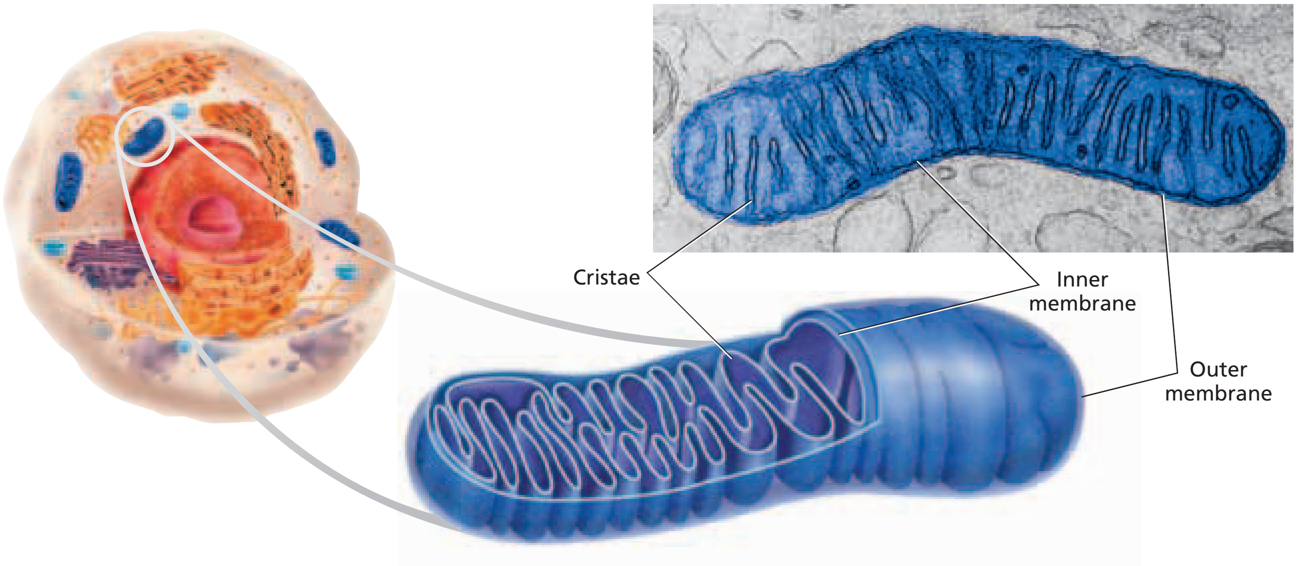


FIGURE 4-13
Mitochondria convert organic molecules into energy for the cell. Mitochondria have an inner membrane and an outer membrane. The folds of the inner membrane, called *cristae*, are the site of energy conversion.

MITOCHONDRIA

Mitochondria (MIET-oh-KAHN-dree-uh) (singular, *mitochondrion*) are tiny organelles that transfer energy from organic molecules to adenosine triphosphate (ATP). ATP ultimately powers most of the cell's chemical reactions. Highly active cells, such as muscle cells, can have hundreds of mitochondria. Cells that are not very active, such as fat-storage cells, have few mitochondria.

Like a nucleus, a mitochondrion has an inner and an outer phospholipid membrane, as shown in Figure 4-13. The outer membrane separates the mitochondrion from the cytosol. The inner membrane has many folds, called *cristae* (KRIS-tee). Cristae contain proteins that carry out energy-harvesting chemical reactions.

Mitochondrial DNA

Mitochondria have their own DNA and can reproduce only by the division of preexisting mitochondria. Scientists think that mitochondria originated from prokaryotic cells that were incorporated into ancient eukaryotic cells. This symbiotic relationship provided the prokaryotic invaders with a protected place to live and provided the eukaryotic cell with an increased supply of ATP.

FIGURE 4-14
Ribosomes are the organelles responsible for building protein. Ribosomes have a large and small subunit, each made of protein and ribosomal RNA. Some ribosomes are free in the cell. Others are attached to the rough endoplasmic reticulum.

RIBOSOMES

Ribosomes are small, roughly spherical organelles that are responsible for building protein. Ribosomes do not have a membrane. They are made of protein and RNA molecules. Ribosome assembly begins in the nucleolus and is completed in the cytoplasm. One large and one small subunit come together to make a functioning ribosome, shown in Figure 4-14. Some ribosomes are free within the cytosol. Others are attached to the rough endoplasmic reticulum.

ENDOPLASMIC RETICULUM

The **endoplasmic reticulum** (EN-doh-PLAZ-mik ri-TIK-yuh-luhm), abbreviated ER, is a system of membranous tubes and sacs, called *cisternae* (sis-TUHR-nee). The ER functions primarily as an intracellular highway, a path along which molecules move from one part of the cell to another. The amount of ER inside a cell fluctuates, depending on the cell's activity. There are two types of ER: rough and smooth. The two types of ER are thought to be continuous.

Word Roots and Origins

reticulum

from the Latin *rete,* meaning "net"; *reticulum* means "little net"

Rough Endoplasmic Reticulum

The rough endoplasmic reticulum is a system of interconnected, flattened sacs covered with ribosomes, as shown in Figure 4-15. The rough ER produces phospholipids and proteins. Certain types of proteins are made on the rough ER's ribosomes. These proteins are later exported from the cell or inserted into one of the cell's own membranes. For example, ribosomes on the rough ER make digestive enzymes, which accumulate inside the endoplasmic reticulum. Little sacs or vesicles then pinch off from the ends of the rough ER and store the digestive enzymes until they are released from the cell. Rough ER is most abundant in cells that produce large amounts of protein for export, such as cells in digestive glands and antibody-producing cells.

Smooth Endoplasmic Reticulum

The smooth ER lacks ribosomes and thus has a smooth appearance. Most cells contain very little smooth ER. Smooth ER builds lipids such as cholesterol. In the ovaries and testes, smooth ER produces the steroid hormones estrogen and testosterone. In skeletal and heart muscle cells, smooth ER releases calcium, which stimulates contraction. Smooth ER is also abundant in liver and kidney cells, where it helps detoxify drugs and poisons. Long-term abuse of alcohol and other drugs causes these cells to produce more smooth ER. Increased amounts of smooth ER in liver cells is one of the factors that can lead to drug tolerance. As Figure 4-15 shows, rough ER and smooth ER form an interconnected network.

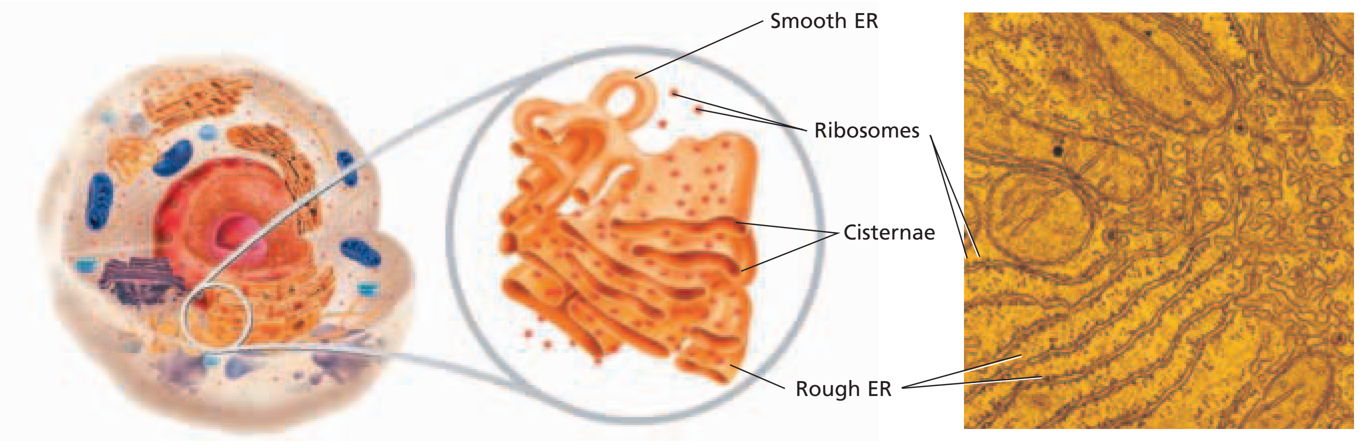


FIGURE 4-15

The endoplasmic reticulum (ER) serves as a site of synthesis for proteins, lipids, and other materials. The dark lines in the photo represent the membranes of the ER, and the narrow lighter areas between the dark lines show the channels and spaces (cisternae) inside the ER.

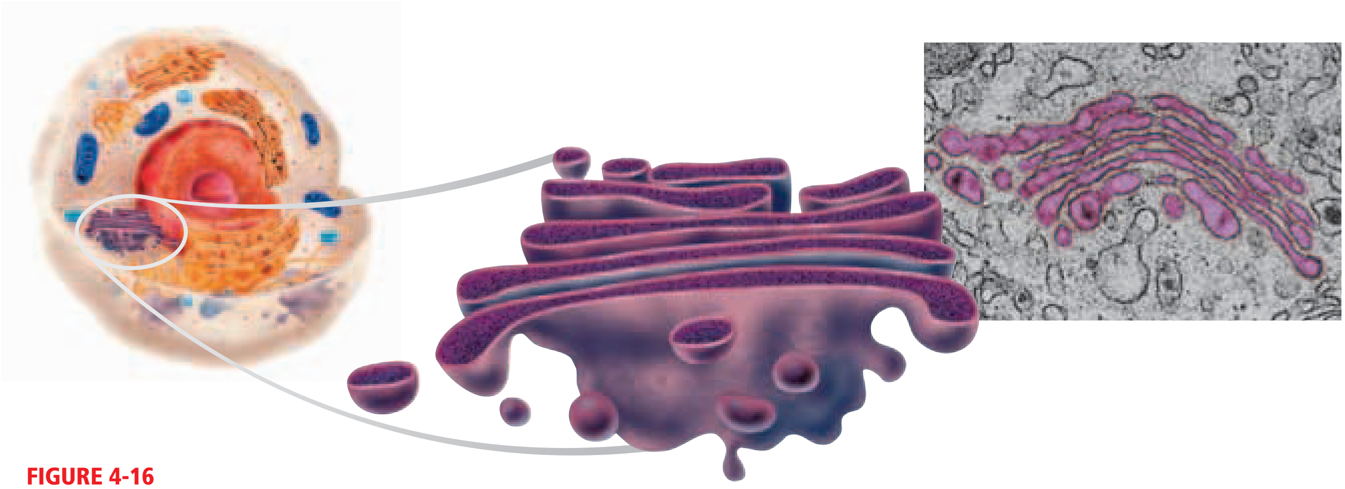


FIGURE 4-16
The Golgi apparatus modifies many cellular products and prepares them for export.

GOLGI APPARATUS

The **Golgi apparatus,** shown in Figure 4-16, is another system of flattened, membranous sacs. The sacs nearest the nucleus receive vesicles from the ER containing newly made proteins or lipids. Vesicles travel from one part of the Golgi apparatus to the next and transport substances as they go. The stacked membranes modify the vesicle contents as they move along. The proteins get “address labels” that direct them to various other parts of the cell. During this modification, the Golgi apparatus can add carbohydrate labels to proteins or alter new lipids in various ways.

VESICLES

Cells contain several types of vesicles, which perform various roles. Vesicles are small, spherically shaped sacs that are surrounded by a single membrane and that are classified by their contents. Vesicles often migrate to and merge with the plasma membrane. As they do, they release their contents to the outside of the cell.

Lysosomes

Lysosomes (LIE-suh-SOHMZ) are vesicles that bud from the Golgi apparatus and that contain digestive enzymes. These enzymes can break down large molecules, such as proteins, nucleic acids, carbohydrates, and phospholipids. In the liver, lysosomes break down glycogen in order to release glucose into the bloodstream. Certain white blood cells use lysosomes to break down bacteria. Within a cell, lysosomes digest worn-out organelles in a process called *autophagy* (aw-TAHF-uh-jee).

Lysosomes are also responsible for breaking down cells when it is time for the cells to die. The digestion of damaged or extra cells by the enzymes of their own lysosomes is called *autolysis* (aw-TAHL-uh-sis). Lysosomes play a very important role in maintaining an organism’s health by destroying cells that are no longer functioning properly.

Peroxisomes

Peroxisomes are similar to lysosomes but contain different enzymes and are not produced by the Golgi apparatus. Peroxisomes are abundant in liver and kidney cells, where they neutralize free radicals (oxygen ions that can damage cells) and detoxify alcohol and other drugs. Peroxisomes are named for the hydrogen peroxide, H_2O_2, they produce when breaking down alcohol and killing bacteria. Peroxisomes also break down fatty acids, which the mitochondria can then use as an energy source.

Other Vesicles

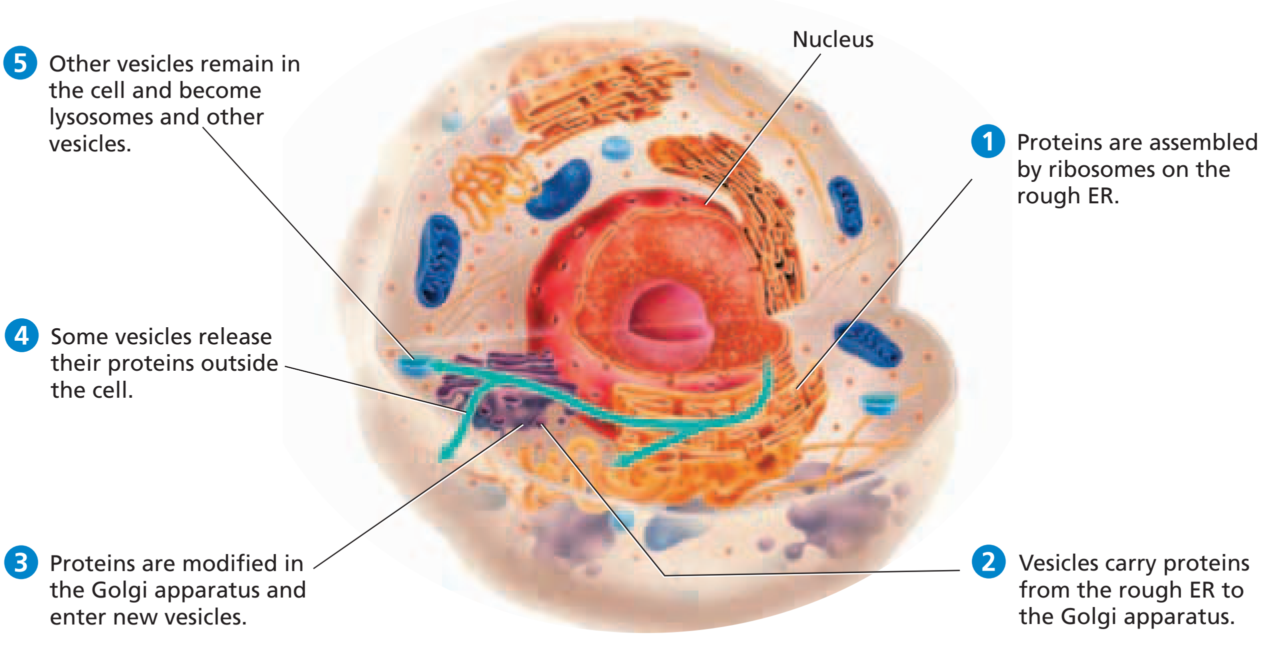
Specialized peroxisomes, called *glyoxysomes,* can be found in the seeds of some plants. They break down stored fats to provide energy for the developing plant embryo. Some cells engulf material by surrounding it with plasma membrane. The resulting pocket buds off to become a vesicle inside the cell. This vesicle is called an *endosome*. Lysosomes fuse with endosomes and digest the engulfed material. Food vacuoles are vesicles that store nutrients for a cell. Contractile vacuoles are vesicles that can contract and dispose of excess water inside a cell.

Protein Synthesis

One of the major functions of a cell is the production of protein. The path some proteins take from synthesis to export can be seen in Figure 4-17. In step 1, proteins are assembled by ribosomes on the rough ER. Then, in step 2, vesicles transport proteins to the Golgi apparatus. In step 3, the Golgi modifies proteins and packages them in new vesicles. In step 4, vesicles release proteins that have destinations outside the cell. In step 5, vesicles containing enzymes remain inside the cell as lysosomes, peroxisomes, endosomes, or other types of vesicles.

FIGURE 4-17

The rough ER, Golgi apparatus, and vesicles work together to transport proteins to their destinations inside and outside the cell.



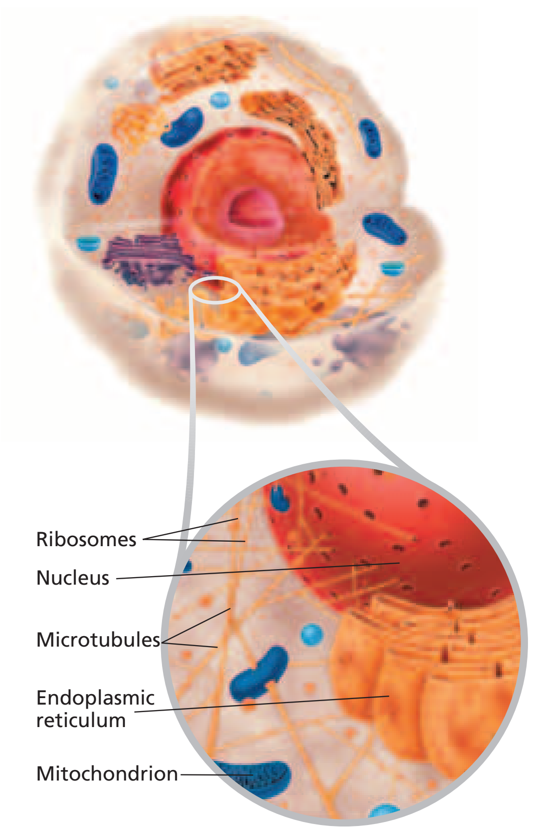


FIGURE 4-18

Microtubules provide a path for organelles and molecules as they move throughout the cell.

CYTOSKELETON

The **cytoskeleton** is a network of thin tubes and filaments that crisscrosses the cytosol. The tubes and filaments give shape to the cell from the inside in the same way that tent poles support the shape of a tent. The cytoskeleton also acts as a system of internal tracks, shown in Figure 4-18, on which items move around inside the cell. The cytoskeleton's functions are based on several structural elements. Three of these are microtubules, microfilaments, and intermediate filaments, shown and described in Table 4-2.

Microtubules

Microtubules are hollow tubes made of a protein called *tubulin.* Each tubulin molecule consists of two slightly different subunits. Microtubules radiate outward from a central point called the *centrosome* near the nucleus. Microtubules hold organelles in place, maintain a cell's shape, and act as tracks that guide organelles and molecules as they move within the cell.

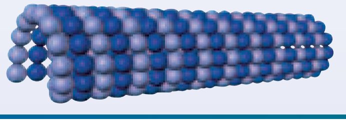
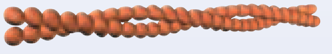
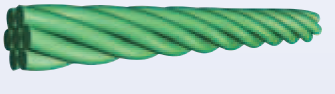
Microfilaments

Finer than microtubules, **microfilaments** are long threads of the beadlike protein actin and are linked end to end and wrapped around each other like two strands of a rope. Microfilaments contribute to cell movement, including the crawling of white blood cells and the contraction of muscle cells.

Intermediate Filaments

Intermediate filaments are rods that anchor the nucleus and some other organelles to their places in the cell. They maintain the internal shape of the nucleus. Hair-follicle cells produce large quantities of intermediate filament proteins. These proteins make up most of the hair shaft.

TABLE 4-2 ***The Structure of the Cytoskeleton***

Property	Microtubules	Microfilaments	Intermediate filaments
Structure	hollow tubes made of coiled protein	two strands of intertwined protein	protein fibers coiled into cables
Protein subunits	tubulin, with two subunits: α and β tubulin	actin	one of several types of fibrous proteins
Main function	maintenance of cell shape; cell motility (in cilia and flagella); chromosome movement; organelle movement	maintenance and changing of cell shape; muscle contraction; movement of cytoplasm; cell motility; cell division	maintenance of cell shape; anchor nucleus and other organelles; maintenance of shape of nucleus
Shape			

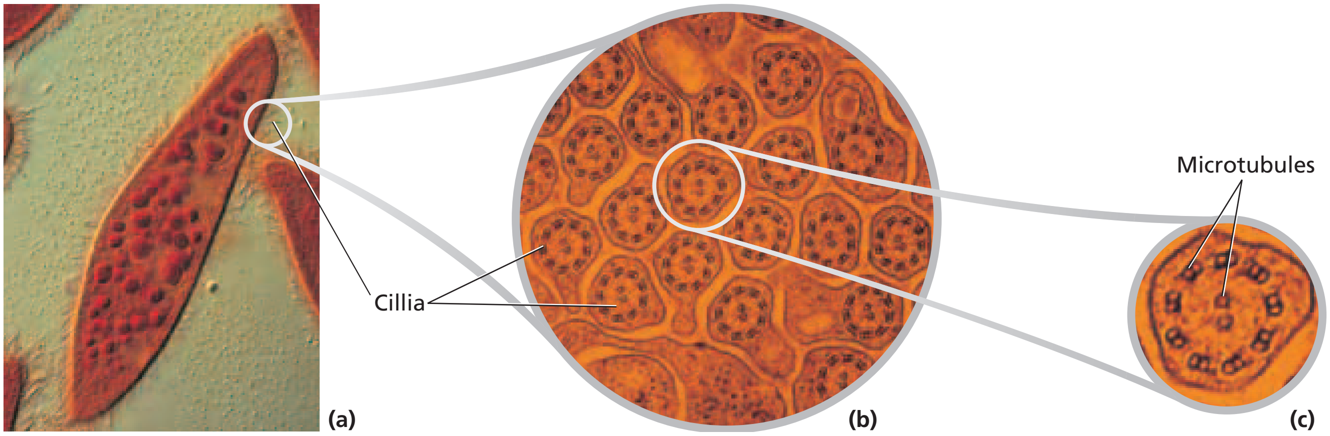


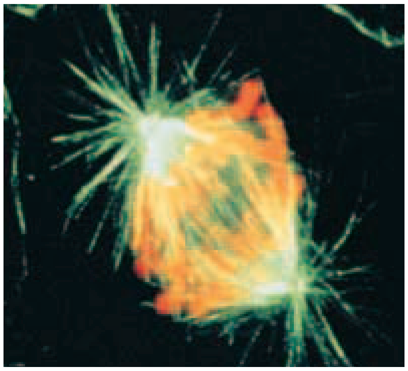
FIGURE 4-19
A SEM of a paramecium shows cilia on the surface of the cell (a). A TEM of a cross section of those cilia (b) reveals the internal structure of the cilia. The characteristic 9+2 configuration of microtubules can be clearly seen (c).

Cilia and Flagella

Cilia (SIL-ee-uh) and **flagella** (fluh-JEL-uh) are hairlike structures that extend from the surface of the cell, where they assist in movement. Cilia are short and are present in large numbers on certain cells, whereas flagella are longer and are far less numerous on the cells where they occur. Cilia and flagella have a membrane on their outer surface and an internal structure of nine pairs of microtubules around two central tubules, as Figure 4-19 shows.

Cilia on cells in the inner ear vibrate and help detect sound. Cilia cover the surfaces of many protists and “row” the protists through water like thousands of oars. On other protists, cilia sweep water and food particles into a mouthlike opening. Many kinds of protists use flagella to propel themselves, as do human sperm cells.

FIGURE 4-20
During cell division, centrioles organize microtubules that pull the chromosomes (orange) apart. The centrioles are at the center of rays of microtubules, which have been stained green with a fluorescent dye.



Centrioles

Centrioles consist of two short cylinders of microtubules at right angles to each other and are situated in the cytoplasm near the nuclear envelope. Centrioles occur in animal cells, where they organize the microtubules of the cytoskeleton during cell division, as shown in Figure 4-20. Plant cells lack centrioles. Basal bodies have the same structure that centrioles do. Basal bodies are found at the base of cilia and flagella and appear to organize the development of cilia and flagella.

SECTION 3 REVIEW

1. Explain how the fluid mosaic model describes the plasma membrane.
2. List three cellular functions that occur in the nucleus.
3. Describe the organelles that are found in a eukaryotic cell.
4. Identify two characteristics that make mitochondria different from other organelles.
5. Contrast three types of cytoskeletal fibers.

CRITICAL THINKING

6. **Relating Concepts** If a cell has a high energy requirement, would you expect the cell to have many mitochondria or few mitochondria? Why?
7. **Analyzing Information** How do scientists think that mitochondria originated? Why?
8. **Analyzing Statements** It is not completely accurate to say that organelles are floating freely in the cytosol. Why not?