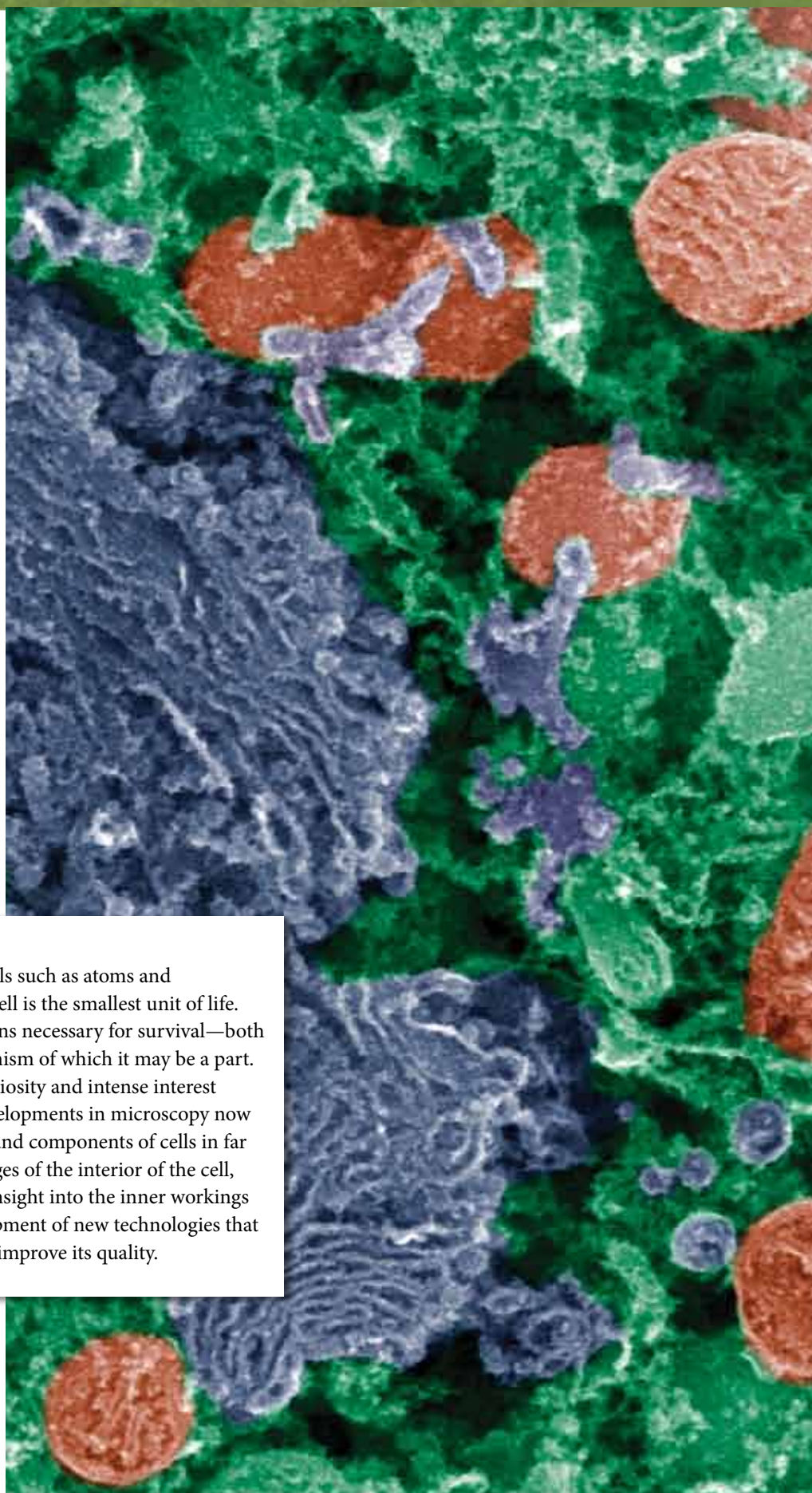
CHAPTER
2 The Cell and Its Components

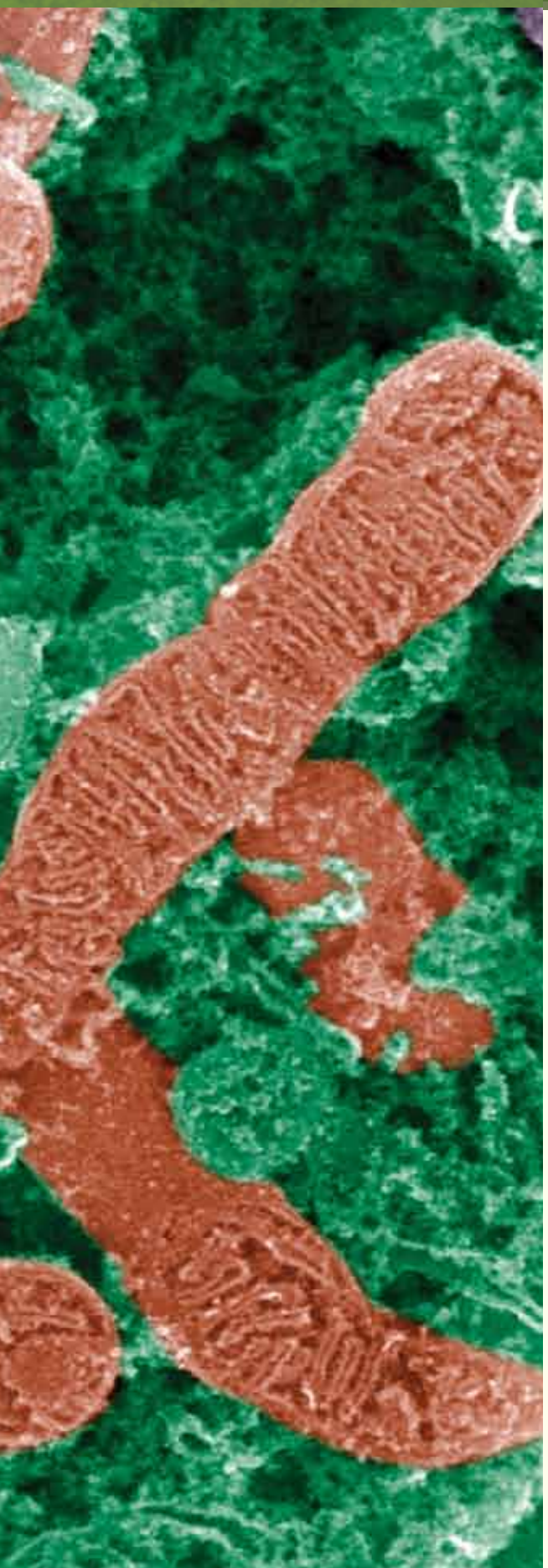
Specific Expectations

In this chapter, you will learn how to . . .

- B1.2 **evaluate**, on the basis of research, some advances in cellular biology and related technological applications (2.2)
- B2.1 **use** appropriate terminology related to biochemistry (2.1, 2.2)
- B2.2 **plan** and **conduct** an investigation to demonstrate the movement of substances across a membrane (2.2)
- B3.1 **explain** the roles of various organelles, such as lysosomes, vacuoles, mitochondria, internal cell membranes, ribosomes, smooth and rough endoplasmic reticulum, and Golgi bodies, in cellular processes (2.1)
- B3.6 **describe** the structure of cell membranes according to the fluid mosaic model, and **explain** the dynamics of passive transport, facilitated diffusion, and the movement of large particles across the cell membrane by the processes of endocytosis and exocytosis (2.2)



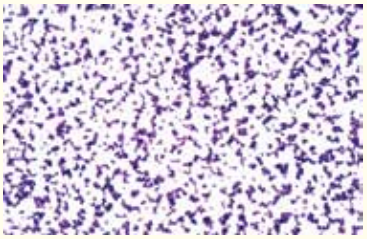
The cell is composed of non-living materials such as atoms and molecules, but it is itself a living entity. The cell is the smallest unit of life. Yet it is capable of performing all the functions necessary for survival—both for itself and for an entire multicellular organism of which it may be a part. Scientists have studied the cell with great curiosity and intense interest since its discovery in the 1660s. Modern developments in microscopy now provide the ability to examine the structure and components of cells in far greater detail than ever before. Detailed images of the interior of the cell, such as the one shown here, have provided insight into the inner workings of the cell and have in turn led to the development of new technologies that combat illness and disease, prolong life, and improve its quality.



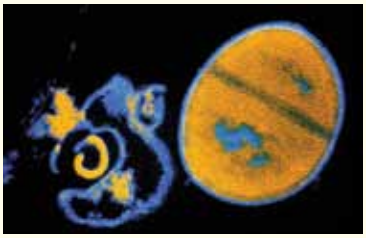
Launch Activity

Look a Little Closer

The bacterium *Staphylococcus aureus* is microscopic, but its effects on the body can be deadly. *S. aureus* can cause food poisoning, boils, rashes, blood infections, and kidney failure, among other problems. In addition, some strains of *S. aureus* are resistant to antibiotics that would normally damage the bacterial cell wall. How can microscopy be used in the fight against this bacterium? What can you learn from different microscope images?



Staphyloccous aureus as viewed under a light microscope.



Staphyloccous aureus as viewed under a transmission electron micrograph

The microscope image on the left was made with a light microscope. A technique called a Gram stain was used to stain the bacterial cells. *S. aureus* is described as Gram positive because it stains purple with the Gram stain. The microscope image on the right was made with a transmission electron microscope (TEM). The TEM directs a beam of electrons through thin slices of the specimen in order to produce an image. Colour can be added to the image later, as shown here.

Procedure

1. Your group will be divided into two teams. The clinical microbiology team will examine the light microscope image. The research lab team will examine the TEM image.
2. With your team, examine your assigned microscope image and make a list of all the details you can observe. For example, note shapes, arrangements of shapes, colours, and level of detail.
3. Take turns with the other team to present your findings to one another.
4. As a group, re-examine and compare the microscope images and list some information that each type of microscopy *cannot* provide.

Questions

1. One of the goals of a clinical microbiologist is to find out which bacterial species is making a person ill. How might a light microscope image help a clinical microbiologist to identify a bacterial species?
2. Research microbiologists have the potential to help people around the world by studying disease-causing bacteria. How might a TEM image help researchers to study the effects of an antibiotic on bacteria?
3. Is one type of microscopy more useful than another? Justify your response.

SECTION 2.1

Structures and Functions of Eukaryotic Cells

Key Terms

nucleolus
nuclear envelope
nuclear pore complexes
endoplasmic reticulum (ER)
ribosome
endomembrane system
vesicle
Golgi apparatus
lysosome
peroxisome
vacuole
chloroplast
mitochondrion
cell wall
cytoskeleton
fluid mosaic model

Animals, plants, fungi, and protists are composed of eukaryotic cells. Cellular organization varies among different organisms, but all eukaryotic cells have these features in common.

- The genetic material—DNA—is contained within a membrane-bound nucleus.
- A *cell membrane* comprised of a *phospholipid bilayer* (double layer) and embedded proteins separates the cell's contents from its surroundings. Note: You will study the cell membrane in section 2.2.
- Filling the cell interior is the jelly-like *cytoplasm*, which consists of everything outside the nucleus but within the cell membrane. This includes the organelles, cytosol, and molecules and ions dissolved or suspended in the cytosol. The cytosol is the fluid itself.

Figure 2.1 and **Figure 2.2** identify the components of a generalized animal and plant cell. The structures and organelles shown in these diagrams and described in the remainder of this section are common to most eukaryotic cells, but there are exceptions. For example, erythrocytes (red blood cells) lack nuclei and the genetic material contained in them, so they are not capable of reproduction.

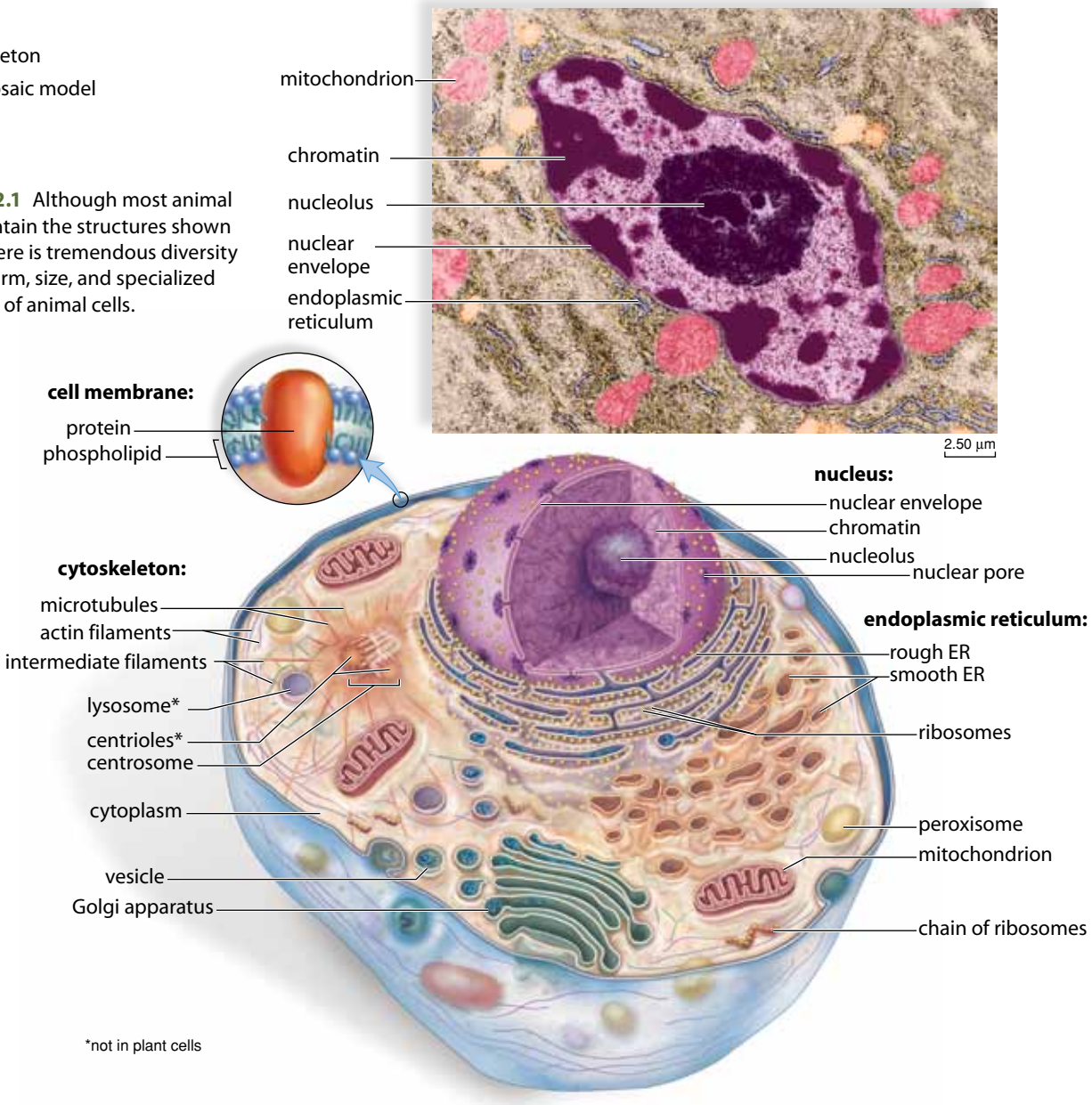


Figure 2.1 Although most animal cells contain the structures shown here, there is tremendous diversity in the form, size, and specialized features of animal cells.

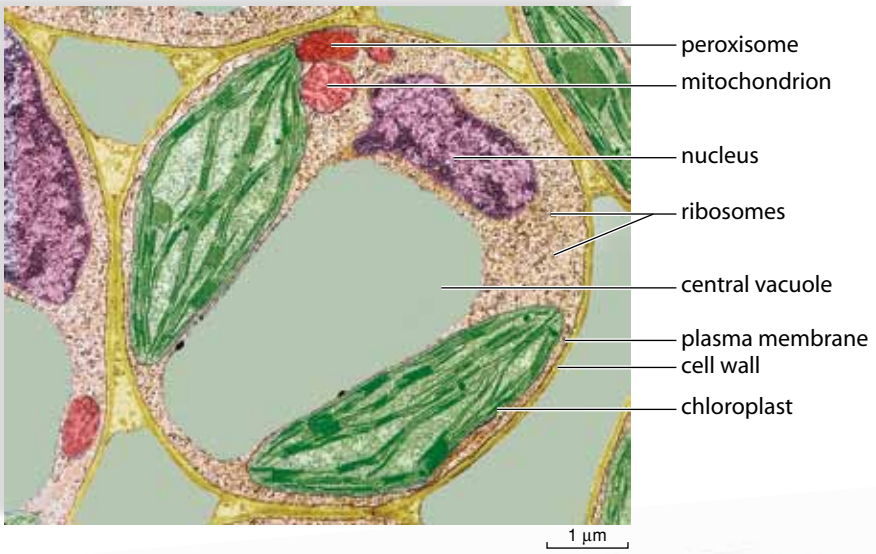
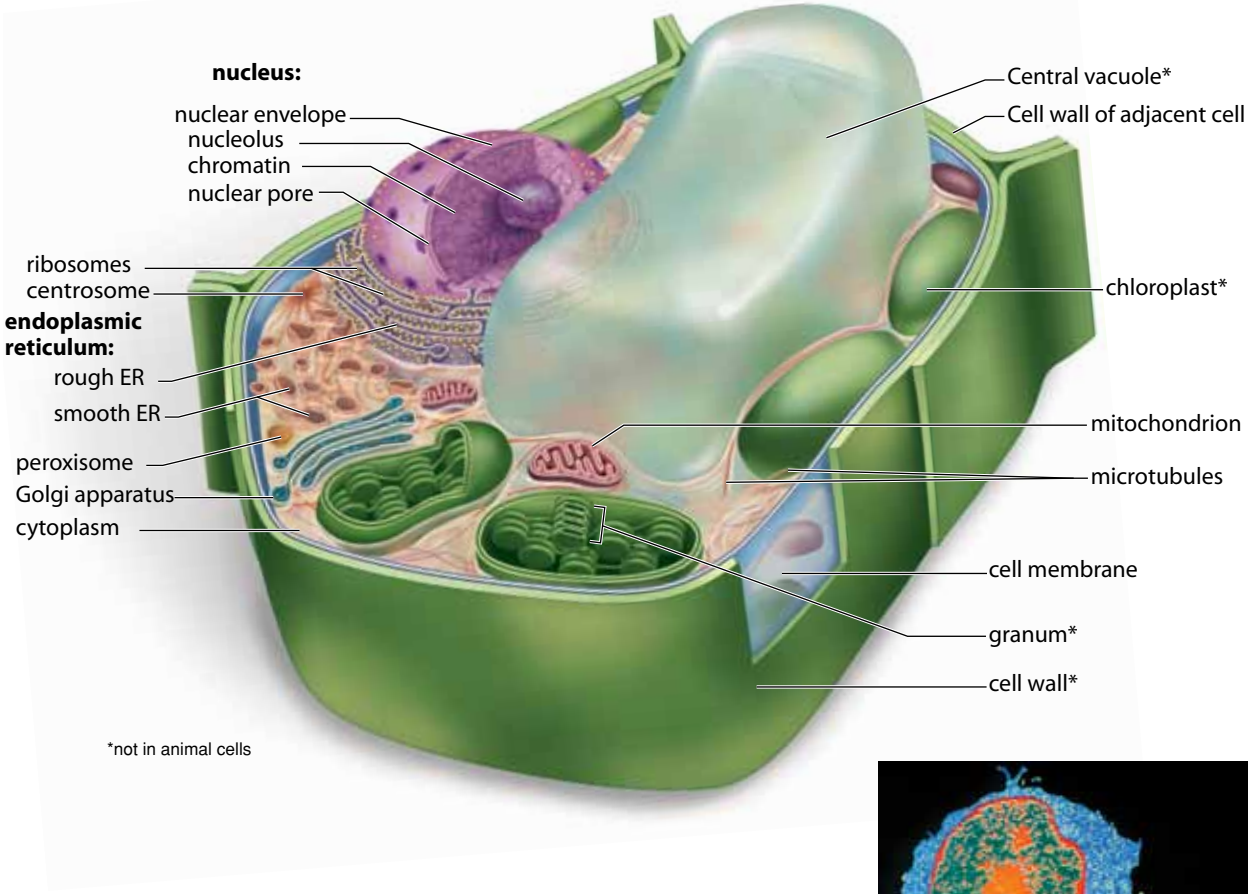


Figure 2.2 Although most plant cells contain the structures shown here, plant cells also exhibit great diversity in their form, size, and specialized features.

***Identify** the organelles that plant cells have but which animal cells lack, and **explain** their significance to plants.*



The Nucleus

The cell nucleus, shown in **Figure 2.3**, contains DNA, which stores and replicates the genetic information of the cell. Each molecule of DNA in the nucleus combines with an equal mass of protein to form a *chromosome*. The number of chromosomes in the nucleus varies from species to species. For example, humans have 46 chromosomes, while mosquitoes have only 6 chromosomes. Chromosomes are visible only in dividing cells. In a non-dividing cell, *chromatin*, a complex mixture of DNA and proteins , represents the unfolded state of chromosomes.

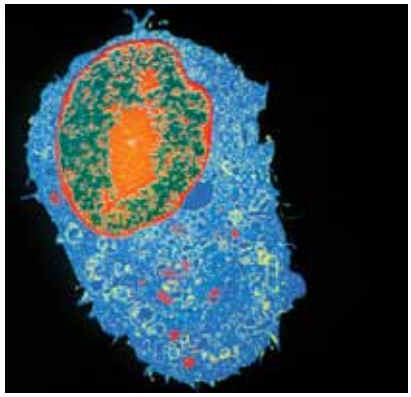


Figure 2.3 The nucleus here is outlined with an orange line. The large region, coloured orange, within the nucleus is the nucleolus.

nucleolus a non-membrane-bound structure in the nucleus, which contains RNA and proteins

nuclear envelope a double membrane surrounding the nucleus

nuclear pore complex a group of proteins forming openings in the nuclear envelope

Various structures and regions of the nucleus are shown in greater detail in **Figure 2.4**. A thick fluid called *nucleoplasm* fills the nucleus, and a network of protein fibres called the *nuclear matrix* provides internal structure and support. Within the nucleus is the **nucleolus**, a denser region containing RNA, protein, and chromatin. The nucleus is surrounded by the **nuclear envelope**, a double membrane consisting of two phospholipid bilayers, which separates the nucleus from the rest of the cell. The narrow space between these, or any two, bilayers is called the *lumen*. The nuclear envelope is studded with thousands of **nuclear pore complexes**, groups of proteins that form openings in the nuclear envelope. Small particles such as water and ions travel freely through these openings, but the passage of macromolecules such as RNA is controlled by the nuclear pores.

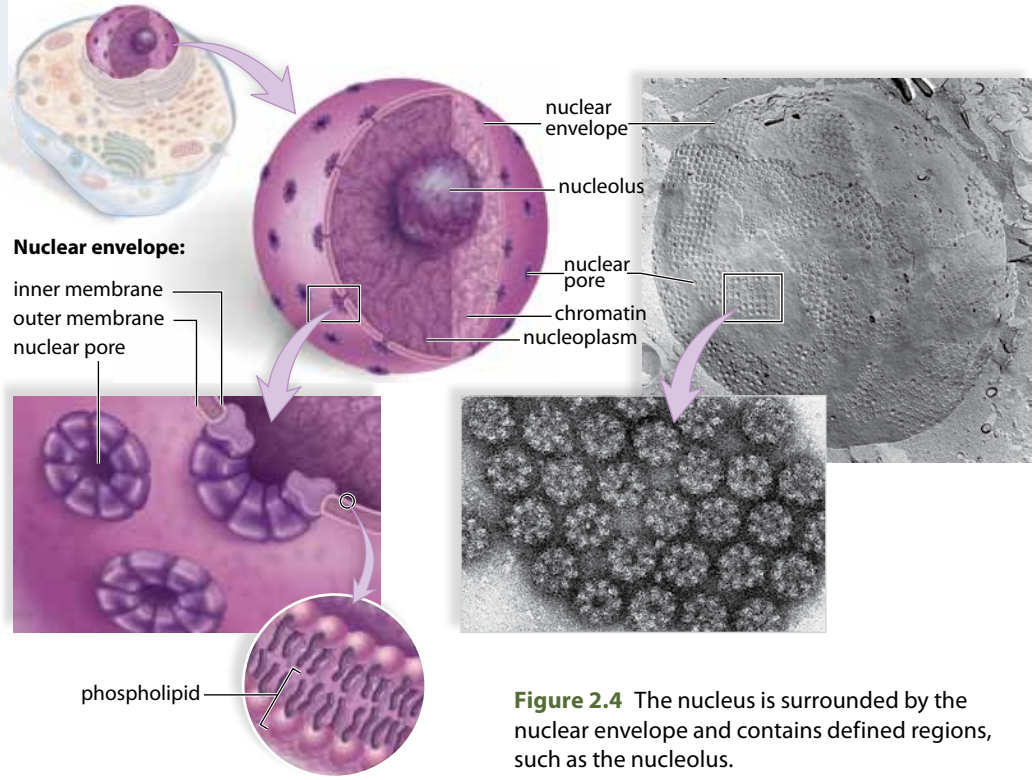


Figure 2.4 The nucleus is surrounded by the nuclear envelope and contains defined regions, such as the nucleolus.

The Endoplasmic Reticulum

endoplasmic reticulum (ER) a complex system of channels and sacs composed of membranes enclosing a lumen; made up of two parts, the rough ER and the smooth ER

ribosome a structure composed of RNA and proteins, and responsible for synthesis of polypeptides in the cytosol and on the surface of the rough endoplasmic reticulum

The nuclear envelope is connected to and part of a complex of membrane-bound tubules and sacs called the **endoplasmic reticulum (ER)**, shown in **Figure 2.5**. The ER surface regions devoted to the synthesis of proteins are studded with **ribosomes**—molecular aggregates of proteins and RNA. Through an electron microscope, ribosome-rich parts of the ER look like sandpaper and are thus called *rough endoplasmic reticulum*. Proteins that are part of membranes or intended for export from the cell are assembled by rough ER ribosomes. Proteins that function in the cytosol are made by ribosomes that are freely suspended there.

Regions of the ER that have no bound ribosomes are called smooth endoplasmic reticulum. The smooth ER synthesizes lipids and lipid-containing molecules such as the phospholipids that make up membranes. Smooth ER performs other functions depending on the type of cell. For example, in the liver, smooth ER helps detoxify drugs and alcohol. In the testes and ovaries, smooth ER produces testosterone and estrogen.

Ribosomes of eukaryotes have different structures and mechanisms compared with those of prokaryotes. This is one reason why antibiotics taken for bacterial infections kill the bacteria cells but not the cells of the body. For example, tetracycline is an antibiotic that inhibits protein synthesis in prokaryotic ribosomes, but it does not affect protein synthesis in human cells.

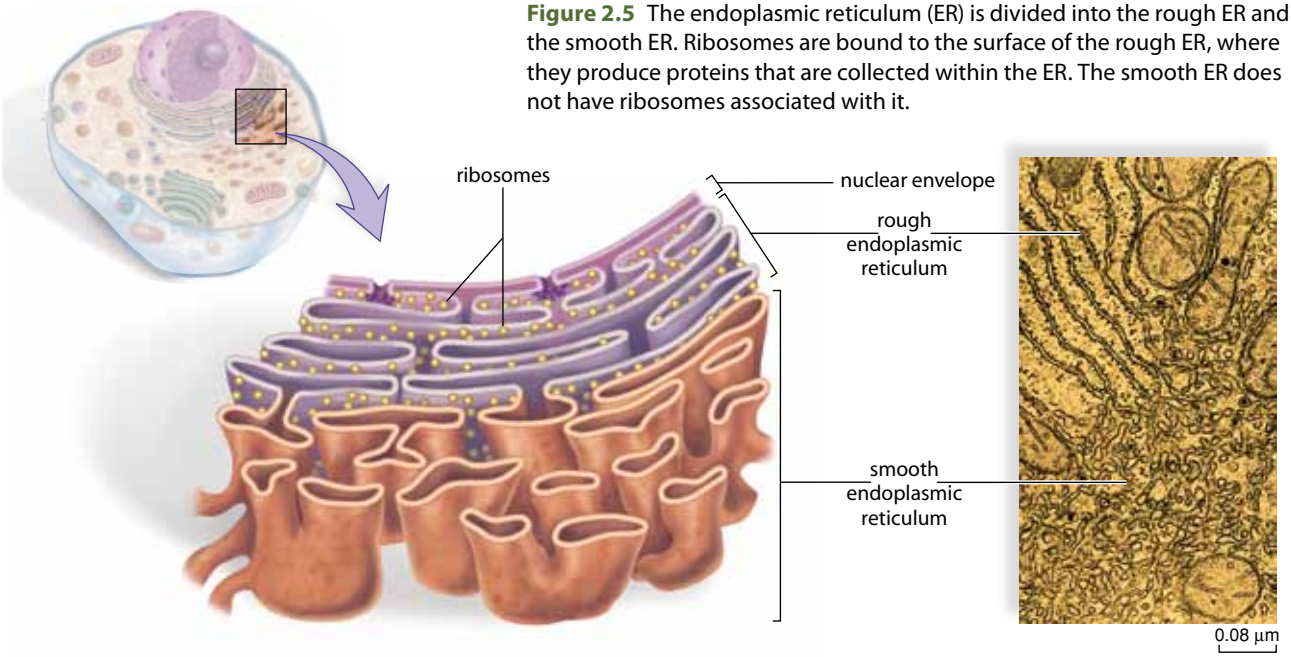


Figure 2.5 The endoplasmic reticulum (ER) is divided into the rough ER and the smooth ER. Ribosomes are bound to the surface of the rough ER, where they produce proteins that are collected within the ER. The smooth ER does not have ribosomes associated with it.

The Endomembrane System: Protein Modification and Transport

The **endomembrane system**, shown in **Figure 2.6**, consists of the nuclear envelope, the endoplasmic reticulum, the Golgi apparatus (described on the next page), and vesicles (also described on the next page). This system acts as the transportation and product-processing section of the cell. The endomembrane system compartmentalizes the cell so that particular functions are restricted to specific regions. The organelles that make up the endomembrane system are connected to one another either directly or by transport vesicles.

endomembrane system the system within the cell that acts to synthesize, modify, and transport proteins and other cell products; includes the endoplasmic reticulum, the Golgi apparatus, vesicles, and the cell membrane, among other structures

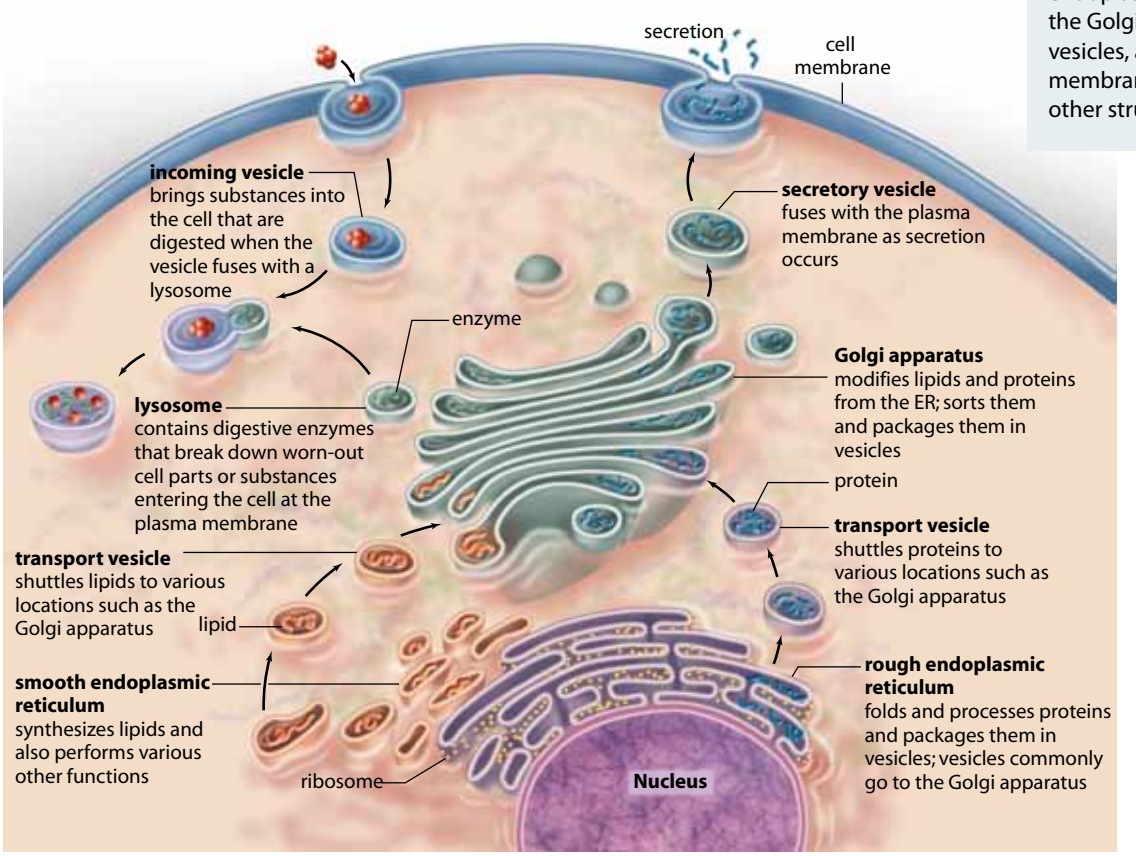


Figure 2.6 The endomembrane system is composed of different organelles that are connected and work together to carry out a number of processes in the cell.

vesicle a membrane-enclosed sac used for transport and storage

Golgi apparatus a stack of curved membrane sacs that packages, processes, sorts, and distributes proteins, lipids, and other substances within the cell; acts like a "post office" for the cell

lysosome a membrane-bound vesicle containing enzymes that catalyze hydrolysis reactions, breaking down macromolecules

Functions of the Endomembrane System

The endomembrane system modifies and transports proteins, as described below.

1. On the surface of the rough ER, polypeptides are produced by bound ribosomes and extruded into the lumen, rather than being released into the cytosol.
2. These polypeptides travel through the lumen to the smooth ER, where they are stored and processed. When proteins are ready for transport, pieces of smooth ER pinch off to form **vesicles** containing the protein.
3. Vesicles from the smooth ER travel across the cell to the *cis face* of the **Golgi apparatus**, which is a stack of curved membrane sacs, shown in **Figure 2.7**. There, the vesicles merge with the membrane of the Golgi apparatus and release their contents into the interior. In the Golgi apparatus, some proteins are stored and others are modified further. For example, some proteins have carbohydrate chains added to them in the Golgi apparatus or in the ER, converting them into *glycoproteins*, which are important parts of cell membranes. (Note: The Golgi apparatus is called Golgi bodies in some resources.)
4. When the modified proteins are ready for transport, pieces of the Golgi apparatus pinch off from the *trans face* to form vesicles. These vesicles transport the proteins to the cell membrane, or to other destinations within the cell.

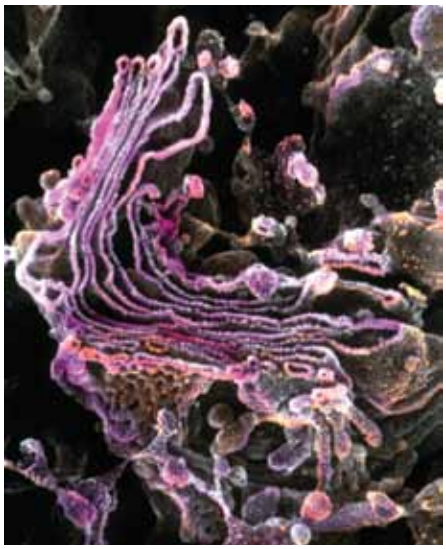


Figure 2.7 Proteins and lipids enter the Golgi apparatus at its *cis* face, or entry face, and leave at the *trans* face, or exit face. The membrane of the Golgi apparatus has a dynamic structure, constantly joining with vesicles at one face, and pinching off to produce vesicles at the other face.

Additional Functions of the Endomembrane System

The endomembrane system has other functions in addition to the modification and transport of proteins. As noted earlier, the smooth ER is responsible for the synthesis and metabolism of lipids, including the steroids and phospholipids that make up cell membranes and organelle membranes. The Golgi apparatus sorts, packages, and distributes these lipids as well as proteins. The Golgi apparatus also manufactures macromolecules, particularly carbohydrates. For example, the Golgi apparatus in many plant cells synthesizes *pectins*, which are non-cellulose structural polysaccharides found in cell walls.

In animal cells, the Golgi apparatus also produces **lysosomes**, which are membrane-enclosed sacs containing digestive enzymes. Lysosomes contain more than 40 enzymes that catalyze hydrolysis reactions, breaking down macromolecules into smaller molecules that can be reused by the cell. Lysosomes break down parts of the cell that are old or no longer needed. They also break down bacteria and other foreign particles that have been ingested by the cell. The enzymes in lysosomes function best at an acidic pH of around 5. Since the cytosol of a cell has a pH of about 7.2, this difference in pH acts as a safeguard for the cell. Even if a lysosome breaks apart, spilling its enzymes into the cell, the enzymes are unlikely to break down the parts of the living cell.

Peroxisomes

Like lysosomes, **peroxisomes** are membrane-enclosed sacs containing enzymes. Peroxisomes form by budding off from the endoplasmic reticulum. Unlike the enzymes in lysosomes, which catalyze hydrolysis reactions, the enzymes in peroxisomes are *oxidases* that catalyze redox reactions. Peroxisomes break down many biological molecules and some toxic molecules. Because toxic substances accumulate in the liver, liver cells contain many peroxisomes. For example, peroxisomes in liver cells oxidize and break down alcohol molecules. Many of the reactions that take place in peroxisomes produce toxic hydrogen peroxide, H_2O_2, so all peroxisomes contain an enzyme known as *catalase* that breaks down hydrogen peroxide into water and oxygen gas. Peroxisomes in some cells synthesize molecules. For example, peroxisomes in liver cells participate in the synthesis of cholesterol and bile acids.

peroxisome membrane-bound sac containing oxidative enzymes that break down excess fatty acids and hydrogen peroxide, and participate in the synthesis of bile acids and cholesterol

vacuole a large, membrane-bound sac in plant cells and some other cells that stores water, ions, macromolecules, sugars, and amino acids

Vesicles and Vacuoles

The term "vesicle" is used to describe membrane-bound sacs used for the transport and storage of substances in the cell. Vesicles form by pinching off from cell membranes and organelle membranes. They can fuse with cell membranes and organelle membranes to release their contents. A typical animal cell contains many small vesicles. Plant cells contain instead a single large central vesicle, called a **vacuole**, shown in **Figure 2.8**. The vacuole stores water, ions, sugars, amino acids, and macromolecules. It also contains enzymes that break down macromolecules and cell wastes. The quantity of water in the central vacuole determines the *turgor pressure*, or internal pressure, of the plant cell. A full vacuole presses against the cell wall, increasing turgor pressure and causing the plant cell to be rigid. This pressure is the source of the rigidity in the flexible stems of herbaceous plants. Without enough water, a vacuole will shrink and pull away from the cell wall. Thus, unwatered plants wilt as the turgor pressure in their cells decreases.

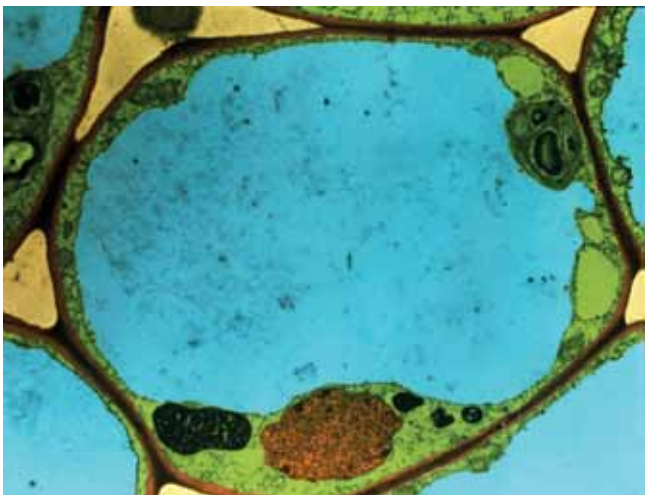


Figure 2.8 The vacuole stores water and other molecules in plant cells.

Learning Check

1. Make a sketch of the nucleus, label its components, and write a detailed caption that describes how the nucleus is organized.
2. Differentiate between the rough and smooth endoplasmic reticulum, and describe the function of each.
3. Explain what the endomembrane system is, including the cell structures that are part of it, and describe its functions.
4. What are peroxisomes?
5. Explain what a vacuole is and how it differs from a vesicle.
6. Explain why the Golgi apparatus is often described as the "post office" of the cell.

chloroplast an organelle in the cells of photosynthetic organisms in which light energy from the Sun is captured and stored in the form of high-energy organic molecules such as glucose

Chloroplasts and Mitochondria

The cells of eukaryotic organisms that carry out photosynthesis typically have one to several hundred **chloroplasts**. These organelles contain the photosynthetic pigment, chlorophyll, which absorbs light energy as part of the process that converts carbon dioxide and water, through redox reactions, into energy-rich organic molecules. As shown in **Figure 2.9**, a thick liquid called *stroma* in the inner membrane surrounds a system of flattened disks called *thylakoids*, which contain chlorophyll in their membranes. A stack of thylakoids is called a *granum* (plural: grana). You will study chloroplasts and photosynthesis in Chapter 4.

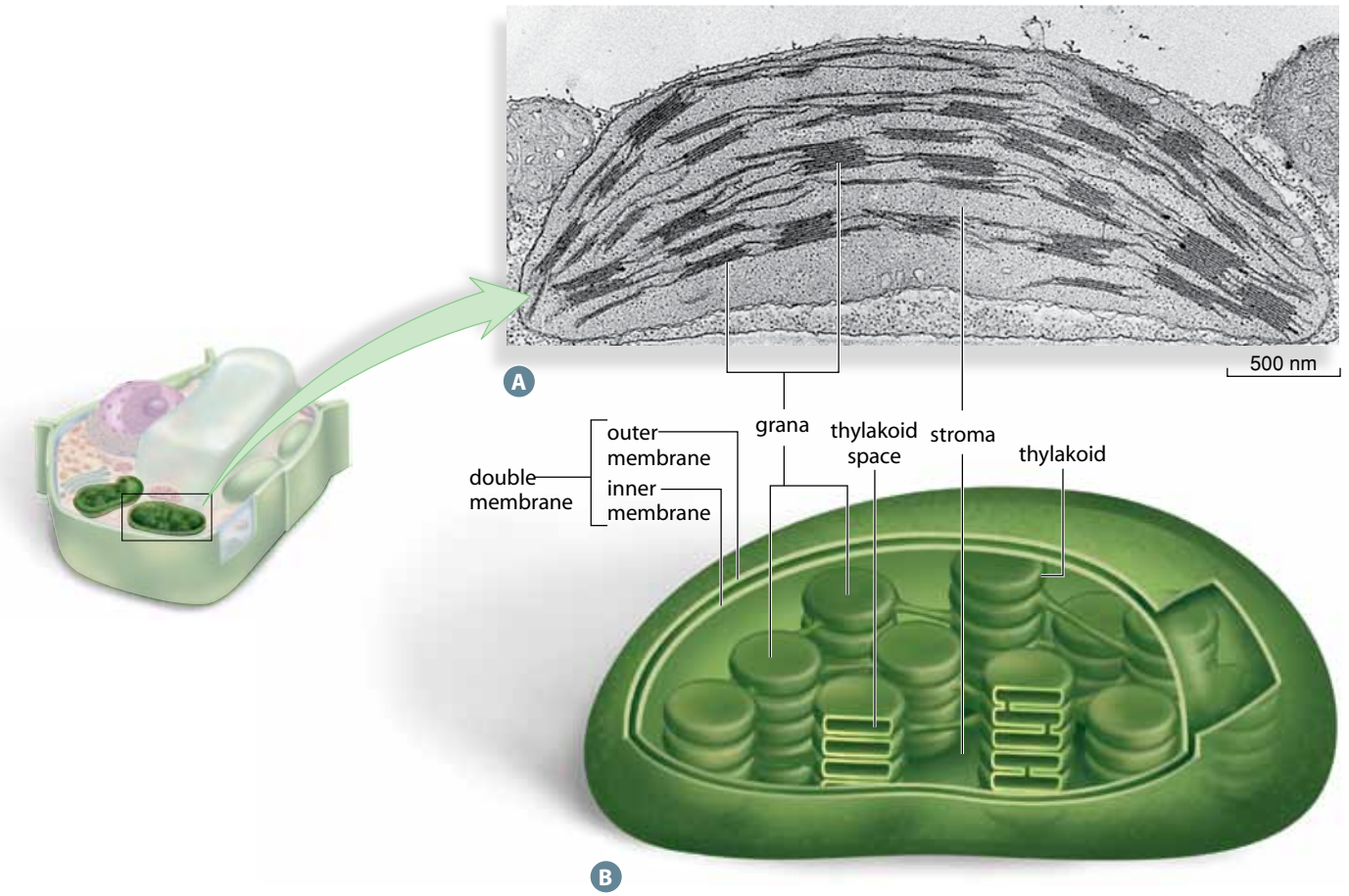


Figure 2.9 Chloroplasts are filled with grana, which are stacks of chloroplyll-containing thylakoids. Chloropyll gives plants their green colour and allows the thylakoids to trap light energy from the Sun.

mitochondrion an organelle in eukaryotic cells in which high-energy organic molecules are oxidized to obtain energy

Activities and chemical reactions in the cell require a steady supply of energy. In eukaryotic cells, **mitochondria** break down high-energy organic molecules to convert stored energy into usable energy. As shown in **Figure 2.10**, mitochondria have a smooth outer membrane and a folded inner membrane. The folds of the inner membrane are called *cristae*, and the fluid-filled space in the inner membrane is called the *matrix*. Both mitochondria and chloroplasts contain some of their own DNA, which encodes some, but not all, of their own proteins. You will study mitochondria and cellular respiration in Chapter 3.

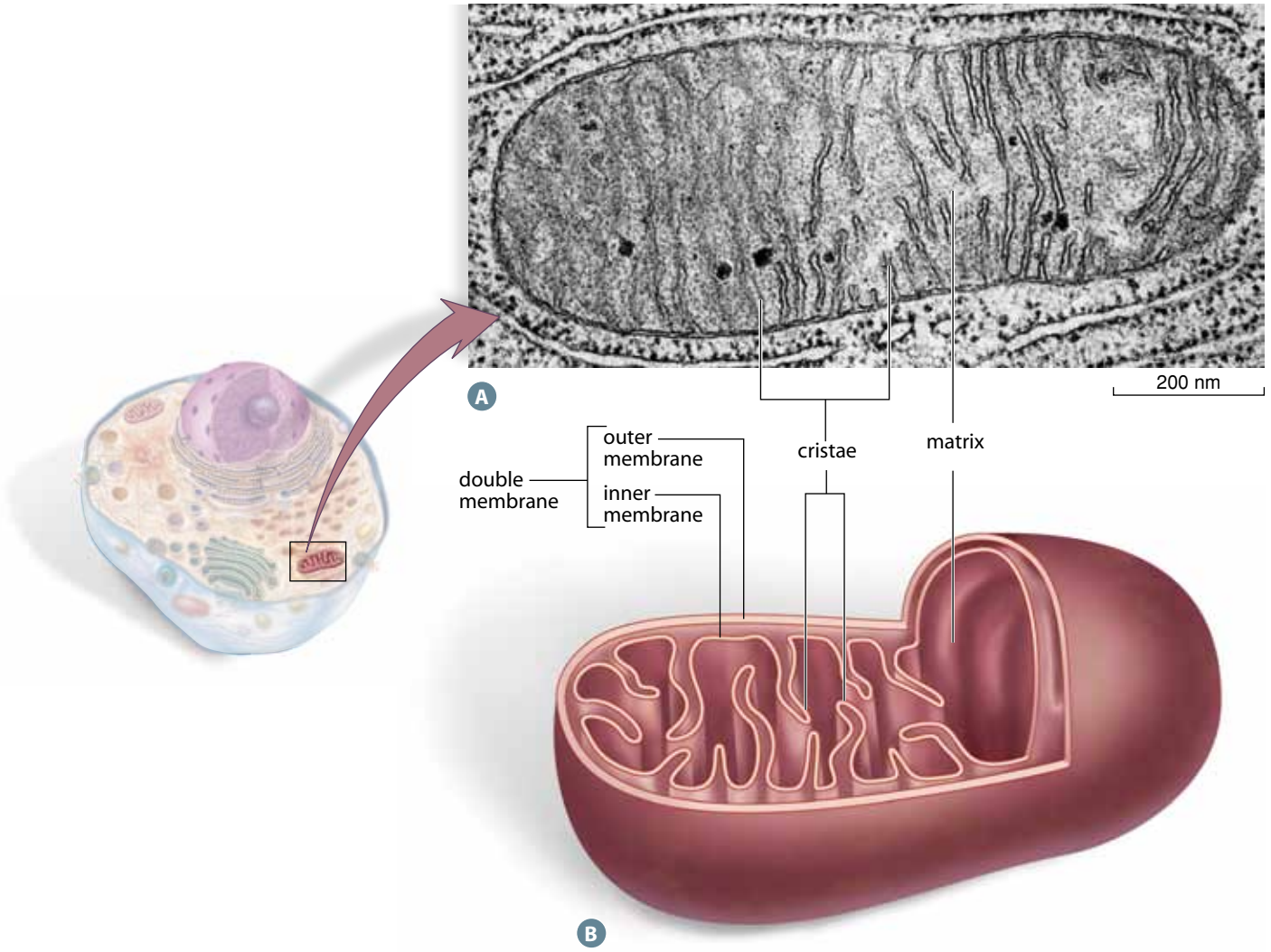


Figure 2.10 Mitochondria are involved in breaking down high-energy organic molecules and storing released energy that can be used by the cell.

The Cell Wall and the Cytoskeleton

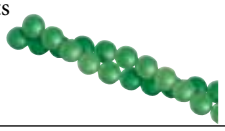
Cells of plants, fungi, and many types of protists have a **cell wall**, which provides protection and support. The composition of the cell wall varies with the type of cell, but it is usually a combination of polysaccharides, glycoproteins, or both. For example, cellulose and other substances such as pectins comprise plant cell walls, while chitin comprises fungal cell walls.

All cells contain an internal network of protein fibres called the **cytoskeleton**. The fibres of the cytoskeleton extend throughout the cytoplasm, providing structure and anchoring the cell membrane and organelles in place. Vesicles and other organelles move along these fibres, which act like tracks that lead from one part of the cell to another. In some cells, cytoskeleton fibres form appendages that enable the cell to propel itself through the fluid surrounding it. **Table 2.1** on the next page identifies and compares the functions of the three types of protein fibres in the cytoskeleton.

cell wall a rigid layer surrounding plant, algae, fungal, bacterial, and some archaea cells, composed of proteins and/or carbohydrates; gives the cell its shape and structural support

cytoskeleton a network of protein fibres that extends throughout the cytosol, providing structure, shape, support, and motility

Table 2.1 Functions of Protein Fibres in the Cytoskeleton

Type of Fibre	Size	Structure	Selected Functions
microtubules 	Thickest fibres (average of 25 nm in diameter)	Proteins that form hollow tubes	• Maintain cell shape • Facilitate movement of organelles • Assist in cell division (spindle formation)
intermediate filaments 	Intermediate thickness (average of 10 nm in diameter)	Proteins coiled together into cables	• Maintain cell shape • Anchor some organelles • Form the internal scaffolding of the nucleus
microfilaments 	Thinnest fibres (average of 8 nm in diameter)	Two strands of actin wound together	• Maintain cell shape • Involved in muscle contraction • Assist in cell division (cleavage furrow)

Cilia and Flagella

Cilia and *flagella*, shown in **Figure 2.11**, are appendages that develop on the outside of some eukaryotic cells. If there are just one or two longer appendages, they are called flagella. If many shorter appendages are present, they are referred to as cilia. These structures are composed of an internal shaft made of microtubules, covered with an outer membrane that is a continuation of the cell membrane.

Flagella are like tails, and their whip-like movement propels cells. For example, a human sperm cell has a single flagellum, while a sperm cell of a cycad (a type of tree) has thousands of flagella. In unicellular protists such as paramecia, the wave-like motion of cilia enable the organisms to move. In multicellular organisms such as human, cells that line the upper respiratory tract have cilia that sweep debris trapped within mucus back up into the throat, where it can swallowed or ejected by coughing.

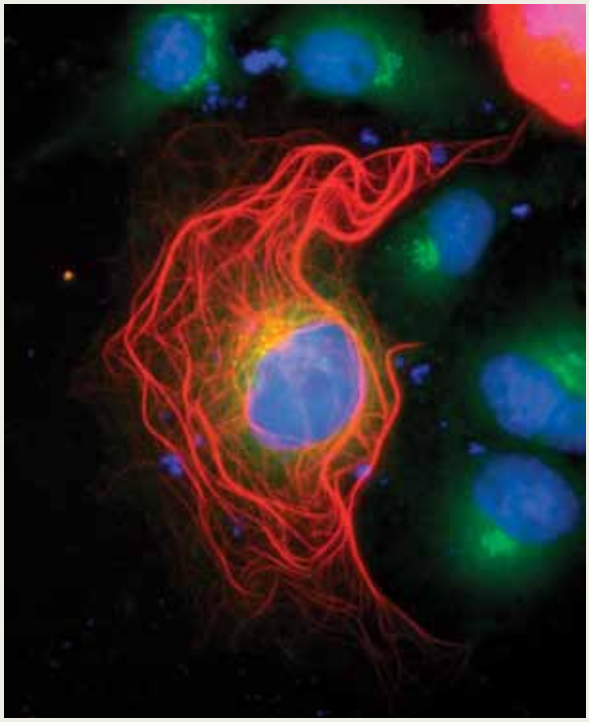
A sperm cell with flagellum

B tracheal epithelial cells with cilia

Figure 2.11 Cilia and flagella are long, thin appendages that allow cells to move themselves, or to move substances over their surface.

Activity 2.1 A Bright Idea: Fluorescence Microscopy

Fluorescence microscopy is a type of light microscopy that makes it possible to see the cytoskeleton, organelles, proteins, and even ions within cells. Fluorescent compounds are used to stain specimens which are exposed to ultraviolet light. The compounds then emit bright visible light of various colours.



These kidney cells were stained with fluorescent compounds that make it easy to observe different organelles. The nuclei are blue, microtubules are red, and Golgi bodies are green. Fluorescence microscopy can also be used to track the transport of proteins and lipids. In what other ways can fluorescence microscopy enhance understanding of cell organelles and their functions?

Materials

- computer with Internet access

Procedure

1. Read the table of selected techniques.
2. Beginning with this book, search for a fluorescence microscope image that shows one or more organelles or cell structures. Continue your research using the Internet.
3. Once you have located a suitable image, record the source. Then identify which organelles are shown and their colours. Find out which technique was used to produce the image and how it was carried out.

Questions

1. What can you learn about cells and cell functions with fluorescence microscopy that you cannot learn with a compound light microscope?

Selected Fluorescence Microscopy Techniques

Technique	Description
Confocal microscopy	Optical slices of a specimen are assembled into a clear three-dimensional image.
Fluorescent In Situ Hybridization (FISH)	Dye-tagged antibodies that bind to specific DNA sequences are used to stain chromosomes.
Indirect immunofluorescence	A primary antibody binds only to highly specific cell components; a secondary, dye-tagged antibody binds to the primary antibody.
Ion staining	Fluorescent probes are added to cells and, if certain ions are present, the cells will fluoresce.

Learning Check

7. Describe similarities and differences between chloroplasts and mitochondria.
8. Describe the structure and function of the cell wall.
9. Describe the structure and function of the cytoskeleton.
10. Compare the functions of the protein fibres in the cytoskeleton.
11. Use an example to describe the structure and function of cilia.
12. Use an example to describe the structure and function of flagella.

The Cell Membrane

All living cells exist in an aqueous medium. For a unicellular organism such as an alga, this medium might be pond water. For the cells of a multicellular organism such as an animal, the aqueous medium is the extracellular fluid that surrounds all cells. The contents of cells are physically separated from this aqueous environment by the cell membrane, which functions as a selective, dynamic cellular boundary. If this remarkable and remarkably thin membrane does not function properly, cellular processes fail, and cells die. The cell membrane is so thin, in fact, that if the cell were the size of a car, the cell membrane would be as thick as a sheet of paper—a mere 0.006 nm across.

The cell membrane maintains the integrity of the cell of which it is a part by regulating the passage of molecules and ions into and out of the cell. In the early 1900s, researchers noted that lipid-soluble molecules entered cells more rapidly than water-soluble molecules. This prompted the hypothesis that lipids are a component of the cell membrane. By 1925, chemical analysis had demonstrated, however, that phospholipids are a component of cell membranes and that they are arranged around the cell in two layers (a bilayer).

The presence of lipids cannot account for all the properties of the cell membrane, such as the fact that some non-lipid substances can pass through it. Researchers in the 1940s hypothesized that proteins are a part of the membranes and proposed a model in which a phospholipid bilayer is sandwiched between two continuous layers of proteins. By the 1950s, electron microscope views of the cell membrane confirmed a sandwich-like appearance, but a suitable model that could link the structure and properties of membranes to various functions remained elusive.

fluid mosaic model the accepted model of the cell membrane, which is a basic framework of a semi-fluid phospholipid bilayer with a mosaic of proteins; carbohydrates may be attached to lipids or proteins

In 1972, two American biologists, Jonathan Singer and Garth Nicolson, proposed a model for membranes that remains in use today. They visualized proteins inserted into the phospholipid bilayer with their non-polar segments in contact with the non-polar interior of the bilayer and their polar portions protruding from the membrane surface. In this **fluid mosaic model**, shown in **Figure 2.12**, an assortment of proteins and other molecules (in other words, "the mosaic") floats in or on the fluid phospholipid bilayer.

Activity 2.2 The Path to the Fluid Mosaic Model

A neutrotransmitter is a chemical that enables nerve cells to communicate with one another. An abnormal production of certain neurotransmitters has been linked to disorders such as depression, bipolar disorder, anxiety disorders, and schizophrenia. Treatments for these disorders include pharmaceutical medications that affect neurotransmitters in some way.

Materials

- print and Internet resources

Procedure

1. To investigate the many researchers and events in this activity most efficiently, cooperative group work is a good idea. For example, you could work in small teams with each team member responsible for researching several people and their contributions.
2. In a group, investigate the role of each of the following individuals or groups of individuals in developing an understanding of the structure and behaviour of membranes and the interactions of lipids (oils) and water.

   Note: Some of these people contributed single ideas and/or techniques, whereas others contributed many more. Be sure to consult a minimum of three information resources for each person to ensure that you have located relevant and reliable information.

   - Benjamin Franklin
   - Lord Rayleigh (John William Strutt)
   - Agnes Pockels
   - Charles Ernest Overton
   - Irving Langmuir
   - Ernest Gorter and F. Grendel
   - James Danielli, E. Newton Harvey, and Hugh Davson
   - J. David Robertson
   - George E. Palade
   - Jonathan Singer and Garth Nicolson

Questions

Record and synthesize the information you gather in the form of a summary table, a graphic organizer, a timeline, or another format of your choice.

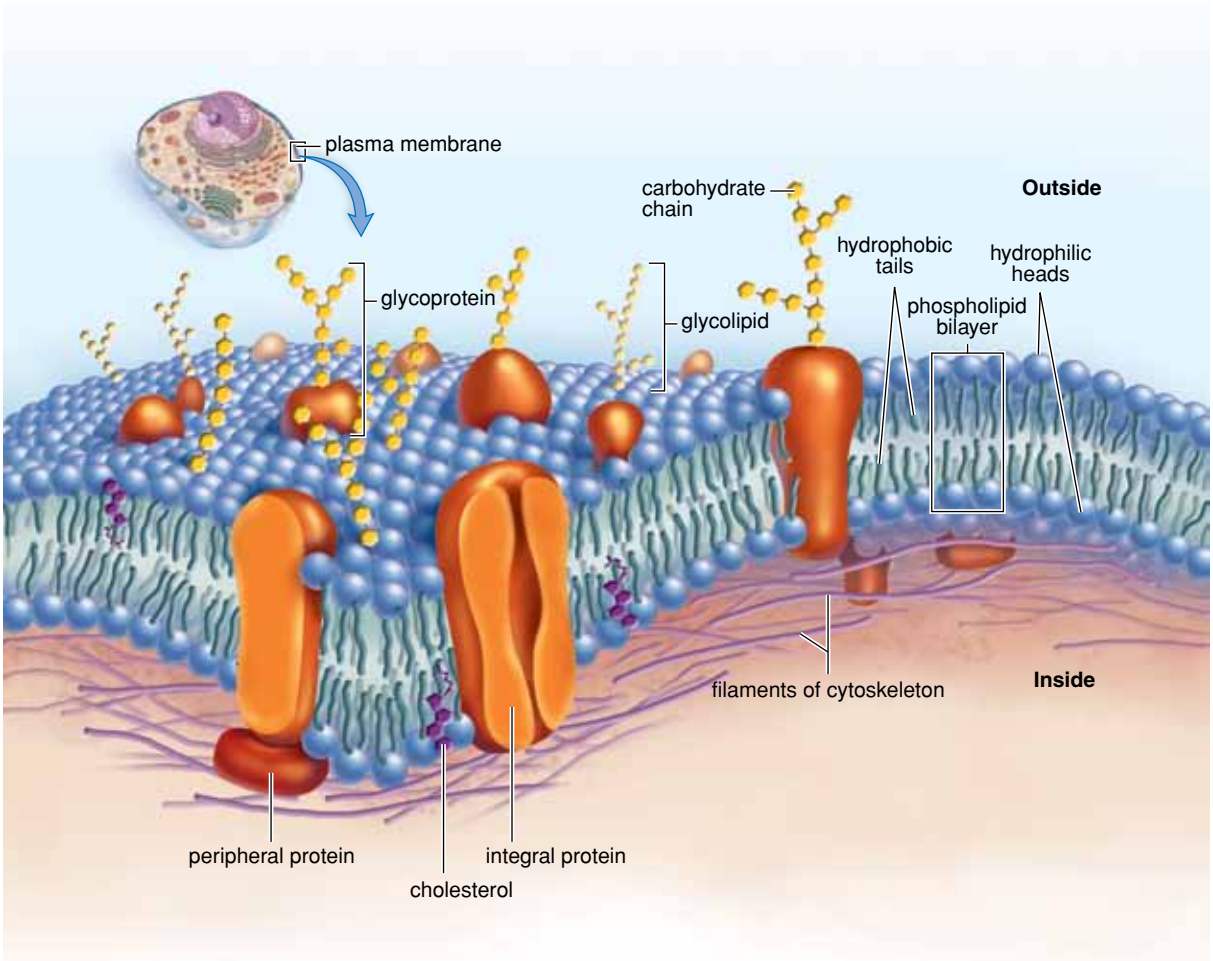


Figure 2.12 In the modern fluid mosaic model, the basic framework of a cell membrane is a phospholipid bilayer into which proteins are inserted. These proteins may be bound on the surface to other proteins or to lipids, including glycoproteins and glycolipids. Glycoproteins and glycolipids are proteins and lipids covalently bonded to carbohydrates.

Features of the Fluid Mosaic Model

According to the fluid mosaic model, each layer—sometimes called a *leaflet*—of a membrane bilayer is composed of various macromolecules. Phospholipids act as the "scaffolding" in which proteins and other macromolecules are embedded. Because membrane lipids are held together by weak intermolecular forces rather than by strong covalent bonds, the molecules in a membrane can move about freely. In fact, phospholipids within the same layer in a membrane exchange places millions of times in a single second, leading to a continual rearrangement of the membrane surfaces. If a puncture or tear occurs in a membrane, molecules will quickly rearrange themselves to seal the rupture.

The lipid bilayer structure of membranes can be explained based on chemical principles and the properties of the phospholipid molecules that form these structures. Recall that a phospholipid molecule has a hydrophilic, polar "head" group and two hydrophobic, non-polar "tails" composed of fatty acids. When placed in water, phospholipids spontaneously form structures in which the polar "heads" cluster together, facing the water molecules, while the non-polar "tails" are shielded from the water. Intermolecular interactions, such as hydrogen bonding, occur between water molecules and between water molecules and the polar "heads" of the phospholipids. The non-polar "tails" cluster together and are held together by hydrophobic interactions. As a result, the polar "heads" end up facing out, and the non-polar tails face inward, away from the aqueous environment.

Learning Check

13. Describe at least two functions of the cell membrane.

14. What kinds of molecules make up a cell membrane?

15. Why are the properties of the cell membrane not adequately explained by the presence of lipids alone in their structure?

16. Use the fluid mosaic model to describe how the components of a cell membrane are organized.

17. Explain why a cell membrane is a dynamic structure, rather than static such as the wall of a building.

18. Describe what happens when phosopholipids are mixed with water, and explain why it happens.

The Fluidity of a Phospholipid Bilayer

At room temperature, a phospholipid bilayer has a viscosity similar to that of vegetable oil. The fluidity of a bilayer is an important property. If it is too fluid, a bilayer permits too many molecules to diffuse in and out of a cell. If it is not fluid enough, a bilayer prevents too many molecules from crossing. The main factors that affect fluidity include the following.

- Temperature: With increasing temperature, the bilayer becomes increasingly fluid until it is unable to act as a barrier. At decreasing temperatures, the bilayer eventually solidifies into a gel-like state.
- Presence of double bonds in the fatty acid "tails": Double bonds form "kinks" in a fatty acid tail. The presence of one or more double bonds causes fatty acids to be less tightly packed and more fluid.
- Fatty acid "tail" length: Longer fatty acid "tails" have more intermolecular attractions and hold together more tightly compared to shorter fatty acid tails, thus reducing fluidity. The most common length of a fatty acid is 16 or 18 carbon atoms.

The presence of cholesterol in cell membranes also affects fluidity. Many eukaryotic cell membranes contain cholesterol molecules. At room temperature and higher, the presence of cholesterol increases the intermolecular forces in the membrane and holds it more tightly together, thus reducing fluidity. For example, cholesterol keeps human cell membranes from being too fluid at body temperature. At lower temperatures, however, cholesterol molecules break up the packing that occurs as phospholipids solidify into a gel. As a result, cholesterol increases the fluidity of the cell membrane at low temperatures.

The Function of Proteins in a Phospholipid Bilayer

Proteins associated with membranes are: integral proteins or peripheral proteins. *Integral proteins* are embedded in the membrane, while *peripheral proteins* are more loosely and temporarily attached to the outer regions of the membrane or to integral proteins.

Peripheral proteins and some integral proteins help to stabilize membranes, and hold them in place by linking them with the cytoskeleton of the cell. Membrane proteins also determine the function of the membrane by performing the following functions.

- Transport: Proteins play an essential role in transporting substances across the cell membranes. This important function of proteins is the subject of the next section.
- Reaction catalysis: Enzymes in cell membranes carry out chemical reactions.
- Cell recognition: The carbohydrate chains that protrude from glycoproteins on the outer layer of the cell membrane enable cells to "recognize" each other. As a result, cells in the body can identify harmful "intruders" such as disease-causing bacteria.
- Signal reception and transduction: Receptor proteins in cell membranes bind to signal molecules, such as hormones, and change shape as a result. This initiates a cellular response to the signal, enabling cells to receive and respond to signals from the brain and other organs.

Section 2.1 Review

Section Summary

- Animals, plants, fungi, and protists are composed of eukaryotic cells, which have DNA, a cell membrane, and cytoplasm. Cytoplasm consists of organelles, the cytosol, and molecules and ions dissolved or suspended in the cytosol. The nucleus includes the nuclear envelope, which is studded with nuclear pore complexes, the nuclear matrix, and the nucleolus.
- The endoplasmic reticulum (ER), consisting of the rough ER and the smooth ER, is a system of channels and membrane-bound-sacs enclosing a narrow space called the lumen.
- The endomembrane system includes the nuclear envelope, the endoplasmic reticulum, the Golgi apparatus, the cell membrane, and vesicles. This system synthesizes, modifies, and transports proteins and other cell products.
- Animal cells contain many small vesicles. Plant cells contain a single large central vesicle called a vacuole.
- Chloroplasts trap light energy from the Sun in the form of high-energy organic molecules. Mitochondria break down high-energy organic molecules to release usable energy.
- Cells of plants, fungi, and many types of protists have a cell wall, which provides protection and support.
- The cytoskeleton provides structure, shape, support, and motility.
- The fluid mosaic model visualizes the cell membrane as a mosaic of proteins and other molecules in a fluid phospholipid bilayer.

Review Questions

1. T/I While researching "eukaryotic cells" online, you and a classmate are surprised to find visuals of various cells that look distinctly different from each other—for example, a bread yeast cell, a pea leaf stoma, and a human liver cell. Why are these highly diverse cells classified together?

2. C In an illustrated table, make labelled sketches to show the functions of the various structures and regions of the nucleus of a cell.

3. T/I What are two important general functions of the organelles in eukaryotic cells?

4. C Using a Venn diagram, compare and contrast rough ER and smooth ER.

5. T/I "The endomembrane system compartmentalizes the cell so that particular functions are restricted to specific regions." Explain how and why a eukaryotic cell could not function or even exist without the endomembrane system.

6. C Use a flowchart to represent the biochemical functions of lysosomes and peroxisomes.

7. K/U Use the following headings to design a summary chart of the structures and organelles of generalized animal and plant cells: Cell Structure or Organelle; Description; Function; Plant, Animal, or Both.

8. A In an animal, which cells would you predict would have the highest concentration of mitochondria? Explain your answer.

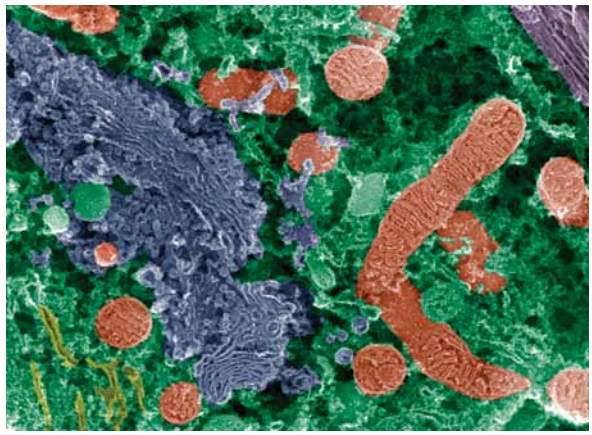
9. K/U Name the cells in your body that have many peroxisomes, and explain why it makes sense that they do.

10. K/U Explain the crucial role of the cell membrane in maintaining the integrity of the cell.

11. C In a table, list and describe the features of the fluid mosaic model of the cell membrane.

12. T/I Create an analogy for the structure and function of the fluid mosaic model that would help a younger student understand this model.

13. A Examine the photograph below, which also appeared on the opening page of this chapter. Identify all the cell structures and organelles that you can, and explain how you recognized them.



SECTION 2.2

The Transport of Substances Across a Cell Membrane

Key Terms

semi-permeable
passive transport
concentration gradient
diffusion
osmosis
facilitated diffusion
channel protein
carrier protein
active transport
electrochemical gradient
membrane-assisted transport
endocytosis
phagocytosis
pinocytosis
receptor-mediated endocytosis
exocytosis

passive transport the movement of ions or molecules across a cell membrane from a region of higher concentration to a region of lower concentration, without the input of energy

concentration gradient a difference in concentration between one side of a membrane and the other

diffusion the net movement of ions or molecules from an area of higher concentration to an area of lower concentration

The cell membrane is able to regulate the passage of substances into and out of the cell, because it is *semi-permeable*. That is, certain substances can move across the membrane while other substances cannot. Processes that enable substances to move in and out of cells without an input of energy from the cell are referred to as **passive transport**. Some ions and molecules can move passively across the cell membrane fairly easily because of a **concentration gradient**—a difference between the concentration on the inside of the membrane and the concentration on the outside of the membrane. Some other substances also move in response to a gradient, but they do so through specific channels formed by proteins in the membrane. Three forms of passive transport are diffusion, osmosis, and facilitated diffusion.

Passive Transport by Diffusion

Molecules and ions dissolved in the cytoplasm and extracellular fluid are in constant random motion. This random motion causes a net movement of these substances from regions of higher concentration to regions of lower concentration. This process, called **diffusion**, is illustrated in **Figure 2.13**. Net movement driven by diffusion will continue until the concentration is the same in all regions. In the context of cells, diffusion involves differences in the concentration of substances on either side of a cell membrane., Therefore, the relative concentrations both inside and outside the cell, as well as how readily a molecule or ion can cross the membrane, are both factors that affect diffusion.

The major barrier to crossing a biological membrane is the membrane's hydrophobic interior that repels polar molecules but not non-polar molecules. If a concentration difference exists for a non-polar molecule such as oxygen, it will move across the membrane until the concentration is equal on both sides. At that time, movement in both directions still occurs, but there is no net change in either direction. Factors that affect the rate of diffusion include the following.

- Molecule size: The larger a molecule is, the more difficult it is for it to diffuse across a membrane. As a result, the rate of diffusion decreases with molecule size.
- Molecule polarity: Although small polar molecules can cross membranes, their rates of diffusion are generally lower than those of non-polar molecules of the same size.
- Molecule or ion charge: In general, charged molecules and ions cannot diffuse across a cell membrane.

Temperature and pressure also affect the rate of diffusion. At higher temperatures, molecules have more energy and move faster, thus increasing the rate of diffusion. At higher pressures, molecules are forced across the membrane and the rate of diffusion increases.

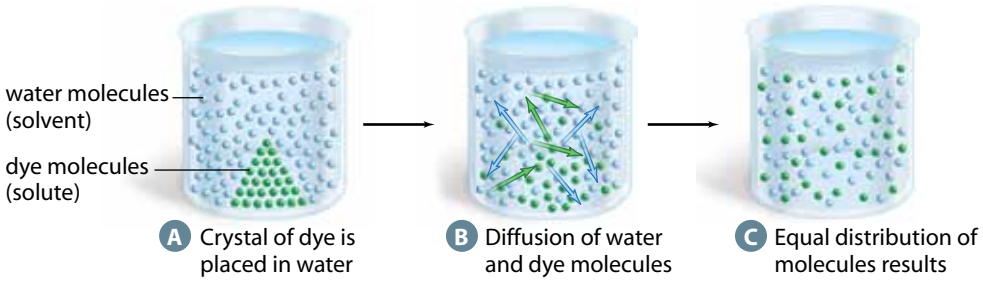


Figure 2.13 When a crystal of dye is dissolved in water, there is a net movement of dye molecules from a higher concentration to a lower concentration. At the same time, there is a net movement of water molecules from a higher to a lower concentration. Eventually, the water and dye molecules are evenly distributed throughout the system.

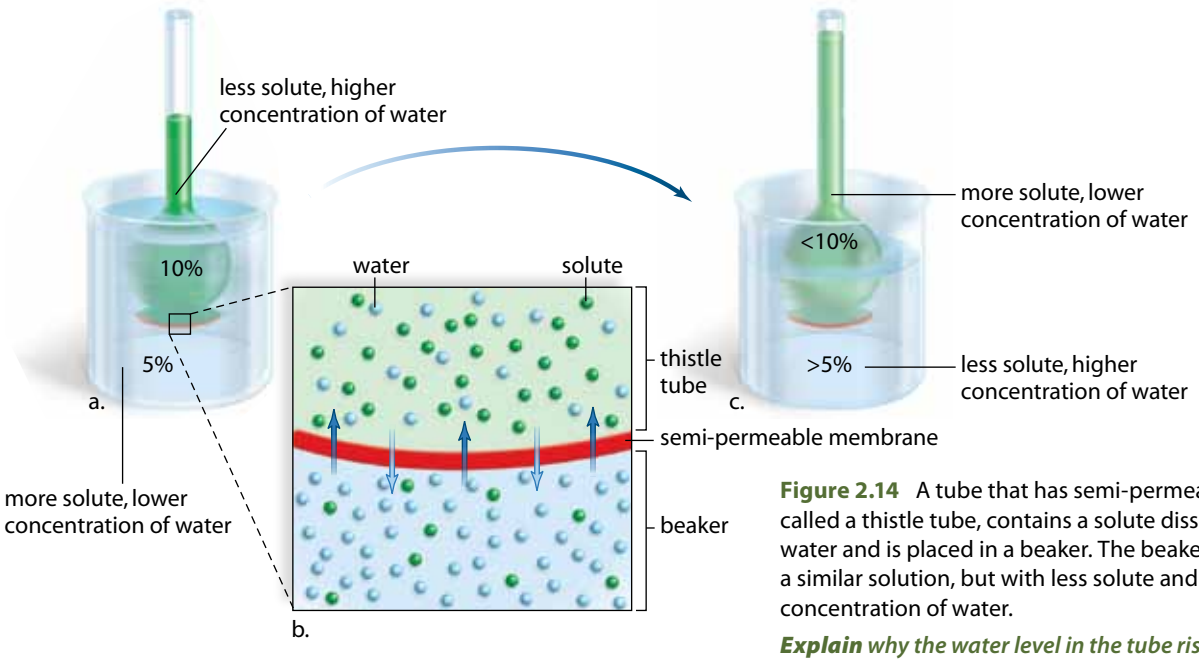


Figure 2.14 A tube that has semi-permeable walls, called a thistle tube, contains a solute dissolved in water and is placed in a beaker. The beaker contains a similar solution, but with less solute and a higher concentration of water.

***Explain** why the water level in the tube rises.*

Passive Transport by Osmosis

The aqueous cytoplasm is a solvent for cellular molecules and ions. Cells must maintain enough water to enable cellular processes. However, cells also interact with extracellular fluid, the composition of which is constantly changing. If too much water enters a cell, it swells. If too much water leaves a cell, it shrinks. Either response can affect the ability of a cell to function. Thus, the regulation of water entry is of crucial importance to a cell.

Movement of water molecules across biological membranes is called **osmosis**. In osmosis, water molecules move because the membrane is impermeable to the solute, and the solute concentrations may differ on either side of the membrane, as shown in **Figure 2.14**. Water molecules move in or out of a cell, along their concentration gradient, until their concentrations on both sides of the membrane are equal. At that time, water molecules continue to move in and out, but there is no net diffusion of water.

osmosis the movement of water from an area of higher concentration to an area of lower concentration, across a semi-permeable membrane

The concentration of all solutes in a solution determines its osmotic concentration. If two solutions have unequal osmotic concentrations, the solution with the higher concentration is *hypertonic* (hyper = "more than"). The solution with the lower concentration is *hypotonic* (hypo = "less than"). When two solutions have the same osmotic concentration, they are *isotonic* (iso = "equal"). **Figure 2.15** shows the effect of osmotic concentration on an animal cell and on a plant cell.

Suggested Investigation

Plan Your Own Investigation
2-A Demonstrating Osmosis

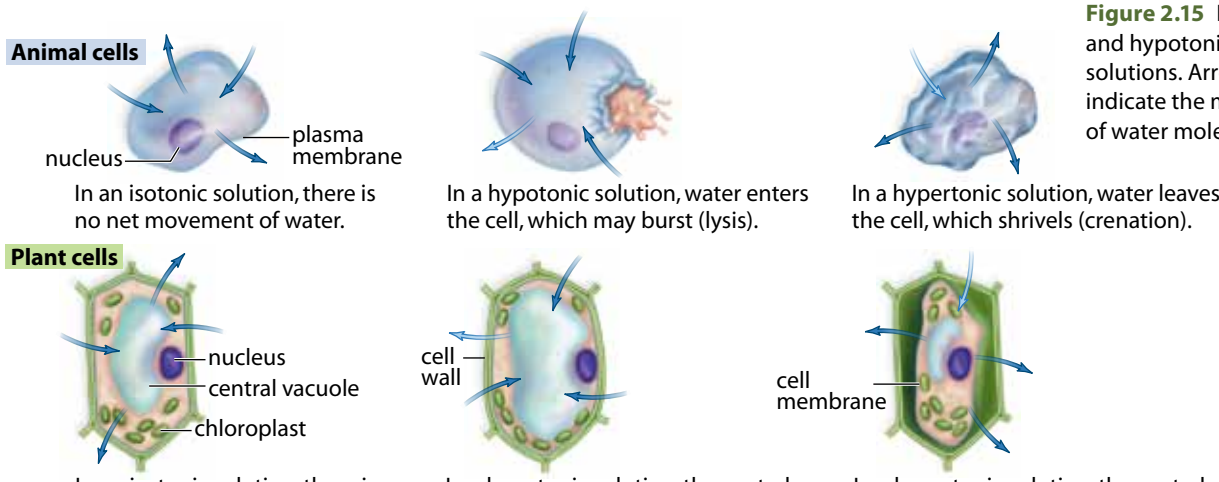


Figure 2.15 Isotonic and hypotonic solutions. Arrows indicate the movement of water molecules.

Learning Check

19. What is a concentration gradient?

20. Describe the process of diffusion, and explain why it occurs.

21. What are three factors that affect the rate of diffusion, and why do they affect it?

22. Explain the similarities and differences between diffusion and osmosis.

23. Would you expect the normal environment of your cells to be typically isotonic, hypertonic, or hypotonic? Explain your reasoning.

34. Would you expect the normal environment of a plant cell to be typically isotonic, hypertonic, or hypotonic? Explain your reasoning

Passive Transport by Facilitated Diffusion

facilitated diffusion the transport of ions or molecules across a membrane by means of a membrane protein along the concentration gradient for that ion or molecule

channel protein a membrane protein that forms a channel across a cell membrane, which allows specific ions or molecules to cross the membrane along their concentration gradients

carrier protein a membrane protein that binds to and transports one or more particles of a substance from one side of a membrane to the other, along the concentration gradient for that substance

Many important molecules required by cells cannot easily cross the plasma membrane. These molecules can still enter the cell by diffusion through specific channel proteins or carrier proteins embedded in the plasma membrane, as long as there is a higher concentration of the molecule outside the cell than inside. This process of diffusion that is mediated by a membrane protein is called **facilitated diffusion**. Channel proteins have a hydrophilic interior that provides an aqueous channel through which polar molecules can pass when the channel is open. Carrier proteins, in contrast to channels, bind specifically to the molecule they assist, much like an enzyme binds to its substrate.

Channel Proteins

Channel proteins form highly specific channels through the cell membrane, as shown in **Figure 2.16A**. The structure of a channel protein determines which particles can travel through it. A channel protein has a tubular shape, like a hollow cylinder. This cylinder is usually composed of one or more helixes, like coiled springs. Recall from Chapter 1 that proteins are composed of linked amino acids, which may have polar, non-polar, or charged side chains. The exterior of a channel protein is usually composed of amino acids with non-polar side chains that interact with the non-polar interior of the cell membrane, anchoring the protein in place. The shape and size of the hole through a channel protein determines the shape and size of particles that can pass through it.

Some channel proteins remain open all the time, while others have gates that the cell can open or close to allow or prevent the passage of particles. Different types of gates open or close in response to a variety of signals, such as hormones, electric charge, pressure, or even light.

In general, channel proteins permit the passage of ions or polar molecules. For example, sodium channel proteins allow sodium ions, Na+, to cross the membrane, and potassium channel proteins allow potassium ions, K^+, to cross it. Cystic fibrosis (CF) is a disease that results in the production of very thick mucus in the breathing passages and pancreas. CF is caused by defective chloride ion channel proteins that do not allow the proper movement of chloride ions, Cl^-, across the cell membrane. This, in turn, interrupts the proper balance of water movement into and out of the cell, which causes the formation of a thick layer of mucus.

Carrier Proteins

Carrier proteins bind to specific molecules, transport them across the membrane, and then release them on the other side, as shown in **Figure 2.16B**. Because they bind to the molecules they are carrying, carrier proteins change shape while transporting molecules. While channel proteins usually transport ions or small polar molecules, carrier proteins can also transport larger molecules such as glucose and amino acids. Because they bind to only a few molecules at a time, carrier proteins have lower rates of diffusion compared to channel proteins.

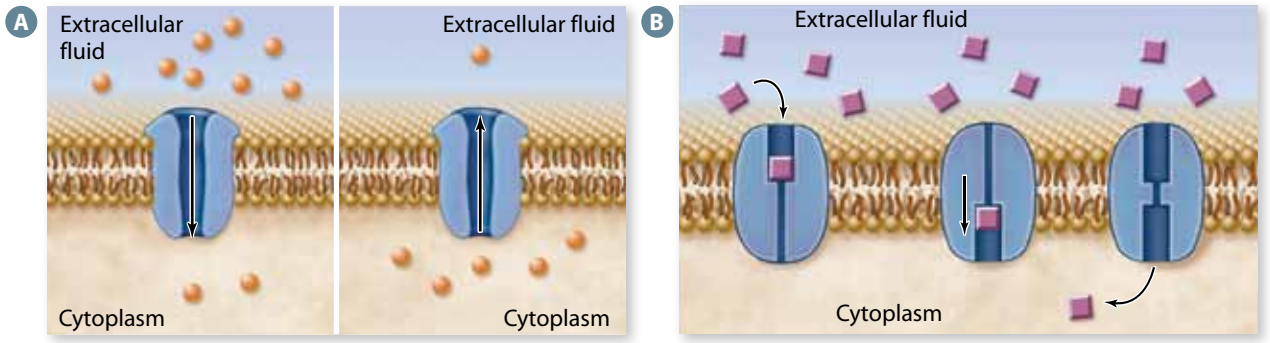


Figure 2.16 Facilitated diffusion involves membrane proteins. **A** Channel proteins form channels through membranes, which allow passage of specific ions and molecules from areas of higher concentration to areas of lower concentration. **B** Carrier proteins bind to molecules and carry them across a membrane from an area of higher concentration to an area of lower concentration.

As with a channel protein, the exterior of a carrier protein is usually composed of non-polar amino acids that interact with the non-polar interior of the membrane. Similarly, the interior of a carrier protein is lined with amino acids that can bind to the particle to be transported. For example, a carrier protein such as Glut1, which transports glucose molecules, is lined with polar or charged amino acids that can form intermolecular bonds with glucose molecules.

Malfunctions in carrier proteins can cause a variety of diseases. For example, cystinurea is a hereditary disease caused by the inability of carrier proteins to remove cystine and some other amino acids from urine. If it is not removed from urine, cystine crystallizes into painful stones, or *calculi*, that can block the flow of urine in the urinary tract.

Active Transport: Movement against a Concentration Gradient

Diffusion, facilitated diffusion, and osmosis are passive transport processes that move substances down their concentration gradients. However, cells also can actively move substances across a cell membrane against, or up, their concentration gradients. This process, called **active transport**, requires the expenditure of energy, usually from ATP.

active transport the transport of a solute across a membrane against its gradient

ATP, or adenosine triphosphate, is the main source of energy in the cell. An ATP molecule is derived from an adenosine nucleotide, but it has a triple phosphate group instead of a single phosphate group. The hydrolysis of the end phosphate group from an ATP molecule releases energy, as shown in **Figure 2.17**. This energy is then used by the cell for other activities. The use of energy from ATP in active transport can be direct or indirect. As you will see below, direct use of ATP is called primary active transport, and indirect use is called secondary active transport. (Although the remainder of the discussion of active transport will occasionally refer to ATP, you will learn more about this important molecule and its role in the process of cellular respiration and metabolism in Chapter 3.)

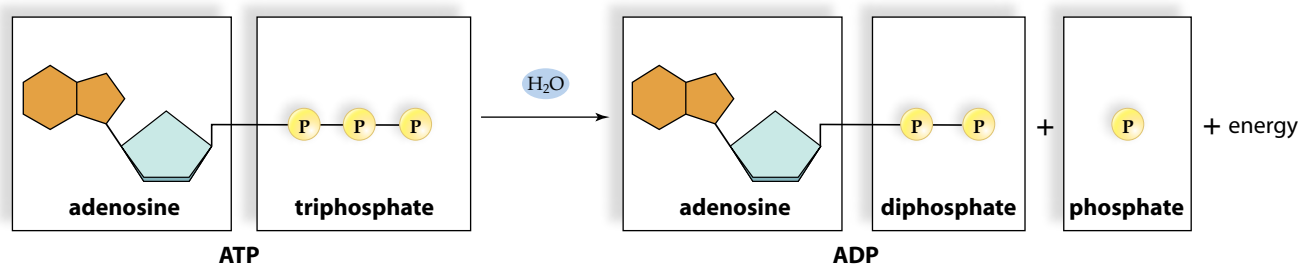


Figure 2.17 ATP undergoes hydrolysis to form ADP and phosphate, with the release of energy. The cell uses this energy for various functions, including the transport of molecules and ions across the cell membrane against their concentration gradients.

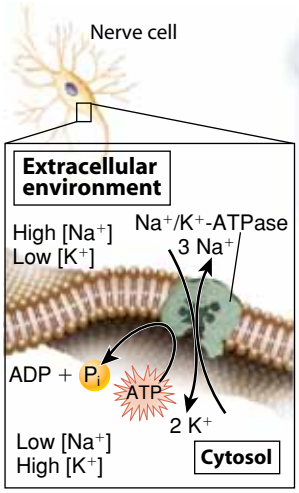
Primary Active Transport

A cellular process that uses ATP directly to move molecules or ions from one side of a membrane to the other is called *primary active transport*. For example, ion pumps are carrier proteins that use ATP to "pump" ions from one side of a membrane to the other, against a concentration gradient. One of the most well-studied examples is the *sodium-potassium pump*. This system transports sodium ions out of the cell while transporting potassium ions into the cell. Both processes occur against concentration gradients, so this carrier protein requires ATP to function, as shown in **Figure 2.18**.

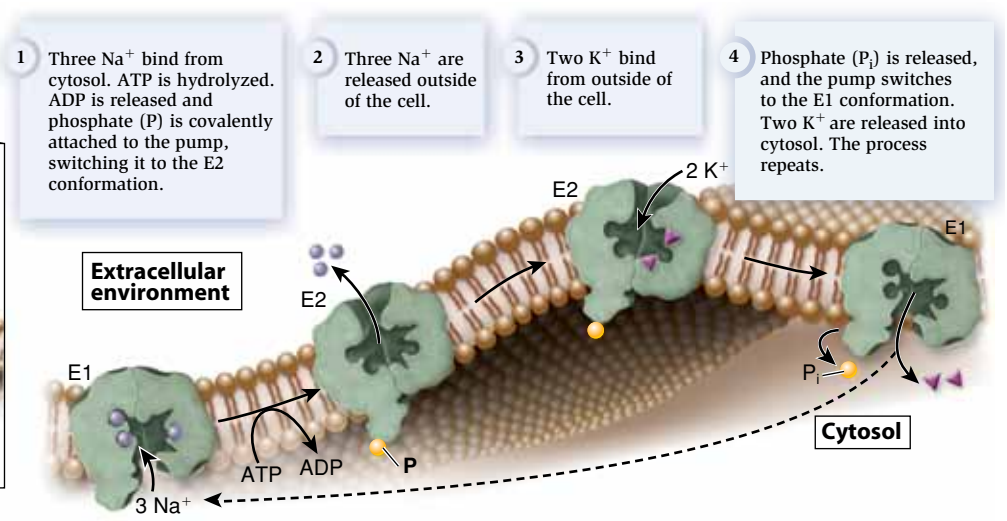
At step 1 in the diagram, three sodium ions, Na^+, on the inside of the cell bind to the ion pump in the cell membrane. At step 2, an ATP molecule also binds to the ion pump, and it is hydrolysed to ADP and a phosphate group. The ADP is released, and the phosphate group temporarily attaches to the ion pump. This causes the ion pump to undergo a change in its shape, which releases sodium ions to the outside of the cell. On the outside of the cell, at step 3, two potassium ions, K+, bind to the ion pump. This binding causes the release of the phosphate group from the protein. The protein returns to its original shape, which causes the release of the potassium ions into the cytosol. The ion pump is then available to transport more sodium ions out of the cell.

Figure 2.18 The sodium-potassium ion pump transports ions across the cell membrane.

***Explain** why the action of a sodium-potassium pump will result in a build-up of negative charge inside the cell.*



(a) Active transport by the Na^+/ K^+-ATPase

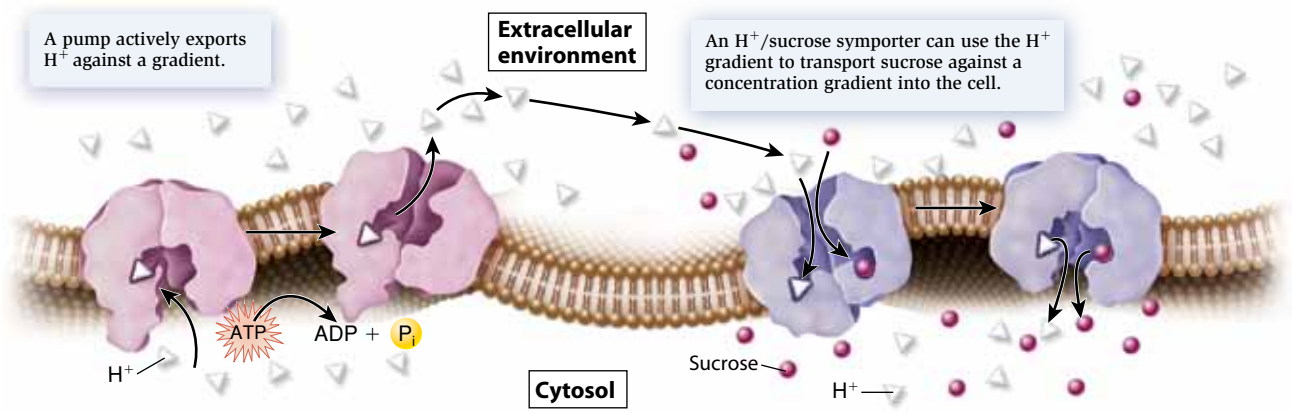


(b) Mechanism of pumping

Secondary Active Transport

As an ion pump functions, a difference in charge, or electric potential, builds up across the membrane. One side of the membrane gains a more positive or negative charge compared to the other side, due to the accumulation of positive or negative ions. At the same time, a concentration gradient builds up across the membrane as the concentration of ions on one side increases compared with the other side. The combination of a concentration gradient and an electric potential across a membrane is called an *electrochemical gradient*. An electrochemical gradient stores potential energy that can be used by the cell.

Secondary active transport uses an electrochemical gradient as a source of energy to transport molecules or ions across a cell membrane. An example of secondary active transport is the hydrogen-sucrose pump. As shown in **Figure 2.19**, hydrogen ions are first pumped out of the cell by a hydrogen ion pump, which uses ATP as an energy source. This process creates an electrochemical gradient, with the area of higher concentration and greater positive charge outside the cell. Sucrose molecules outside the cell bind to a hydrogen-sucrose pump in the cell membrane. As well as binding sucrose molecules, this carrier protein allows hydrogen ions to move into the cell. As they do so, the hydrogen ions provide the energy that transports sucrose against its concentration gradient.



(a) Primary active transport

(b) Secondary active transport

Figure 2.19 In secondary active transport, the electrochemical gradient created by primary active transport via an ion pump is used by a different protein to transport other molecules across a cell membrane. This kind of transport is common in bacteria and in plant cells.

Learning Check

25. What do facilitated diffusion and active transport have in common, and how do they differ?

26. Compare and contrast a channel protein and a carrier protein.

27. What is ATP, and what role does it play in active transport?

28. How is an electrochemical gradient similar to and different from a concentration gradient?

29. Distinguish between primary active transport and secondary active transport.

30. What is the sodium-potassium pump, and how does it work?

Activity 2.3 Understanding the Sodium-Potassium Pump

Palytoxin is a deadly compound found in certain marine animals. When scientists first isolated palytoxin from sea corals in the 1970s, they did not know how it affected people exposed to it. In time, they began to suspect that the toxin was interfering with the sodium-potassium pump. Researchers have measured the effect of palytoxin on ion transport through the sodium-potassium pump using the patch-clamp technique. This involves using a fine-tipped microelectrode to measure the electric current across pumps in the cell membrane. In this activity, you will examine some of the researchers' results and conclusions.

Procedure

1. Read the following observations that researchers made after adding palytoxin to a membrane, and then answer the questions.

- Observation 1: The current across a single pump jumped from 0 picoamperes to 1 picoamperes.
- Observation 2: When ATP was added to the cytoplasm-facing side of the membrane, the current across a group of pumps increased by a factor of 8 times.
- Observation 3: A molecule 0.75 nm in diameter was able to pass through the pump. (For comparison purposes, a hydrogen atom measures 0.1 nm in diameter.)

Questions

1. How does the patch-clamp technique help researchers study ion transport across cell membranes?

2. In general, about 10^7–10^8 ions/s pass through an open ion channel. In contrast, only 10^2 ions/s pass through an ion pump. How would you expect the strength of an electric current across an ion channel to compare with the strength across an ion pump?

3. What does Observation 1 suggest about ion flow through the sodium-potassium pump when palytoxin is added?

4. Given that the sodium-potassium pump is a form of active transport, suggest an explanation for Observation 2.

5. What does Observation 3 suggest about the size of the passage through the sodium-potassium pump?

Membrane-Assisted Transport

membrane-assisted transport transport method used to move materials that are too large to cross the cell membrane through a channel or carrier protein

endocytosis process by which the cell membrane engulfs extracellular material to bring it inside the cell

phagocytosis endocytosis involving solid particles

pinocytosis endocytosis involving liquid particles

Although a cell can accumulate and excrete smaller molecules and ions using membrane proteins, macromolecules are too large to cross the cell membrane through a channel or by means of a carrier protein. Instead, the cell forms vesicles to surround incoming or outgoing material and move it across the cell membrane through **membrane-assisted transport**. Like active transport, membrane-assisted transport requires energy from the cell. The two forms of membrane-assisted transport are endocytosis and exocytosis.

Endocytosis

Endocytosis is the process by which a cell engulfs material by folding the cell membrane around it and then pinching off to form a vesicle inside the cell. **Figure 2.20** shows three methods of endocytosis: phagocytosis, pinocytosis, and receptor-mediated endocytosis.

If the material the cell takes in is made up of discrete particles, such as an organism or some other fragment of organic matter, the process is called **phagocytosis** (which literally means "cell-eating"). If the material the cell takes in is liquid, the process is called **pinocytosis** (which literally means "cell-drinking"). Virtually all eukaryotic cells constantly carry out these kinds of endocytotic processes, trapping particles and extracellular fluid in vesicles and ingesting them.

Receptor-mediated endocytosis involves the use of receptor proteins on a portion of a cell membrane that bind with specific molecules outside the cell. The area of the cell membrane containing receptor proteins is called a coated pit, because it is coated with a layer of protein. During this form of endocytosis, the receptor proteins bind with molecules and the pit folds inward to form a vesicle. The contents of the vesicle may be used by the cell or digested by the cell, and the receptor proteins may be recycled to the cell membrane.

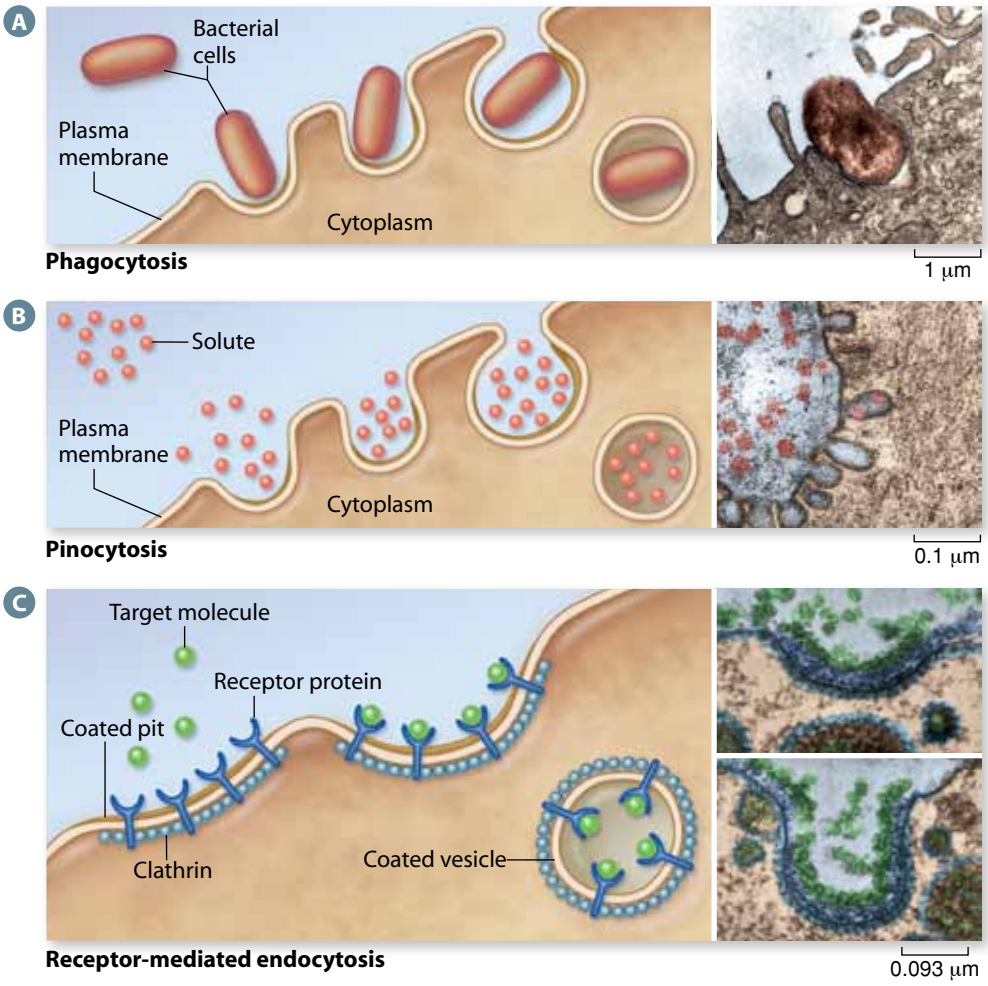


Figure 2.20 In phagocytosis, a cell engulfs a large particle along with some of the liquid surrounding it. In pinocytosis, a cell engulfs a liquid and the small particles dissolved or suspended in it. In receptor-mediated endocytosis, receptor proteins in the cell membrane bind to specific molecules outside the cell. The cell membrane folds inward to create a vesicle containing the bound particles. These vesicles are coated with clathrin, a protein that forms a cage around a vesicle.

Exocytosis

Macromolecules and other large particles can leave a cell by a process called exocytosis, which is shown in **Figure 2.21**. Exocytosis is the opposite of endocytosis. In **exocytosis**, vesicles that contain cell products to be released, or waste material to be excreted, fuse with the cell membrane and empty their contents into the extracellular environment. The vesicle itself becomes part of the cell membrane.

exocytosis transport method in which a vacuole fuses with the cell membrane and releases its contents outside the cell

In plant cells, exocytosis is an important means of exporting through the cell membrane the materials needed to construct the cell wall. In animal cells exocytosis provides a mechanism for secreting (releasing) many hormones, neurotransmitters, digestive enzymes, and other substances. For example, specialized glands secrete sebum, which is an oily substance that lubricates human skin, hair, and eyes. As another example, cells in the intestines of animals secrete enzymes and acid that aid in the digestive process.

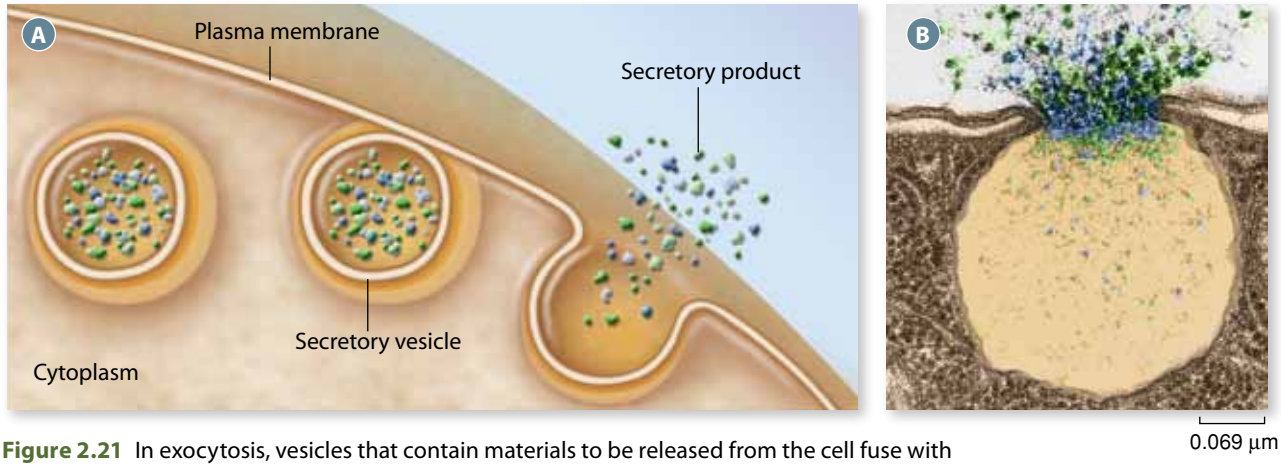


Figure 2.21 In exocytosis, vesicles that contain materials to be released from the cell fuse with the cell membrane and then release their contents into the extracellular environment.

Cellular Transport: A Summary

Table 2.2 summarizes the various mechanisms by which cells transport molecules, ions, and cellular materials or products across a cell membrane.

Suggested Investigation

Inquiry Investigation 2-B Diffusion Across a Semi-permeable Membrane

Table 2.2 Mechanisms for Transport of Substances Across a Cell Membrane

Is Energy Required for the Mechanism to Function?	Type of Cellular Transport Mechanism	Primary Direction of Movement of Substances	Essential Related Factor(s)	Examples of Transported Substances
No	diffusion	toward lower concentration	concentration gradient	lipid-soluble molecules, water, gases
No	facilitated diffusion	toward lower concentration	channel protein or carrier protein and concentration gradient	some sugars and amino acids
Yes	active transport	toward higher concentration	carrier protein and energy	sugars, amino acids, ions
Yes	endocytosis	toward interior of cell	vesicle formation	macromolecules
Yes	exocytosis	toward exterior of cell	fusion of vesicle with cell membrane	macromolecules

Investigating Multi-Drug Resistance in Cancer Cells

The Sharom lab team. Back row, left to right: Pulari Krishnankutty Nair, David Ward, Ashley Parfitt, Dr. Frances Sharom, Adam Clay, Peihua Lu. Front row, left to right: Kevin Courtney, Dr. Miguel Lugo, Jonathan Crawford, Joseph Chu. Not present: Dr. Gavin King.

Related Career

Oncologists are medical doctors who specialize in cancer treatment. An oncologist may be involved in cancer screening and diagnosis. This type of doctor is typically responsible for patient therapy and any patient follow up or palliative care as well. Becoming an oncologist in Canada involves completion of an undergraduate degree and a degree in medicine, followed by a period of further training, or residency.

Chemotherapeutic medications are often used to fight cancerous cells. Sometimes these cells can become resistant to the medications, however. The problem is compounded when there is resistance to several chemotherapeutic medications—a situation called multi-drug resistance.

Dr. Frances Sharom is a professor in the Department of Molecular and Cellular Biology at the University of Guelph in Guelph, Ontario. The Canadian scientist, shown above with the members of her lab team, is also the Canada Research Chair in Membrane Protein Biology. Dr. Sharom and members of her team are especially interested in multi-drug resistance due to the presence of the P-glycoprotein (Pgp) multi-drug transporter in the plasma membrane of cancerous tumour cells. A glycoprotein is a protein that has one or more carbohydrates attached to it. The Pgp transporter causes multi-drug resistance in these cells by pumping out hydrophobic chemotherapeutic medications. Because the cells are able to pump out the medication, they are less responsive to chemotherapeutic treatment. Medications pumped out by the Pgp transporter include TAXOL™, which is developed from the bark and needles of yew trees (*Taxus sp.*). TAXOL™ is used to treat several types of cancers, including breast, lung, bladder, and ovarian cancers. Vinblastine, a chemical that occurs naturally in the Madagascar periwinkle plant (*Catharanthus roseus*), is used to treat various lymphomas, as well as breast, testicular, and bladder cancer. It is also susceptible to transport out of the cell by the Pgp transporter. Thus, cancerous tumour cells that have Pgp-type resistance (that is, have the gene for the Pgp transporter) are less responsive to vinblastine treatment. Fortunately, the ATP-driven pump action that enables the Pgp transporter to transport chemotherapeutic medications from the cell is susceptible to other chemicals known as chemosensitizers, or modulators. These chemicals may reduce Pgp-type multi-drug resistance when administered with chemotherapeutic medications.

Dr. Sharom and her team are especially interested in how the Pgp transporter binds to medications and transports them out of the cell. They are also interested in how these processes are powered by the hydrolysis of ATP. The researchers use a technology known as fluorescence spectroscopy to map the multi-drug binding pocket of the Pgp transporter and to identify the conformational changes in the transporter when it binds to chemotherapeutic medications.

QUESTIONS

1. Draw a diagram or flowchart to illustrate how chemotherapeutic medications interact with cancerous tumour cells possessing the Pgp transporter, as well as how these medications interact with tumour cells lacking this transporter. Write a detailed caption for your diagram, clearly indicating which cells are drug-resistant.
2. Suggest how an understanding of the method by which the Pgp transporter binds to medications and transports them from the cell could be applied to cancer treatments.
3. Brainstorm three other careers that are related to the work described in this feature. Use Internet and/or print resources to research one of these careers. Then write a brief summary explaining the nature of this career.

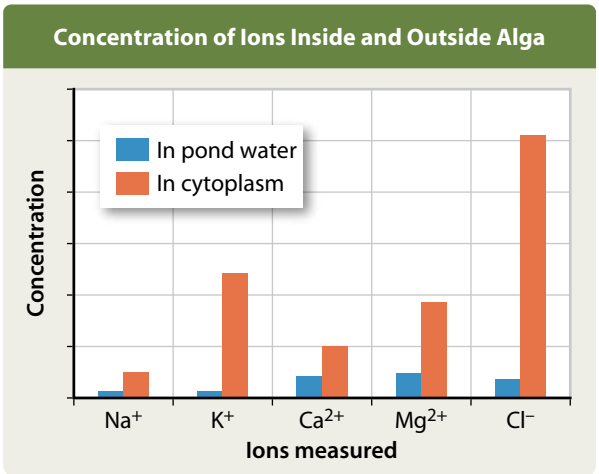
Section 2.2 Review

Section Summary

- Transport of substances across membranes can occur by diffusion—the passive movement of a substance along a concentration gradient.
- Ions and large hydrophilic molecules cannot cross the cell membrane, but diffusion can still occur through facilitated diffusion, which involves the help of channel proteins and carrier proteins.
- Osmosis is the diffusion of water across membranes. The direction of movement depends on the solute concentration on either side of the membrane.
- Active transport uses energy and specialized protein carriers to move materials against a concentration gradient.
- Primary active transport uses pumps that directly use energy and generate a gradient.
- Secondary active transport involves the use of an existing gradient to actively transport another substance.
- In endocytosis , the cell membrane surrounds material and pinches off to form a vesicle. Phagocytosis is endocytosis involving solid particles. Pinocytosis is endocytosis involving liquid particles. In receptor-mediated endocytosis, specific molecules bind to receptors on the cell membrane.
- In exocytosis, material in a vesicle is secreted when the vesicle fuses with the membrane.

Review Questions

1. K/U Use the following terms to explain the movement of water across a membrane: solute, solvent, concentration.
2. C Draw an animal cell in an isotonic environment. Add labels and a caption to explain clearly the movement of substances in and out of this cell and the effect of this movement on the cell.
3. K/U Describe at least two different mechanisms a cell has to bring in material that otherwise cannot pass through the cell membrane.
4. A A drop of a 5% solution of NaCl is added to a leaf of an aquatic plant. When the leaf is viewed under a microscope, colourless regions appear at the edges of each cell as the cell membranes shrink from the cell walls. Describe what is happening and why.
5. T/I An egg is placed in a jar of household vinegar and left for about one week, after which time the shell has dissolved completely, leaving a thin membrane to contain the contents of the egg. The egg is then carefully removed and the vinegar residue is carefully washed from the membrane. Describe two procedures that could be performed to investigate active and/or passive transport with this membrane system.
6. K/U Explain what a channel protein is and why channel proteins are important to cells.
7. K/U Describe the function of cholesterol as it relates to the cell membrane.
8. C Use a Venn diagram to compare the similarities and differences of endocytosis and active transport.
9. K/U Identify three characteristics of substances that affect their rate of diffusion. Provide an explanation for each.
10. A If a cell membrane were completely permeable to all substances, could the cell continue to live? Explain your answer.
11. K/U Do substances that are moving in and out of a cell by diffusion and osmosis stop moving once the substances are evenly distributed on either side of the membrane? Explain your reasoning.
12. A Explain how the properties of the molecules and macromolecules that comprise biological membranes are important to processes that transport materials in and out of cells.
13. T/I The graph below shows the relative concentrations of five different ions inside and outside the cells of a unicellular pond alga. Interpret and explain the information in the graph.



Plan Your Own INVESTIGATION

2-A

Skill Check

- ✓ Initiating and Planning
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communicating

Demonstrating Osmosis

How can you observe the effects of osmosis without using a microscope or chemical tests? Working in groups and using the material provided, you will design and conduct an investigation to demonstrate osmosis. Your investigation must enable you to draw conclusions about the following.

- What is the solute concentration of the solutions used relative to the sample of plant material?
- What is the direction of the flow of water between a sample of plant material and the surrounding solution?

Safety Precautions

- Be sure your hands are dry when you pick up any glassware so that you do not drop it.

Suggested Materials

- 250 mL beakers
- 10 percent NaCl solution
- distilled or filtered water
- potato strips
- scale or balance

Pre-Lab Questions

1. Why is it so important not to eat or drink anything in the lab?
2. Describe the direction of the flow of water when plant cells are placed in a hypertonic solution.
3. What is the difference between a *control* in an investigation and *controlled variables*?
4. Identify a quantitative observation that you could make to determine whether a sample of plant material has gained or lost water.
5. Identify one or more qualitative observations that you could make to determine whether a sample of plant material has gained or lost water.

Question

How does solute concentration influence the direction of osmosis?

Hypothesis

Formulate a hypothesis about the direction of osmosis between a sample of plant material and a surrounding solution. Use this hypothesis as the basis of your experimental design.

Prediction

On the basis of your hypothesis, formulate a prediction about the results that you expect to observe.

*Go to **Scientific Inquiry** in **Appendix A** for information on formulating a hypothesis and prediction, and planning an investigation.*

*Go to **Organizing Data in a Table** in **Appendix A** for help with designing a table for data.*

*Go to **Significant Digits and Rounding** in **Appendix A** for help with reporting measurements.*

Plan and Conduct

1. With your group, brainstorm different methods you could use the materials provided to test your hypothesis. Select one method for your experimental design.
2. As you prepare your procedure, consider the time required for each step. Also be sure to include a step about cleaning up your station.
4. Prepare the data table you will use to record your observations.
5. Review your procedure with your teacher. Do not begin the investigation until your teacher has approved your procedure.
6. Record your observations in your table. Make notes about any findings that do not fit in your data table. Record any questions that come up as you conduct your investigation.

Analyze and Interpret

1. Was your prediction correct? Make reference to specific results to explain what you mean.
2. Using the terms "isotonic," "hypotonic," and "hypertonic" as appropriate, describe the solute concentration of the solutions used relative to the sample of plant material.
3. What did you use as a control in your investigation? Why was this control necessary?

Conclude and Communicate

4. Did your observations support or refute your hypothesis? Explain.
5. State your conclusions about the influence of solute concentration on the direction of osmosis.

Extend Further

6. **INQUIRY** How could you revise your procedure to compare osmosis in different types of samples? What samples would you test? What controlled variables would you use? Design a new procedure to investigate these questions. Review your new procedure with your teacher, then carry it out and report on your findings.
7. **RESEARCH** What is oral rehydration therapy, and how is related to this investigation? When and why is oral rehydration therapy used, and how does it work?

Inquiry INVESTIGATION 2-B

Skill Check

- Initiating and Planning
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communicating

Diffusion Across a Semi-permeable Membrane

Dialysis tubing is a semi-permeable membrane used to separate small dissolved particles from large ones. Ions, water, and small organic molecules can pass through pores in the membrane by simple diffusion. Large molecules, however, cannot fit through the pores.

In this investigation, you will compare the ability of two solutes—starch and glucose—to diffuse across dialysis tubing. This tubing will serve as a model of a cell membrane.

Safety Precautions

- Be sure your hands are dry when you pick up any glassware so that you do not drop it.
- Wear gloves, a lab coat, and eye protection when handling Lugol's iodine.

Suggested Materials

- 15 cm length of pre-soaked dialysis tubing
- string or thread
- scissors
- sink or tray
- 10 percent glucose solution in a beaker
- 2 mL syringe or medicine dropper
- 10 percent starch solution in a beaker
- 300 mL beaker
- distilled or filtered water
- 4 glucose test strips
- watch or clock
- 1 percent starch solution in a beaker
- Lugol's iodine in a squeeze bottle

*Go to **Writing a Lab Report** in **Appendix A** help with communicating the results of your investigation.*

Pre-Lab Questions

1. How many pieces of glassware should you carry at a time? Why?
2. Why is it important not to wear contact lenses in the laboratory?
3. What chemical test indicates the presence of starch?
4. Why is it necessary to wait a specified time after using a glucose test strip before you can read the result?

Question

Will starch or glucose be able to diffuse across the dialysis tubing?

Hypothesis

Make a hypothesis about which molecules will or will not be able to diffuse across the dialysis tubing.

Procedure

1. Obtain a piece of dialysis tubing from the container in which it is soaking. Cut a length of string or thread about 10 cm or 15 cm long. With the help of your lab partner, fold over one end of the dialysis tubing about 5 mm and tightly tie this end to keep it closed.
2. Gently rub the dialysis tubing at the free end so that it opens. While working over a sink or tray, pour the 10 percent glucose solution into the dialysis tubing until it is about half full.
3. Use a 2 mL syringe or medicine dropper to add 2 mL of 10 percent starch solution to the dialysis tubing.
4. Fold over the free end of the dialysis tubing and tie it tightly shut. If possible, rinse the dialysis tubing under running water.
5. The solution-filled dialysis tubing is your model cell. Place the model cell in a 300 mL beaker. Pour enough filtered or distilled water over the model cell to cover it. Note the time.
6. Test for glucose in the water using a glucose test strip. Be sure to follow the product instructions for using and reading the test strip.
7. After 45 min, use fresh glucose test strips to test fresh 10 percent glucose solution, 1 percent starch solution, and the water surrounding your model cell. Record your observations.
8. Put on your protective eyewear and gloves. Add a few drops of Lugol's iodine to the 1 percent starch solution. Keep adding Lugol's iodine until the mixture changes colour.
9. Add 1 mL–2 mL of Lugol's iodine to the water surrounding your model cell. Record your observations.
10. Clean up as directed by your teacher.

Analyze and Interpret

1. How did you check for the diffusion of glucose and starch across the model cell membrane?
2. What was an example of a control in this investigation?
3. If you added 20 mL of 10 percent glucose solution in the dialysis tubing and then added 2 mL of 10 percent starch solution, what was the total concentration of starch in the model cell?
4. Describe the appearance of the model cell when you first covered it with water and 45 min later.

Conclude and Communicate

5. Describe the relative solute concentrations inside and around the model cell when you first covered it with water.
6. Describe the direction of diffusion of solute and water molecules across the model cell membrane over the course of the investigation.
7. Was your hypothesis supported by your observations? Explain.
8. Is dialysis tubing an effective model of a cell membrane? Justify your response.

Extend Further

9. **INQUIRY** Design an investigation to determine the approximate size of molecules of a common household substance, such as vitamin C, beet juice, or vinegar.
10. **RESEARCH** How did Canadian surgeon Gordon Murray's invention help people with failing kidneys? Use your understanding of diffusion to explain how his invention worked.

STSE

Case Study

Synthetic Red Blood Cells

Benefit or Detriment to Society?

Scenario

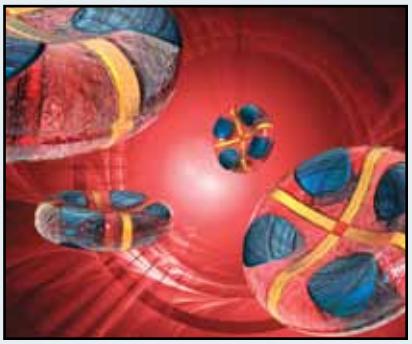
For many years, scientists have sought to design synthetic red blood cells (sRBCs) that can transport oxygen throughout the body. In 1957, Thomas Chang, then an undergraduate student at McGill University in Montreal, experimented with improvised materials in his dormitory to construct a permeable "cell" that carried hemoglobin, the iron-containing molecule in red blood cells responsible for oxygen transport in the body.

Since then, many other scientists have tried to create sRBCs and there have been several successes. Many scientists believe that practical application of sRBCs in medicine will become a reality in the near future. However, this future is by no means assured. Read the following articles, each of which has a different viewpoint regarding the future of sRBCs, and then decide whether this technology is beneficial or detrimental to society.

Synthetic Red Blood Cell Research: A Call for Further Funding

Ivan Mikhailovich, PhD

SYNTHETIC BLOOD GIVES LIFE WHERE REAL BLOOD CANNOT. Thanks to sRBC technology, generations to come can be assured a stable and safe blood supply. Access to this blood supply would not depend on refrigeration. The relatively short shelf life of donated blood would no longer be a problem. Nor would this blood carry with it the risks of blood-borne diseases such as HIV and hepatitis C. Adverse reactions due to blood-type incompatibility would be overcome. Such a world is possible, but only with further funding for sRBC research.



An artist's conception of theoretical synthetic blood cells, or respirocytes, in a blood vessel. Synthetic cells would have the same function as red blood cells and could be used to treat various blood conditions.

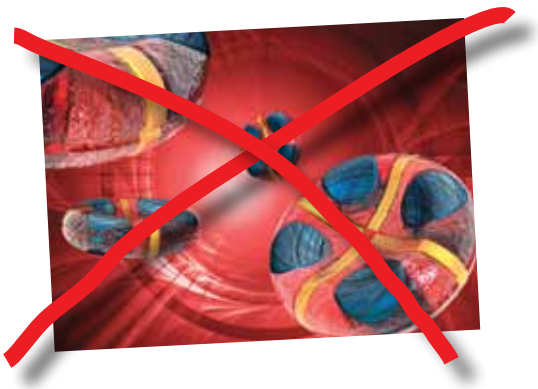
Research in sRBC technology has advanced greatly in the last few years. In 2004, Shinji Takeoka published ground-breaking research in the *Journal of the Japan Medical Association*. Takeoka's team encapsulated a high concentration of hemoglobin (isolated from expired donated blood) within an artificial phospholipid bilayer membrane. The stability of this artificial bilayer ensures a long shelf life. In liquid state, the cells have a shelf life of approximately two years at room temperature. They last even longer if dehydrated. In comparison, donated blood lasts only three weeks with refrigeration.

In 2009, Samir Mitragotri and his team at the University of California, Santa Barbara created sRBCs that mimic natural red blood cells even more closely, in both shape and function. Mitragotri's team synthesized these cells by coating a polymer mould, which was later removed, with numerous layers of hemoglobin and other proteins. The sRBCs have the same doughnut-like shape that increases the surface area of human red blood cells. By treating the polymer with a common household chemical, rubbing alcohol, Mitragotri's team produced artificial cells with the same size, shape, and oxygen-carrying ability as human red blood cells. The sRBCs can even manoeuvre through tiny capillaries.

These advances have led to clinical trials of sRBCs and practical use in medicine. In the near future, sRBCs will also be engineered to target pharmaceuticals to specific areas in the body. With adequate funding, other advances will soon follow.

Nanotechnology Reviews…Synthetic Red Blood Cells

Hardeep Hundial, MSc



Several practical hurdles make us skeptical that synthetic blood will be used in clinical medicine anytime soon. Two of these hurdles are safety and money.

Disease-free blood that lasts for years and that can be easily transported to accident locations or disaster sites—what could be the downside? A lot, it turns out. Before practical application of this technology becomes possible, sRBCs need to be tested to make sure they are both safe and effective. While animal testing is a starting point, this technology also needs to be tested on its ultimate target, human beings. Human testing, referred to as clinical trials, raises many difficult questions, such as, "Can participant safety be ensured?"

Fortunately, there are trials of other blood substitutes to learn from: clinical trials for non-cellular synthetic blood that began in the 1980s. Non-cellular synthetic blood products are the predecessors of sRBCs. They are based on either modified hemoglobin molecules or fluorocarbons, which contain both fluorine and carbon. Both types of synthetic molecules can carry oxygen and transport it within the body as real blood does. Unlike real blood, however, these blood products contain no cells. Early clinical trials were conducted in the United States and Germany with both trauma victims and volunteers. Several allergic reactions were recorded, as were incidents of kidney failure. In the late 1990s, one company stopped its clinical trials when it learned that nearly half of the patients that received synthetic blood died, compared to 17 percent of patients in the control group. In 2008, the *Journal of the American Medical Association* published a study reporting a 30 percent greater risk of death and a tripling of the heart attack rate in patients that received blood substitutes in clinical trials. As a result, the Ottawa Health Research Institute halted all human blood–substitute testing in Canada.

Will cellular blood substitutes such as sRBCs pose less risk for clinical trial participants than their non-cellular counterparts? There is no way to know until clinical trials take place. However, based on past performance of non-cellular blood substitutes in the human body, such trials would generate serious ethical questions. It makes little sense to continue wasting valuable funding on this research, especially when blood-product screening can now ensure a disease-free product. Funds would be much better spent on initiatives to increase blood donations or research to improve the shelf life of human blood products.

Research and Analyze

1. Find out more about the two main types of non-cellular synthetic blood products. Describe these blood products and the results of clinical trials associated with them, as well as any practical medical applications. Does your research support the claim made in the *Nanotechnology* review that it would be unsafe to test sRBCs on humans? Write a supported opinion piece to express your viewpoint.
2. Respirocytes are theoretical nanomachines that could function as synthetic red blood cells. Scientists claim that such cells could carry much more oxygen than normal red blood cells, enabling humans to stay underwater for hours or sprint at high speeds for several minutes, all on a single breath. Find out more about how respirocytes might influence human performance in the future. Based on your research, decide whether you would prefer to work for a company that has successfully pioneered respirocyte technology or a non-profit group that opposes this technology.
3. Research the benefits and the risks of sRBCs in more detail. Create a table to summarize your findings, as well as the points made in this case study. Using the information in your table, perform a risk-benefit analysis of sRBC technology. Refer to Analyzing STSE Issues in Appendix A if necessary.

Take Action

4. **PLAN** You and a group of other students are volunteering as interns at a science webzine. Your assignment is to research, design, and write an edition about the science and the issues related to synthetic red blood cells (sRBCs). Complete the following questions as a group.
   a. Discuss whether sRBC research is beneficial or detrimental to society. Should sRBC research and associated clinical trials proceed? Refer to your responses to questions 1 to 3 in your discussion.
   b. Based on your discussion, design your webzine edition. Each intern will be responsible for one article in the edition. Your design should include an outline of each proposed article. Articles can have differing viewpoints, but all viewpoints must be supported by research from reputable sources.
5. **ACT** Write and produce the webzine.

Chapter 2 SUMMARY

Section 2.1 Structures and Functions of Eukaryotic Cells

The cell membrane defines the boundary between the internal and external environment of a cell, and organelles compartmentalize its biochemical activities.

Key Terms

nucleolus
nuclear envelope
nuclear pore complexes
endoplasmic reticulum (ER)
ribosome
endomembrane system
vesicle
Golgi apparatus
lysosome
peroxisome
vacuole
chloroplast
mitochondrion
cell wall
cytoskeleton
fluid mosaic model

Key Concepts

- Animals, plants, fungi, and protists are composed of eukaryotic cells, which have DNA, a cell membrane, and cytoplasm. Cytoplasm consists of organelles, the cytosol, and molecules and ions dissolved or suspended in the cytosol. The nucleus includes the nuclear envelope, which is studded with nuclear pore complexes, the nuclear matrix, and the nucleolus.
- The endoplasmic reticulum (ER), consisting of the rough ER and the smooth ER, is a system of channels and membrane-bound-sacs enclosing a narrow space called the lumen.
- The endomembrane system includes the nuclear envelope, the endoplasmic reticulum, the Golgi apparatus, the cell membrane, and vesicles. This system synthesizes, modifies, and transports proteins and other cell products.
- Animal cells contain many small vesicles. Plant cells contain a single large central vesicle called a vacuole.
- Chloroplasts trap light energy from the Sun in the form of high-energy organic molecules. Mitochondria break down high-energy organic molecules to release usable energy.
- Cells of plants, fungi, and many types of protists have a cell wall, which provides protection and support.
- The cytoskeleton provides structure, shape, support, and motility.
- The fluid mosaic model visualizes the cell membrane as a mosaic of proteins and other molecules in a fluid phospholipid bilayer.

Section 2.2 The Transport of Substances Across a Cell Membrane

The passage of substances across a cell membrane takes place by means of passive transport, active transport, and membrane-assisted transport.

Key Terms

passive transport
concentration gradient
diffusion
osmosis
facilitated diffusion
channel protein
carrier protein
active transport
membrane-assisted transport
endocytosis
phagocytosis
pinocytosis
exocytosis

Key Concepts

- Transport of substances across membranes can occur by diffusion—the passive movement of a substance along a concentration gradient.
- Ions and large hydrophilic molecules cannot cross the cell membrane, but diffusion can still occur through facilitated diffusion, which involves the help of channel proteins and carrier proteins.
- Osmosis is the diffusion of water across membranes. The direction of movement depends on the solute concentration on either side of the membrane.
- Active transport uses energy and specialized protein carriers to move materials against a concentration gradient.
- Primary active transport uses pumps that directly use energy and generate a gradient.
- Secondary active transport involves the use of an existing gradient to actively transport another substance.
- In endocytosis , the cell membrane surrounds material and pinches off to form a vesicle. Phagocytosis is endocytosis involving solid particles. Pinocytosis is endocytosis involving liquid particles. In receptor-mediated endocytosis, specific molecules bind to receptors on the cell membrane.
- In exocytosis, material in a vesicle is secreted when the vesicle fuses with the membrane.

Chapter 2 REVIEW

Knowledge and Understanding

1. How do peroxisomes protect themselves from the reactive hydrogen peroxide they produce?

a. The hydrogen peroxide is stored within vesicles inside the peroxisomes.

b. Hydrogen peroxide is passively transported into the cytosol.

c. Hydrogen peroxide is actively transported out of peroxisomes.

d. Carbohydrates are combined with hydrogen peroxide to create less reactive substances.

e. The enzyme catalase breaks down hydrogen peroxide within peroxisomes.

2. Which of the following is common to both mitochondria and chloroplasts?

a. chlorophyll

b. grana

c. thylakoids

d. double membrane

e. nucleolus

3. Which cellular process directly uses the energy of ATP hydrolysis to move molecules against their concentration gradient across a membrane?

a. facilitated diffusion

b. primary active transport

c. osmosis

d. diffusion

e. secondary active transport

4. Which organelle uses enzyme-catalyzed hydrolysis to break down macromolecules into simpler molecules?

a. rough endoplasmic reticulum

b. nucleus

c. lysosome

d. peroxisome

e. Golgi apparatus

5. While observing plant cells, a student noticed that chloroplasts appeared throughout each of the cells. Before the observation she had expected to see the chloroplasts at the periphery of the cell near the cell wall. How can the student's observation be explained?

a. During preparation the cells may have been exposed to a hypertonic solution that resulted in plasmolysis.

b. The cells used for the observation were isolated from the roots rather than the shoots of the plant.

c. Light from the microscope caused the cells to become actively photosynthetic.

d. During preparation the cells may have lysed as a result of exposure to a hypotonic solution.

e. Many of the chloroplasts may have contained an excess of thylakoids.

6. Which organelle is involved in both the synthesis of bile acids and redox reactions that break down toxic substances?

a. lysosome

b. central vacuole

c. mitochondrion

d. peroxisome

e. Golgi apparatus

7. What do glycoproteins and glycolipids have in common?

a. Both molecules are modified in lysosomes before being secreted from the cell.

b. Carbohydrates are covalently bonded to them.

c. Each is synthesized by ribosomes in the cytosol.

d. Each is synthesized by ribosomes at the rough ER.

e. Each is loosely attached to one of the leaflets of a membrane.

8. Chefs often place salad greens in water to make the vegetables crispy. What organelle is principally responsible for this increase in plant cell rigidity?

a. Golgi apparatus

b. smooth ER

c. lysosome

d. chloroplast

e. central vacuole

9. Why do phospholipids placed in water form bilayers?

a. The "heads" of the phospholipids engage in hydrophobic interactions with water molecules.

b. The fatty acid "tails" engage in hydrogen bonding with water molecules.

c. Each of the molecules has a polar and a non-polar region.

d. The water molecules cannot interact with phospholipids since each has a different polarity.

e. Lipid bilayers are required for the attachment of peripheral proteins.

10. Which event requires a net input of energy?

a. passage of an ion through a channel protein

b. passage of an uncharged molecule through a channel protein

c. the facilitated diffusion of a polar molecule out of a cell by a carrier protein

d. the unassisted passage of a non-polar solute through the phospholipid bilayer of a membrane as it moves down its concentration gradient

e. the movement of an ion out of a cell against its electrochemical gradient

11. In the fluid mosaic model of membranes, what does the term "mosaic" tell us about membranes?

a. Membranes are composed of a mixture of substances.

b. The components of membranes float in a bilayer of lipids.

c. Some membrane proteins have polar regions that are exposed at both faces of a membrane.

d. The two leaflets of any given membrane are identical but may be different when compared to membranes from another source.

e. Membranes have lipid molecules sandwiched between layers of protein.

12. What transport mechanism exports material from a cell without using a transport protein or the movement of the material directly through the lipid bilayer?

a. plasmolysis

b. exocytosis

c. hydrolysis

d. signal transduction

e. pinocytosis

13. Which of the situations below would result in plasmolysis?

a. placing an animal cell in an isotonic solution

b. washing a normal plant cell with a hypotonic solution

c. exposing a typical animal cell to a hypotonic solution

d. leaving a plant cell in a hypertonic solution

e. moving a normal, healthy plant cell into an isotonic solution

14. In which of the following does the membrane of a vesicle become part of the cell membrane?

a. pinocytosis

b. phagocytosis

c. exocytosis

d. active transport

e. facilitated transport

15. Oxygen enters a cell by which process?

a. pinocytosis

b. diffusion

c. primary active transport

d. facilitated diffusion

e. osmosis

Answer the questions below.

16. Identify one example of a protein type made by ribosomes bound to the rough endoplasmic reticulum. Identify one example of a protein type made by ribosomes freely suspended in the cytosol.

17. Describe two structural features of membrane phospholipids that affect membrane fluidity. Use one or two sentences to explain how each feature affects membrane fluidity.

18. Explain why it is beneficial for a cell to use enzymes that work best at an acidic pH inside lysosomes.

19. List three factors that affect the rate of diffusion of a substance through a membrane (a simple lipid bilayer without transport proteins). Use one or two short sentences to describe the effect of each factor on diffusion.

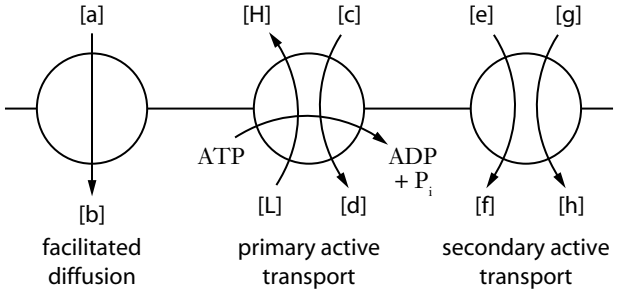
20. Identify the cell structures described in the following statements.

a. This very long extension of the cell membrane contains many microtubules and is used to propel cells in their environment.

b. This series of curved membrane sacs is used to modify, sort, and package lipids and proteins.

c. These flattened, disk-like membranes contain pigment molecules that absorb light energy.

21. Three transport proteins are shown in the diagram below. For each of the labels (a to h) in the diagram, identify the concentration of the transported molecule as either H (high) or L (low). The concentration brackets for one of the transported molecules have been completed for you as an example.



22. Describe the sources of energy used by primary active transport and secondary active transport.

23. Describe both an electrochemical gradient and a concentration gradient across a membrane, and explain the difference between them.

24. Channel and carrier proteins transport molecules at different rates. Explain why this is the case.

25. List the structures that are found in plant cells but not animal cells. Describe one important function of each structure.

26. Explain why most membrane proteins and phospholipids are able to move relative to one another and why this characteristic is important.

Thinking and Investigation

27. Secreted proteins follow a pathway from their synthesis to their release from the cell. Some steps in that pathway are listed below. Arrange and rewrite the steps in the proper order that ends with their release from the cell.

- **a.** The proteins are packaged into vesicles that form at the *trans* face of the Golgi.
- **b.** Vesicles merge with the *cis* face of the Golgi apparatus.
- **c.** Vesicles fuse with the cell membrane and release proteins by exocytosis.
- **d.** During their synthesis proteins are inserted into the lumen of the rough ER.
- **e.** Proteins are packaged into vesicles formed at the rough ER.
- **f.** Proteins are modified in the Golgi apparatus.

28. Using your understanding of osmosis, predict what change(s) would occur in an animal cell suddenly exposed to a solution with a much higher solute concentration than the interior of the cell. Explain your reasoning with one or two sentences using the term(s) isotonic, hypertonic, or hypotonic as appropriate.

29. Which organelle would you expect to find in greater quantity in the cells of an organ specialized for the synthesis of a lipid hormone-smooth ER or rough ER? Explain your reasoning.

30. Explain why the pumping of a different number of sodium and potassium ions across the cell membrane by sodium-potassium pumps is biologically significant.

31. Plants with non-woody stems (herbaceous plants) rely heavily on turgor pressure to help hold them upright.

- **a.** Given that fact, what do you think the normal, healthy environment is like for those plant cells (isotonic, hypotonic, or hypertonic)?
- **b.** If the environment of these plant cells had less water but otherwise had the same amount of solutes present as normal (e.g. drought conditions), would the plants be better or less able to stand upright? Explain with one or two sentences.

32. Many polar molecules are able to diffuse directly through the lipid bilayer of a membrane, and yet cells have carrier proteins for the passive transport of many such molecules. Suggest a possible explanation why a cell would have carriers for molecules able to diffuse through a lipid bilayer.

33. Antibodies are proteins of the immune system that are able to recognize and bind specific molecules, even other proteins such as membrane proteins. The binding of an antibody can be visualized by tagging it with a fluorescent dye visible by fluorescence microscopy. This type of microscopy employs an ultraviolet light source that causes the attached dye molecules to fluoresce various colours depending on the type of dye used. During microscopy the ability of the attached dyes to fluoresce can be destroyed at will, even over small areas of a cell surface, using a finely focussed laser beam. These "photobleached" dyes appear dark. Given this technological ability, construct a flowchart that shows the steps you could take to demonstrate that many membrane proteins are able to move laterally when a membrane is in the fluid state.

34. Several cold-sensitive and cold-tolerant varieties of a plant were discovered in the wild. Careful observations revealed that the membrane fluidity of the cold-sensitive plants varied widely with changes in temperature whereas the cold-tolerant plants showed much less fluctuation in membrane fluidity at those same temperatures. Using your knowledge and understanding of membrane fluidity and phospholipid structure, suggest a testable hypothesis for the observations made with these plants.

35. Radioactive amino acids are readily available and can be used by cells to make proteins. The location of radioactive proteins in cells can be detected and imaged microscopically. Given those facts and your understanding of protein synthesis in the endomembrane system, design the procedure for an investigation to show that many proteins synthesized at the rough ER move through compartments of the endomembrane system and emerge at the *trans*-face of the Golgi apparatus.

36. Provide a short point-form explanation for the appearance of carbohydrate chains at the external face but not the cytoplasmic (cytosolic) face of the cell membrane.

37. Two different molecules (A and B) are the same size and both are uncharged polar molecules. Neither molecule diffuses easily through a lipid bilayer, but both have transport proteins for their specific import into cells. Molecule A is transported into cells at a rate that is approximately 1000 times faster than molecule B, even when their concentration gradients are identical. Using your understanding of membrane transport, offer an explanation for the difference in the rates of transport of the two molecules.

Communication

38. Proteins control a wide variety of cellular processes. Create a table like the one shown below, listing three functions of membranes that are directly due to the presence and function of membrane proteins. Use point form to describe each function.

Function	Description

39. Write three or four sentences to explain why phospholipids spontaneously form lipid bilayers when placed in water. Draw and label a diagram of a phospholipid bilayer to support your answer.

40. Explain the following statement in your own words: Unlike pinocytosis, receptor-mediated endocytosis brings specific molecules into a cell.

41. Draw and label a Venn diagram that compares and contrasts pinocytosis and phagocytosis.

42. List five of the several different ways molecules might enter a cell.

43. Construct a concept map for the entry of polar molecules across a lipid bilayer. Be sure to include the major categories of entry as higher-order labels in your map, using the terms "diffusion", "transport protein", and "membrane-assisted transport".

44. Write a "shock and awe" tabloid-type newspaper article about the effects of either hypotonic or hypertonic solutions on red blood cells. Be sure to create a title that will grab and hold your readers. The article should be three to five very short paragraphs in the inverted-pyramid style typical of a newspaper article.

45. Draw and label a Venn diagram that compares and contrasts the channel proteins and carrier proteins used in facilitated diffusion.

46. Construct a Venn diagram that compares and contrasts the carrier proteins used in passive transport and primary active transport.

47. Although some channel proteins are open all the time, others are gated and thus open and close in response to a variety of stimuli. List three types of changes that are known to affect the opening and closing of gated channels.

48. Draw and label a Venn diagram comparing and contrasting the structure, function and location of chloroplasts and mitochondria.

49. Draw a flow chart to explain how the rough ER, smooth ER, Golgi apparatus and vesicles function together as components of the endomembrane system. Begin with the statement:

Polypeptides are produced by rough ER and put into the lumen.

50. Summarize your learning in this chapter using a graphic organizer. To help you, the Chapter 2 Summary lists the Key Terms and Key Concepts. Refer to Using Graphic Organizers in Appendix A to help you decide which graphic organizer to use.

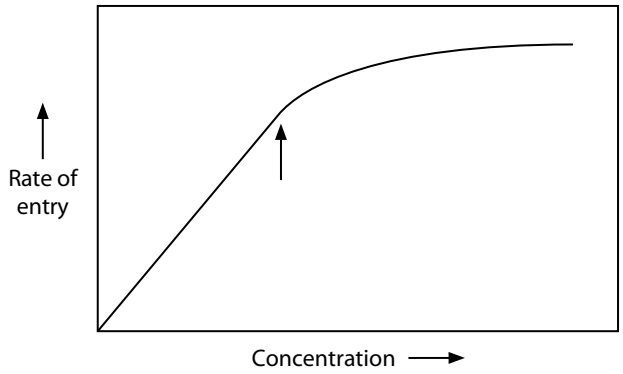
Application

51. BIG IDEAS Biochemical compounds play important structural and functional roles in cells of all organisms. Vesicles were constructed in the lab using only a single type of phospholipid in the presence or absence of cholesterol. Vesicle batch A contained vesicles with lipid bilayers composed only of the phospholipid. Vesicle batch B contained vesicles with both the phospholipid and cholesterol. The membrane fluidity of the two different batches of vesicles was examined at a high temperature and at a low temperature.

- **a.** Which vesicle batch would you expect to exhibit the greatest membrane fluidity at the high temperature?
- **b.** Which vesicle batch would you expect to exhibit the lowest membrane fluidity at the low temperature?
- **c.** Using your understanding of cholesterol and membranes, explain your choices in a short paragraph of a few sentences.

52. The rate of entry of a molecule into cells was examined by a researcher attempting to determine the transport mechanism for the molecule. In several parallel experiments, the cells were exposed to different starting concentrations of the molecule, and the rate of entry was determined at each concentration. As shown

in the graph below, the rate of entry was linear at low starting concentrations, but at high concentrations the rate of entry levelled off.



a. What mechanism likely resulted in the entry of the molecules into the cells-diffusion through the lipid bilayer of the membrane or facilitated diffusion?

b. Explain the shape of the line seen in the graph. Why did the rate of diffusion begin to slow at the point indicated by the arrow in the graph?

c. If the plot indicated a linear relationship over the entire range of concentrations (even at very high concentrations), how would this change your answer to part (a)?

53. Predict which of the following cellular processes would be directly affected by the improper functioning of mitochondria. Explain your choice(s).

A. gain or loss of water by a cell

B. facilitated diffusion of glucose into or out of a cell

C. pumping ions by a sodium-potassium pump

D. moving hydrogen ions (protons) against their gradient by a hydrogen ion pump

54. When a large number of animal cells were initially placed into a slightly hypotonic solution, there was a net movement of water across their cell membranes. Once the concentration of water is equal inside and outside the cells, would you expect there to be any movement of water across the cell membranes? Explain your reasoning.

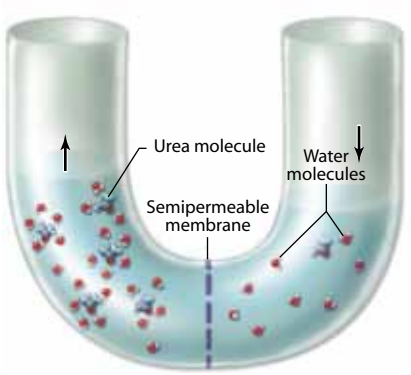
55. Almost all membrane proteins can be easily classified by a biochemist or cell biologist as being either integral or peripheral. What is the principal difference between an integral and a peripheral membrane protein?

56. Predict which type of protein would be released from the phospholipid bilayer by a mild treatment of cells such as the application of heat or a change in the pH of the environment. Explain with one or two sentences.

57. Most cell membrane receptor proteins bind a signal molecule on the exterior side of the cell membrane and then after a change in their shape some other molecule is able to bind the cytosolic side of the receptor protein. Are these types of receptor proteins peripheral or integral? How do you know?

58. While trying to purify a membrane protein a cell biologist discovered that the protein could only be released from the membrane by destroying the phospholipid bilayer with detergent. What type of protein was the cell biologist purifying? Explain.

59. Examine the illustration shown below. Write a detailed caption of at least four sentences to identify and describe the process shown in the illustration.



60. BIG IDEAS Biological molecules and their chemical properties affect cellular processes and biochemical reactions. Since the enzymes inside a lysosome work best at an acidic pH of ~5 (a higher concentration of protons than in the cytosol), a lysosome needs to establish and maintain a low pH in its interior.

a. What type of gradient is present when two compartments separated by a membrane each have a different pH?

b. Would the maintenance of a special environment like the interior of a lysosome require the expenditure of energy? Explain why (or why not).

c. Using your knowledge of membrane transport suggest a mechanism that could be used by a lysosome to both establish and maintain a low pH in its interior. Draw and label a diagram to help illustrate your written statement(s).

Chapter 2 SELF-ASSESSMENT

Select the letter of the best answer below.

1. K/U Which components does the nucleolus contain?

a. nucleoplasm
b. nuclear matrix
c. RNA and protein
d. lumen
e. nuclear core complex

2. K/U Which structure is typically found in plant cells but not animal cells?

a. cell membrane
b. mitochondria
c. peroxisome
d. nuclear envelope
e. large central vacuole

3. K/U Which is a function of rough endoplasmic reticulum?

a. synthesis of lipids
b. detoxification of alcohol
c. production of estrogen
d. protein synthesis of cell-membrane components
e. None of the above.

Use the table below to answer question 4.

Results for the F_1 Generation

1	rough endoplasmic reticulum
2	*trans* face of Golgi apparatus
3	*cis* face of Golgi apparatus
4	smooth endoplasmic reticulum
5	transport vesicle
6	secretory vesicle

4. K/U What is the correct sequence of organelles involved in producing and transporting a glycoprotein that will be a receptor on the cell surface?

a. 1, 2, 3, 4, 5, 6
b. 1, 4, 5, 3, 2, 6
c. 4, 5, 1, 2, 3, 6
d. 4, 1, 2, 3, 5, 6
e. 6, 3, 2, 5, 1, 4

5. K/U Which cellular component makes up the inner shaft of cilia?

a. flagella
b. cell membrane
c. microfilaments
d. microtubules
e. intermediate filaments

6. K/U Which statement best describes the movement of molecules that make up a cell membrane?

a. The membrane molecules are held together by covalent bonds.
b. Phospholipids leak out of the membrane if it is torn.
c. The molecules in the membrane can move about fairly freely.
d. Phospholipids can move about freely, but all proteins are fixed in place.
e. Proteins can move about freely, but phospholipids are fixed in place.

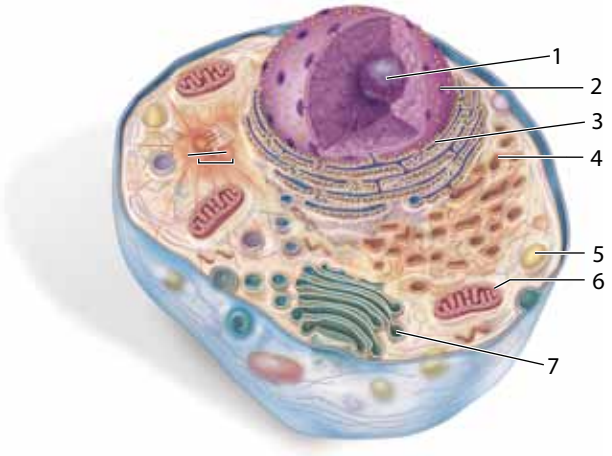
7. K/U Which is an example of passive transport?

a. A cell takes in particles by pinocytosis.
b. The sodium-potassium pump transports ions from one side of the membrane to the other, against a concentration gradient.
c. A pump uses ATP as an energy source to transport hydrogen ions out of a cell.
d. An ion channel permits sodium ions to diffuse through a cell membrane.
e. A membrane protein uses a hydrogen ion concentration gradient to transport sucrose against its concentration gradient and into a cell.

8. A What form of membrane-assisted transport would a white blood cell use to ingest a bacterial cell?

a. exocytosis
b. phagocytosis
c. pinocytosis
d. receptor-mediated endocytosis
e. secretion

Use the diagram below to answer questions 9 and 10.



9. K/U Which numbered organelle contains enzymes that break down hydrogen peroxide?

a. 3
b. 4
c. 5
d. 6
e. 7

10. K/U Which numbered structure allows RNA to pass through the nuclear envelope?

a. 1
b. 2
c. 3
d. 4
e. 5

Use sentences and diagrams as appropriate to answer the questions below.

11. K/U Why are red blood cells incapable of reproduction?

12. K/U In what ways are the roles of cholesterol in the cell membrane contradictory?

13. A Paramecia are unicellular organisms that live in fresh water. They contain contractile vacuoles, which squeeze excess water out of the cell. Explain why paramecia need contractile vacuoles. Use appropriate terminology with respect to osmotic concentrations.

14. A In babies who are born with Tay-Sachs disease, lipids build up in the brain instead of being broken down and their components recycled. Infer why Tay-Sachs disease is known as a lysosomal storage disease.

15. K/U What did the observation that lipid-soluble molecules entered cells more rapidly than water-soluble molecules suggest to researchers who were studying the cell membrane?

16. C Draw and label a Venn diagram that compares and contrasts vesicles in plant cells and animal cells.

17. T/I The prefix *hydro-* refers to water, and the suffix *-lysis* refers to splitting something. Explain how active transport depends on the hydrolysis of a certain molecule.

18. T/I Osmosis occurs readily across the cell membrane by simple diffusion. In some cases, however, water crosses the cell membrane 10 times faster than it would by simple diffusion. What could logically explain this observation?

19. T/I Lizards are sometimes called "cold-blooded" because they depend on the surrounding temperatures to keep themselves warm. Predict how the cell membranes of a lizard might change from winter to summer with respect to the membrane lipids and amount of cholesterol that they contain. Justify your predictions.

20. A On a homework-help website, a student asks the following question: "What is the role of ribosomes on the smooth ER"

a. Explain why this question, as stated, is scientifically incorrect.
b. Rewrite the question so that it correctly asks what the student intended to ask.
c. Answer the rewritten question.

21. C **a.** Draw and label a simple diagram of a section of cell membrane, including the phospholipid bilayer, a channel protein, a carrier protein, and an ion pump.
b. Indicate on your diagram the types of substances that can cross the cell membrane at various points.

22. T/I What happens to the surface area of a cell during exocytosis? Explain.

23. A Electron microscope images reveal that certain disease-causing bacteria cause the cells lining the intestine to bulge outwards. What does this observation indicate about the effect of the bacteria on the cytoskeleton?

24. T/I How could you test the effect of calcium ions on exocytosis? Assume that you have access to tissue cell cultures, fluorescent labels, and an appropriate microscope, among other materials and equipment.

25. A One of the disease symptoms that results from abnormal mitochondria is extreme muscle weakness. Explain why this symptom occurs.

Self-Check

If you missed question...	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Review section(s)...	2.1	2.1	2.1	2.1	2.1	1.1	2.2	2.2	2.1	2.1	2.1	2.1	2.2	2.1	2.1	2.1	2.2	2.2	2.1	2.2	2.1 2.2	2.2	2.1 2.2	2.1 2.2	2.1 2.2