7.1 Life Is Cellular

Key Questions

- *What is the cell theory?*
- *How do microscopes work?*
- *How are prokaryotic and eukaryotic cells different?*

Vocabulary

cell • cell theory •
cell membrane • nucleus •
eukaryote • prokaryote

Taking Notes

Outline Before you read, make an outline using the green and blue headings in the text. As you read, fill in notes under each heading.

THINK ABOUT IT What's the smallest part of any living thing that still counts as being "alive"? Is a leaf alive? How about your big toe? How about a drop of blood? Can we just keep dividing living things into smaller and smaller parts, or is there a point at which what's left is no longer alive? As you will see, there is such a limit, the smallest living unit of any organism—the cell.

The Discovery of the Cell

What is the cell theory?

"Seeing is believing," an old saying goes. It would be hard to find a better example of this than the discovery of the cell. Without the instruments to make them visible, cells remained out of sight and, therefore, out of mind for most of human history. All of this changed with a dramatic advance in technology—the invention of the microscope.

Early Microscopes In the early 1600s, eyeglass makers in Europe discovered that using several glass lenses in combination could magnify even the smallest objects to make them easy to see. Before long, they had built the first true microscopes from these lenses, opening the door to the study of biology as we know it today.

In 1665, Englishman Robert Hooke used an early compound microscope to look at a nonliving thin slice of cork, a plant material. Under the microscope, cork seemed to be made of thousands of tiny empty chambers. Hooke called these chambers "cells" because they reminded him of a monastery's tiny rooms, which were called cells. The term *cell* is used in biology to this day. Today we know that living cells are not empty chambers, that in fact they contain a huge array of working parts, each with its own function.

In Holland around the same time, Anton van Leeuwenhoek used a single-lens microscope to observe pond water and other things. To his amazement, the microscope revealed a fantastic world of tiny living organisms that seemed to be everywhere, in the water he and his neighbors drank, and even in his own mouth. Leeuwenhoek's illustrations of the organisms he found in the human mouth—which today we call bacteria—are shown in **Figure 7–1**.

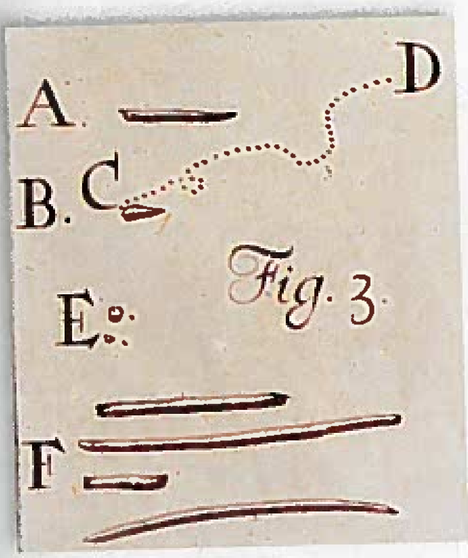


FIGURE 7–1 Early Microscope Images Using a simple microscope, Anton van Leeuwenhoek was the first to observe living microorganisms. These drawings, taken from one of his letters, show bacteria in the human mouth.

The Cell Theory Soon after van Leeuwenhoek, observations by scientists made it clear that **cells** are the basic units of life. In 1838, German botanist Matthias Schleiden concluded that all plants are made of cells. The next year, German biologist Theodor Schwann stated that all animals are made of cells. In 1855, German physician Rudolf Virchow concluded that new cells can be produced only from the division of existing cells, confirming a suggestion made by German Lorenz Oken 50 years earlier. These discoveries, confirmed by many biologists, are summarized in the **cell theory,** a fundamental concept of biology. **The cell theory states:**

- **All living things are made up of cells.**
- **Cells are the basic units of structure and function in living things.**
- **New cells are produced from existing cells.**

Exploring the Cell

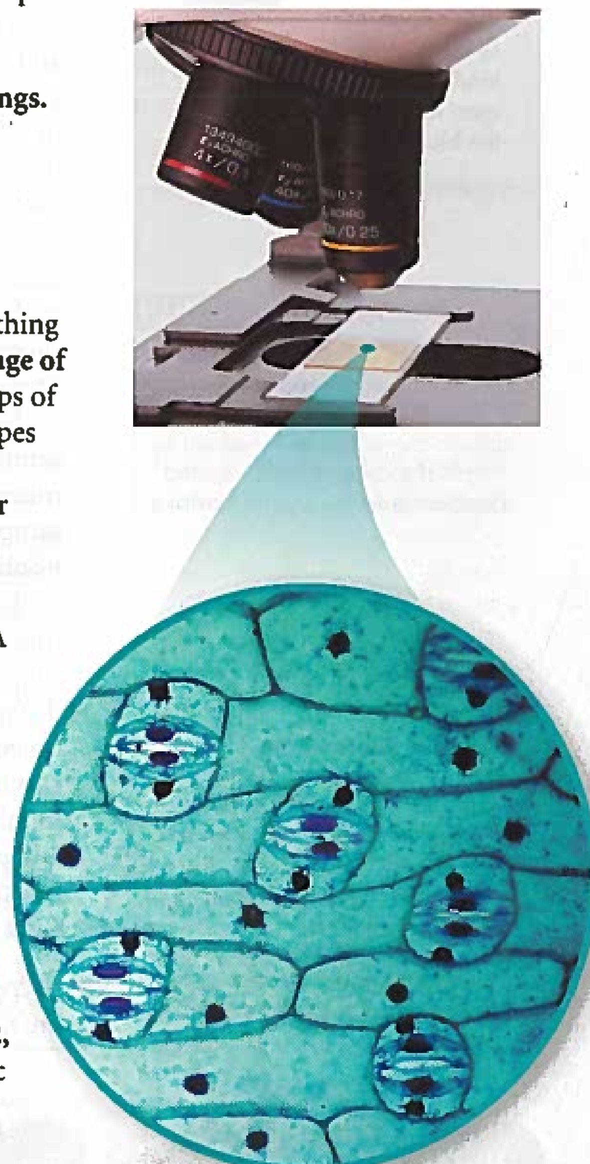
How do microscopes work?

A microscope, as you know, produces an enlarged image of something very small. **Most microscopes use lenses to magnify the image of an object by focusing light or electrons.** Following in the footsteps of Hooke, Virchow, and others, modern biologists still use microscopes to explore the cell. But today's researchers use microscopes and techniques more powerful than the pioneers of biology could ever have imagined.

Light Microscopes and Cell Stains The type of microscope you are probably most familiar with is the compound light microscope. A typical light microscope allows light to pass through a specimen and uses two lenses to form an image. The first set of lenses, located just above the specimen, enlarges the image of the specimen. The second set of lenses magnifies this image still further. Unfortunately, light itself limits the detail, or resolution, of images in a microscope. Like all forms of radiation, lightwaves are diffracted, or scattered, as they pass through matter. Because of this, light microscopes can produce clear images of objects only to a magnification of about 1000 times.

Another problem with light microscopy is that most living cells are nearly transparent, making it difficult to see the structures within them. Using chemical stains or dyes, as in **Figure 7–2**, can usually solve this problem. Some of these stains are so specific that they reveal only certain compounds or structures within the cell. Many of the slides you'll examine in your biology class laboratory will be stained this way.

A powerful variation on these staining techniques uses dyes that give off light of a particular color when viewed under specific wavelengths of light, a property called fluorescence. Fluorescent dyes can be attached to specific molecules and can then be made visible using a special fluorescence microscope. New techniques, in fact, enable scientists to engineer cells that attach florescent labels of different colors to specific molecules as they are produced. Fluorescence microscopy makes it possible to see and identify the locations of these molecules and even allows scientists to watch them move around in a living cell.



LM 35×

FIGURE 7–2 Cell Stains This specimen of onion leaf skin has been stained with a compound called toluidine blue. The dye makes the cell boundaries and nuclei clearly visible.

MYSTERY CLUE

At the hospital, a sample of Michelle's blood was drawn and examined. The red blood cells appeared swollen. What kind of microscope was most likely used to study the blood sample?

Electron Microscopes Light microscopes can be used to see cells and cell structures as small as 1 millionth of a meter—certainly pretty small! But what if scientists want to study something smaller than that, such as a virus or a DNA molecule? For that, they need electron microscopes. Instead of using light, electron microscopes use beams of electrons that are focused by magnetic fields. Electron microscopes offer much higher resolution than light microscopes. Some types of electron microscopes can be used to study cellular structures that are 1 billionth of a meter in size.

There are two major types of electron microscopes: transmission and scanning. Transmission electron microscopes make it possible to explore cell structures and large protein molecules. But because beams of electrons can only pass through thin samples, cells and tissues must be cut into ultrathin slices before they can be examined. This is the reason that such images often appear flat and two dimensional.

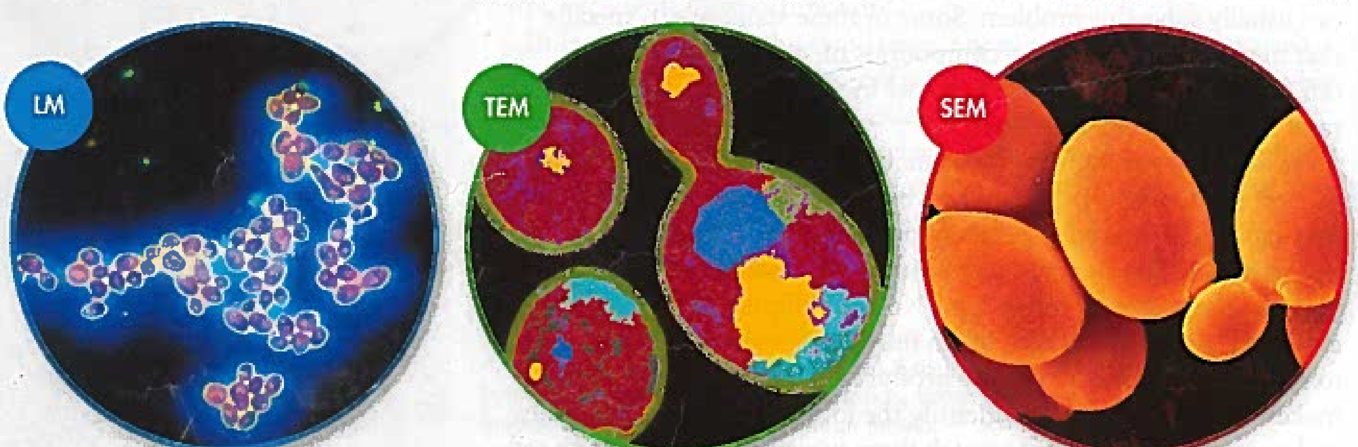
In scanning electron microscopes, a pencil-like beam of electrons is scanned over the surface of a specimen. Because the image is formed at the specimen's surface, samples do not have to be cut into thin slices to be seen. The scanning electron microscope produces stunning three-dimensional images of the specimen's surface.

Electrons are easily scattered by molecules in the air, which means samples must be placed in a vacuum to be studied with an electron microscope. As a result, researchers must chemically preserve their samples. Electron microscopy, then, can only be used to examine nonliving cells and tissues.

Look at **Figure 7–3**, which shows yeast cells as they might look under a light microscope, transmission electron microscope, and scanning electron microscope. You may wonder why the cells appear to be different colors in each micrograph. (A micrograph is a photo of an object seen through a microscope.) The colors in light micrographs come from the cells themselves, or from the stains and dyes used to highlight them. Electron micrographs, however, are actually black and white. Electrons, unlike light, don't come in colors. So scientists often use computer techniques to add "false color" to make certain structures stand out.

In Your Notebook *You are presented with a specimen to examine. What are two questions you would ask to determine the best microscope to use?*

FIGURE 7–3 Micrographs Different types of microscopes can be used to examine cells. Here, yeast cells are shown in a light micrograph (LM 500×), transmission electron micrograph (TEM 4375×), and a scanning electron micrograph (SEM 3750×).
Infer ***If scientists were studying a structure found on the surface of yeast, which kind of microscope would they likely use?***



Quick Lab
GUIDED INQUIRY

What Is a Cell?

❶ Look through a microscope at a slide of a plant leaf or stem cross section. Sketch one or more cells. Record a description of their shape and internal parts.

❷ Repeat step 1 with slides of nerve cells, bacteria, and paramecia.

❸ Compare the cells by listing the characteristics they have in common and some of the differences among them.

Analyze and Conclude

1. Classify Classify the cells you observed into two or more groups. Explain what characteristics you used to put each cell in a particular group.

Prokaryotes and Eukaryotes

How are prokaryotic and eukaryotic cells different?

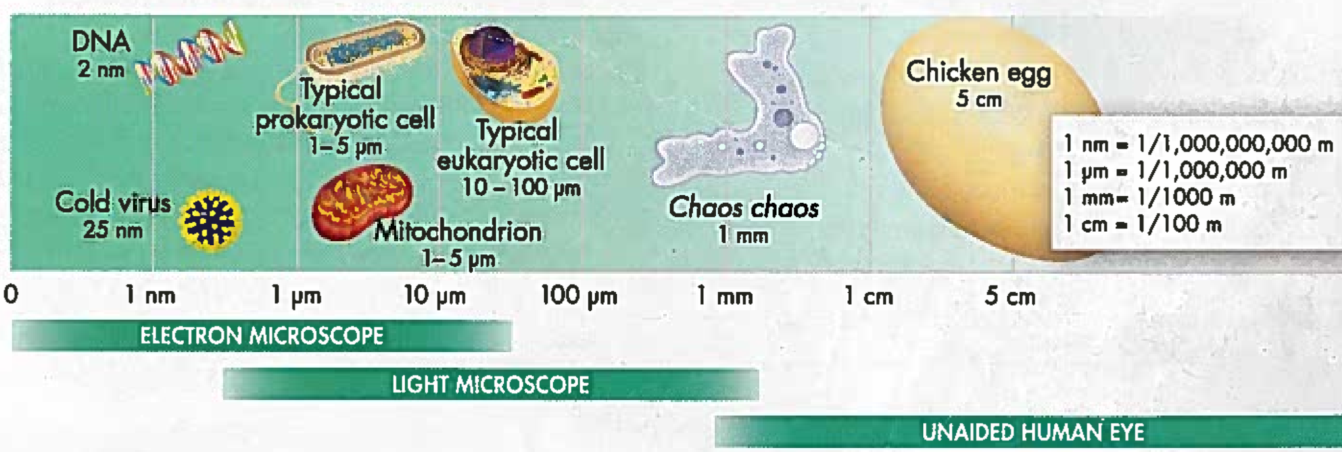
Cells come in an amazing variety of shapes and sizes, some of which are shown in **Figure 7–4.** Although typical cells range from 5 to 50 micrometers in diameter, the smallest *Mycoplasma* bacteria are only 0.2 micrometer across, so small that they are difficult to see under even the best light microscopes. In contrast, the giant amoeba *Chaos chaos* can be 1000 micrometers (1 millimeter) in diameter, large enough to be seen with the unaided eye as a tiny speck in pond water. Despite their differences, all cells, at some point in their lives, contain DNA, the molecule that carries biological information. In addition, all cells are surrounded by a thin flexible barrier called a **cell membrane.** (The cell membrane is sometimes called the *plasma membrane* because many cells in the body are in direct contact with the fluid portion of the blood—the plasma.) There are other similarities as well, as you will learn in the next lesson.

Cells fall into two broad categories, depending on whether they contain a nucleus. The **nucleus** (plural: nuclei) is a large membrane-enclosed structure that contains genetic material in the form of DNA and controls many of the cell's activities. **Eukaryotes** (yoo KAR ee ohts) are cells that enclose their DNA in nuclei. **Prokaryotes** (pro KAR ee ohts) are cells that do not enclose DNA in nuclei.

BUILD Vocabulary

WORD ORIGINS The noun **prokaryote** comes from the Greek word *karyon*, meaning "kernel," or nucleus. The prefix *pro-* means "before." Prokaryotic cells first evolved before nuclei developed.

FIGURE 7–4 Cell Size Is Relative The human eye can see objects larger than about 0.5 mm. Most of what interests cell biologists, however, is much smaller than that. Microscopes make seeing the cellular and subcellular world possible.



Prokaryotes As seen in **Figure 7–5,** prokaryotic cells are generally smaller and simpler than eukaryotic cells, although there are many exceptions to this rule. **Prokaryotic cells do not separate their genetic material within a nucleus.** Despite their simplicity, prokaryotes carry out every activity associated with living things. They grow, reproduce, respond to the environment, and, in some cases, glide along surfaces or swim through liquids. The organisms we call bacteria are prokaryotes.

Eukaryotes Eukaryotic cells are generally larger and more complex than prokaryotic cells. Most eukaryotic cells contain dozens of structures and internal membranes, and many are highly specialized. **In eukaryotic cells, the nucleus separates the genetic material from the rest of the cell.** Eukaryotes display great variety: some, like the ones commonly called "protists," live solitary lives as unicellular organisms; others form large, multicellular organisms—plants, animals, and fungi.

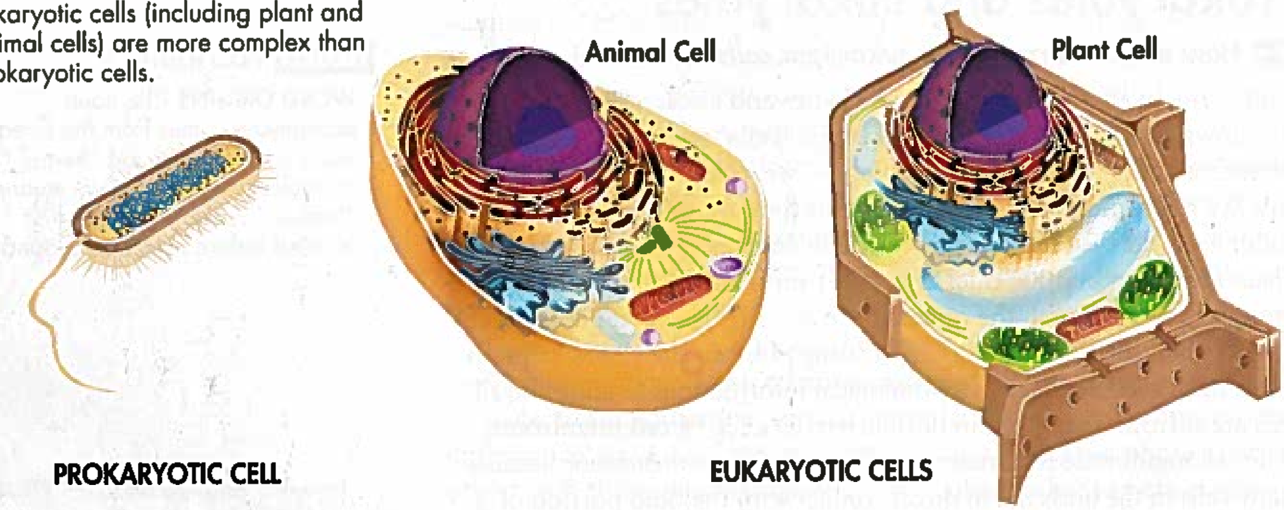


FIGURE 7–5 Cell Types In general, eukaryotic cells (including plant and animal cells) are more complex than prokaryotic cells.

7.1 Assessment

Review Key Concepts

1. a. **Review** What is a cell?
   b. **Explain** What three statements make up the cell theory?
   c. **Infer** How did the invention of the microscope help the development of the cell theory?
2. a. **Review** How do microscopes work?
   b. **Apply Concepts** What does it mean if a micrograph is "false-colored?"
3. a. **Review** What features do all cells have?
   b. **Summarize** What is the main difference between prokaryotes and eukaryotes?

PRACTICE PROBLEMS MATH

A light microscope can magnify images up to 1000 times. To calculate the total magnification of a specimen, multiply the magnification of the eyepiece lens by the magnification of the objective lens used. (For more information on microscopes, see Appendix B.)

4. **Calculate** What is the total magnification of a microscope that has an eyepiece magnification of 10× and an objective lens magnification of 50×.
5. **Calculate** A 10 micrometer cell is viewed through a 10× objective and a 10× eyepiece. How large will the cell appear to the microscope user?

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7.2 Cell Structure

Key Questions

What is the role of the cell nucleus?

What are the functions of vacuoles, lysosomes, and the cytoskeleton?

What organelles help make and transport proteins?

What are the functions of chloroplasts and mitochondria?

What is the function of the cell membrane?

Vocabulary

cytoplasm • organelle • vacuole • lysosome • cytoskeleton • centriole • ribosome • endoplasmic reticulum • Golgi apparatus • chloroplast • mitochondrion • cell wall • lipid bilayer • selectively permeable

Taking Notes

Venn Diagram Create a Venn diagram that illustrates the similarities and differences between prokaryotes and eukaryotes.

THINK ABOUT IT At first glance, a factory is a puzzling place. Machines buzz and clatter; people move quickly in different directions. So much activity can be confusing. However, if you take the time to watch carefully, what might at first seem like chaos begins to make sense. The same is true for the living cell.

Cell Organization

What is the role of the cell nucleus?

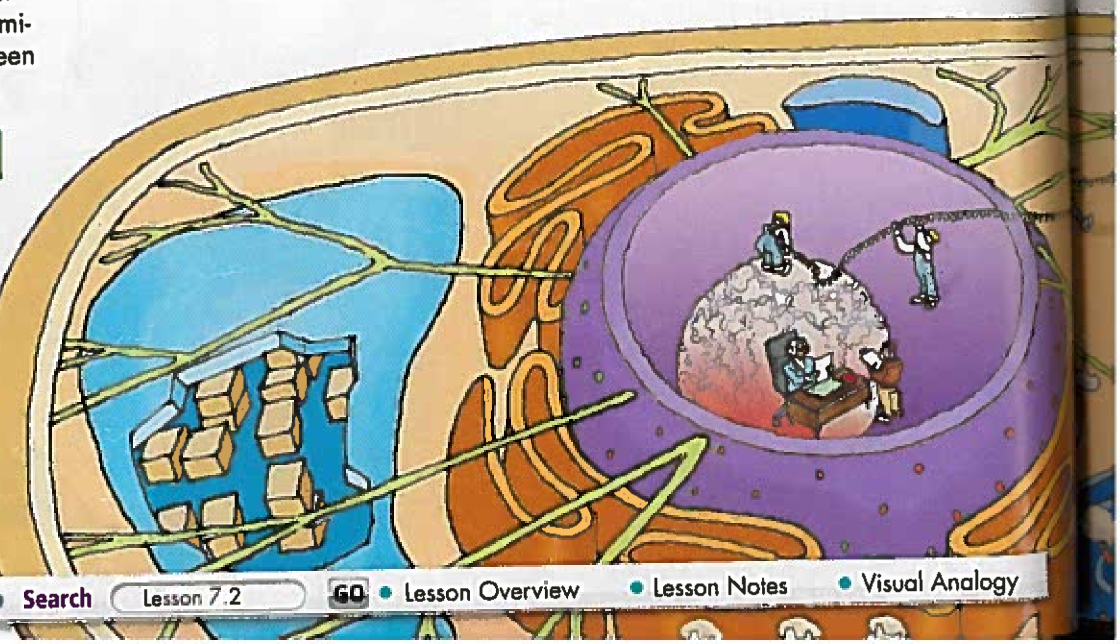
The eukaryotic cell is a complex and busy place. But if you look closely at eukaryotic cells, patterns begin to emerge. For example, it's easy to divide each cell into two major parts: the nucleus and the cytoplasm. The **cytoplasm** is the fluid portion of the cell outside the nucleus. As you will see, the nucleus and cytoplasm work together in the business of life. Prokaryotic cells have cytoplasm too, even though they do not have a nucleus.

In our discussion of cell structure, we consider each major component of plant and animal eukaryotic cells—some of which are also found in prokaryotic cells—one by one. Because many of these structures act like specialized organs, they are known as **organelles**, literally "little organs." Understanding what each organelle does helps us understand the cell as a whole. A summary of cell structure can be found on pages 206–207.

VISUAL ANALOGY

THE CELL AS A LIVING FACTORY

FIGURE 7–6 The specialization and organization of work and workers contribute to the productivity of a factory. In much the same way, the specialized parts in a cell contribute to the cell's over all stability and survival.



Comparing the Cell to a Factory In some respects, the eukaryotic cell is much like a living version of a modern factory (**Figure 7–6**). The different organelles of the cell can be compared to the specialized machines and assembly lines of the factory. In addition, cells, like factories, follow instructions and produce products. As we look through the organization of the cell, we'll find plenty of places in which the comparison works so well that it will help us understand how cells work.

The Nucleus In the same way that the main office controls a large factory, the nucleus is the control center of the cell. **The nucleus contains nearly all the cell's DNA and, with it, the coded instructions for making proteins and other important molecules.** Prokaryotic cells lack a nucleus, but they do have DNA that contains the same kinds of instructions.

The nucleus, shown in **Figure 7–7**, is surrounded by a nuclear envelope composed of two membranes. The nuclear envelope is dotted with thousands of nuclear pores, which allow material to move into and out of the nucleus. Like messages, instructions, and blueprints moving in and out of a factory's main office, a steady stream of proteins, RNA, and other molecules move through the nuclear pores to and from the rest of the cell.

Chromosomes, which carry the cell's genetic information, are also found in the nucleus. Most of the time, the threadlike chromosomes are spread throughout the nucleus in the form of chromatin—a complex of DNA bound to proteins. When a cell divides, its chromosomes condense and can be seen under a microscope. You will learn more about chromosomes in later chapters.

Most nuclei also contain a small dense region known as the nucleolus (noo KLEE uh lus). The nucleolus is where the assembly of ribosomes begins.

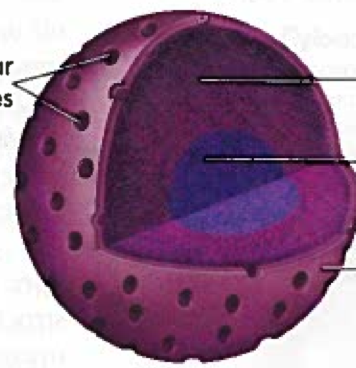
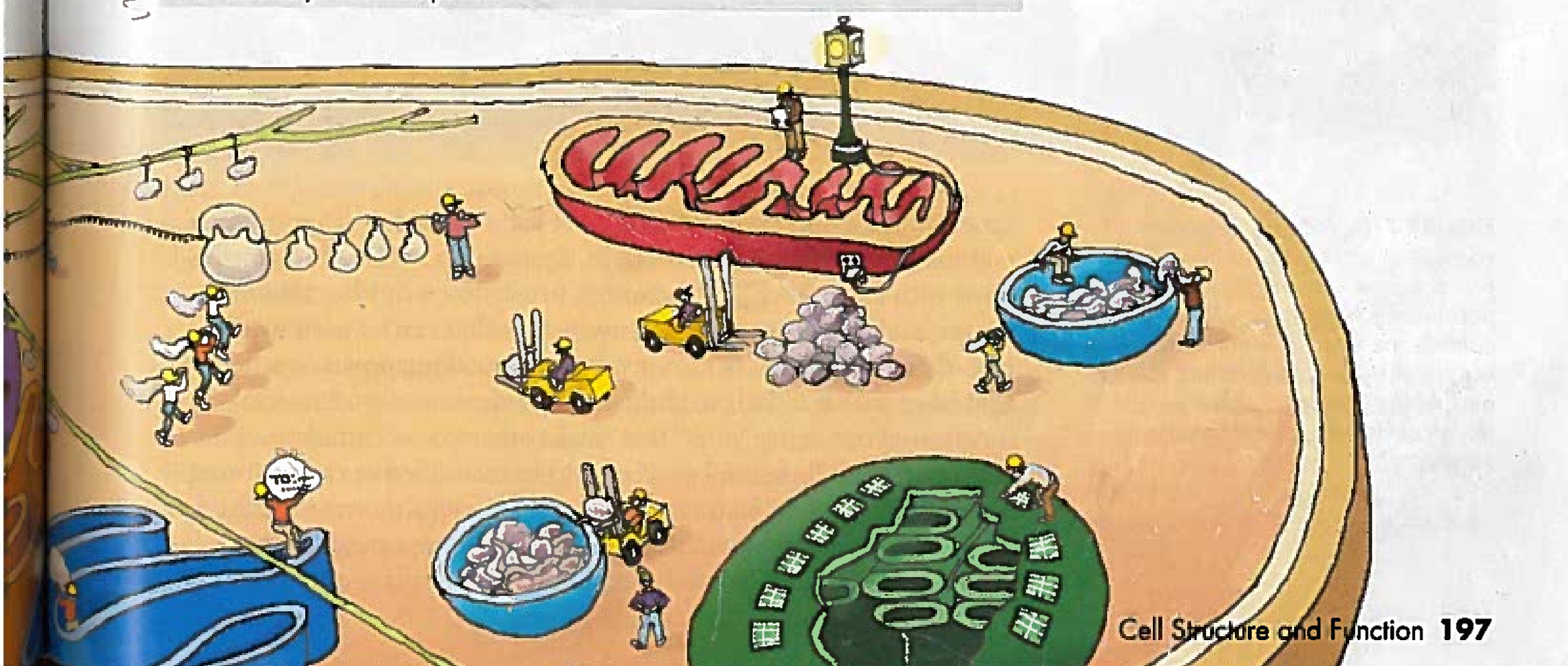


FIGURE 7–7 The Nucleus The nucleus controls most cell processes and contains DNA. The small, dense region in the nucleus is known as the nucleolus.

In Your Notebook *Describe the structure of the nucleus. Include the words* nuclear envelope, nuclear pore, chromatin, chromosomes, *and* nucleolus *in your description.*



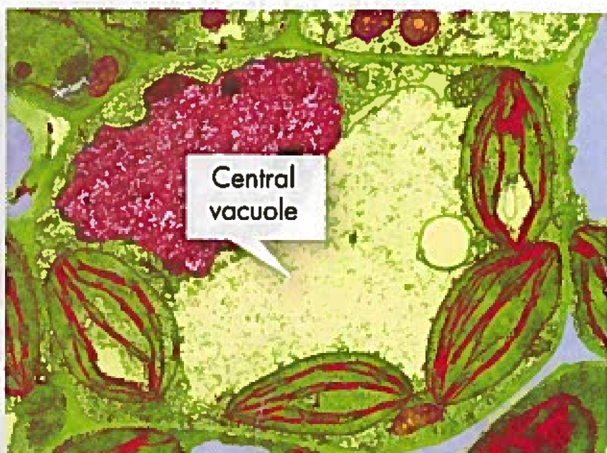
Organelles That Store, Clean Up, and Support

What are the functions of vacuoles, lysosomes, and the cytoskeleton?

Many of the organelles outside the nucleus of a eukaryotic cell have specific functions, or roles. Among them are structures called vacuoles, lysosomes, and cytoskeleton. These organelles represent the cellular factory's storage space, cleanup crew, and support structures.

Vacuoles and Vesicles Every factory needs a place to store things, and so does every cell. Many cells contain large, saclike, membrane-enclosed structures called **vacuoles. Vacuoles store materials like water, salts, proteins, and carbohydrates.** In many plant cells, there is a single, large central vacuole filled with liquid. The pressure of the central vacuole in these cells increases their rigidity, making it possible for plants to support heavy structures, such as leaves and flowers. The image on the left in **Figure 7–8** shows a typical plant cell's large central vacuole.

Vacuoles are also found in some unicellular organisms and in some animals. The paramecium on the right in **Figure 7–8** contains an organelle called a contractile vacuole. By contracting rhythmically, this specialized vacuole pumps excess water out of the cell. In addition, nearly all eukaryotic cells contain smaller membrane-enclosed structures called vesicles. Vesicles store and move materials between cell organelles, as well as to and from the cell surface.



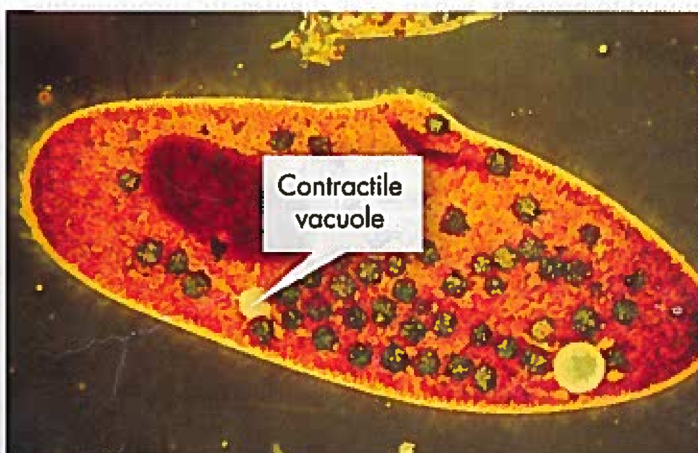
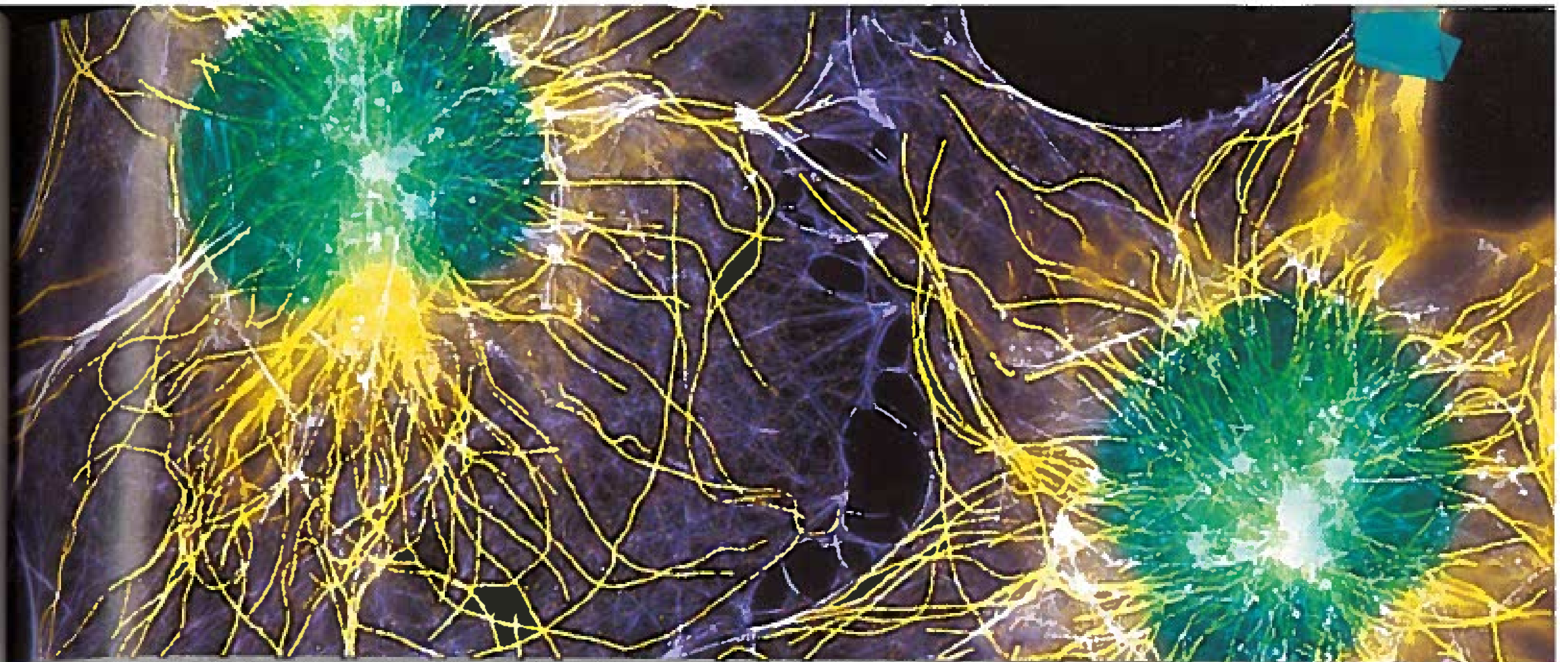


FIGURE 7–8 Vacuoles The central vacuole of plant cells stores salts, proteins, and carbohydrates. A paramecium's contractile vacuole controls the water content of the organism by pumping water out. **Apply Concepts** ***How do vacuoles help support plant structures?***

Lysosomes Even the neatest, cleanest factory needs a cleanup crew, and that's where lysosomes come in. **Lysosomes** are small organelles filled with enzymes. **Lysosomes break down lipids, carbohydrates, and proteins into small molecules that can be used by the rest of the cell. They are also involved in breaking down organelles that have outlived their usefulness.** Lysosomes perform the vital function of removing "junk" that might otherwise accumulate and clutter up the cell. A number of serious human diseases can be traced to lysosomes that fail to function properly. Biologists once thought that lysosomes were only found in animal cells, but it is now clear that lysosomes are also found in a few specialized types of plant cells as well.



LM 1175×

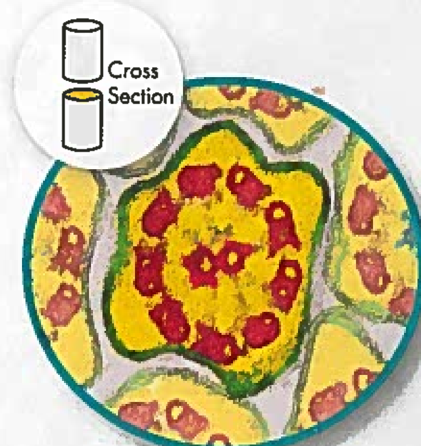
FIGURE 7–9 Cytoskeleton The cytoskeleton supports and gives shape to the cell, and is involved in many forms of cell movement. These connective tissue fibroblast cells have been treated with fluorescent tags that bind to certain elements. Microfilaments are pale blue, microtubules are yellow, and the nuclei are green.

The Cytoskeleton As you know, a factory building is supported by steel or cement beams and by columns that hold up its walls and roof. Eukaryotic cells are given their shape and internal organization by a network of protein filaments known as the **cytoskeleton.** Certain parts of the cytoskeleton also help transport materials between different parts of the cell, much like the conveyor belts that carry materials from one part of a factory to another. Cytoskeletal components may also be involved in moving the entire cell as in cell flagella and cillia. **The cytoskeleton helps the cell maintain its shape and is also involved in movement.** Fluorescence imaging, as seen in **Figure 7–9,** clearly shows the complexity of a cell's cytoskeletal network. Microfilaments (pale blue) and microtubules (yellow) are two of the principal protein filaments that make up the cytoskeleton.

▶ ***Microfilaments*** Microfilaments are threadlike structures made up of a protein called actin. They form extensive networks in some cells and produce a tough flexible framework that supports the cell. Microfilaments also help cells move. Microfilament assembly and disassembly is responsible for the cytoplasmic movements that allow amoebas and other cells to crawl along surfaces.

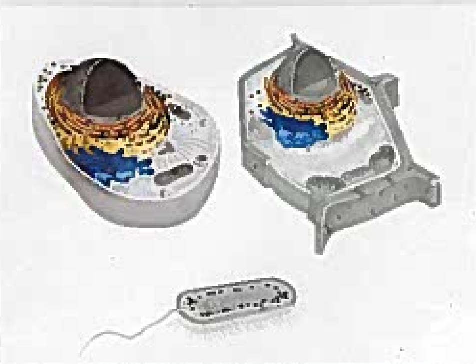
▶ ***Microtubules*** Microtubules are hollow structures made up of proteins known as tubulins. In many cells, they play critical roles in maintaining cell shape. Microtubules are also important in cell division, where they form a structure known as the mitotic spindle, which helps to separate chromosomes. In animal cells, organelles called centrioles are also formed from tubulins. **Centrioles** are located near the nucleus and help organize cell division. Centrioles are not found in plant cells.

Microtubules also help build projections from the cell surface—known as cilia (singular: cilium) and flagella (singular: flagellum)—that enable cells to swim rapidly through liquid. The microtubules in cilia and flagella are arranged in a "9 + 2" pattern, as shown in **Figure 7–10.** Small cross-bridges between the microtubules in these organelles use chemical energy to pull on, or slide along, the microtubles, producing controlled movements.



TEM 110,000×

FIGURE 7–10 The "9 + 2" Pattern of Microtubules In this micrograph showing the cross section of a cilium, you can clearly see the 9 + 2 arrangement of the red microtubules.
Apply Concepts ***What is the function of cilia?***



Organelles That Build Proteins

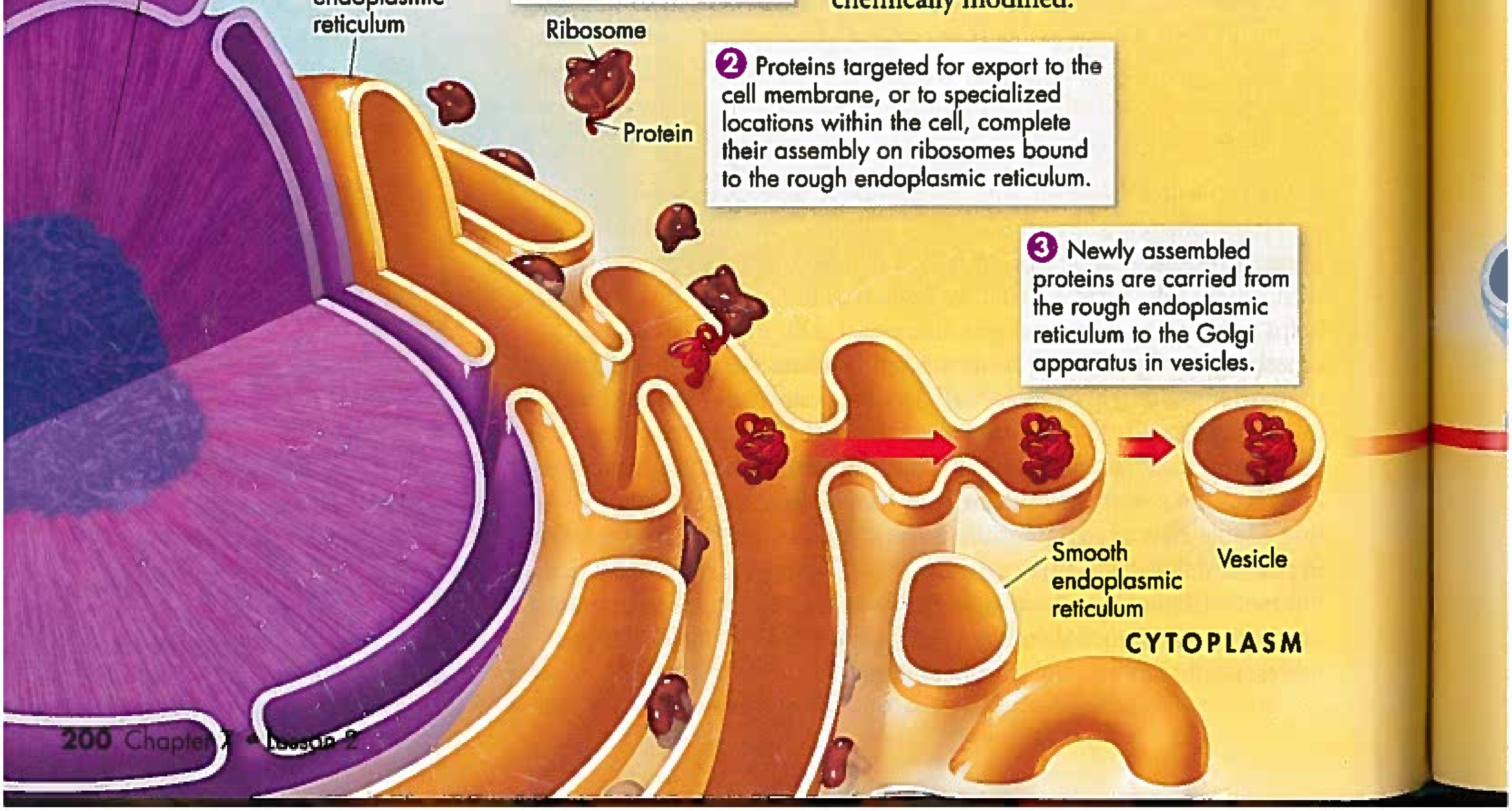
What organelles help make and transport proteins?

Life is a dynamic process, and living things are always working, building new molecules all the time, especially proteins, which catalyze chemical reactions and make up important structures in the cell. Because proteins carry out so many of the essential functions of living things, a big part of the cell is devoted to their production and distribution. Proteins are synthesized on ribosomes, sometimes in association with the rough endoplasmic reticulum in eukaryotes. The process of making proteins is summarized in **Figure 7–11.**

Ribosomes One of the most important jobs carried out in the cellular "factory" is making proteins. **Proteins are assembled on ribosomes. Ribosomes** are small particles of RNA and protein found throughout the cytoplasm in all cells. Ribosomes produce proteins by following coded instructions that come from DNA. Each ribosome, in its own way, is like a small machine in a factory, turning out proteins on orders that come from its DNA "boss." Cells that are active in protein synthesis are often packed with ribosomes.

Endoplasmic Reticulum Eukaryotic cells contain an internal membrane system known as the **endoplasmic reticulum** (en doh PLAZ mik rih TIK yuh lum), or ER. The endoplasmic reticulum is where lipid components of the cell membrane are assembled, along with proteins and other materials that are exported from the cell.

The portion of the ER involved in the synthesis of proteins is called rough endoplasmic reticulum, or rough ER. It is given this name because of the ribosomes found on its surface. Newly made proteins leave these ribosomes and are inserted into the rough ER, where they may be chemically modified.



Proteins made on the rough ER include those that will be released, or secreted, from the cell as well as many membrane proteins and proteins destined for lysosomes and other specialized locations within the cell. Rough ER is abundant in cells that produce large amounts of protein for export. Other cellular proteins are made on "free" ribosomes, which are not attached to membranes.

The other portion of the ER is known as smooth endoplasmic reticulum (smooth ER) because ribosomes are not found on its surface. In many cells, the smooth ER contains collections of enzymes that perform specialized tasks, including the synthesis of membrane lipids and the detoxification of drugs. Liver cells, which play a key role in detoxifying drugs, often contain large amounts of smooth ER.

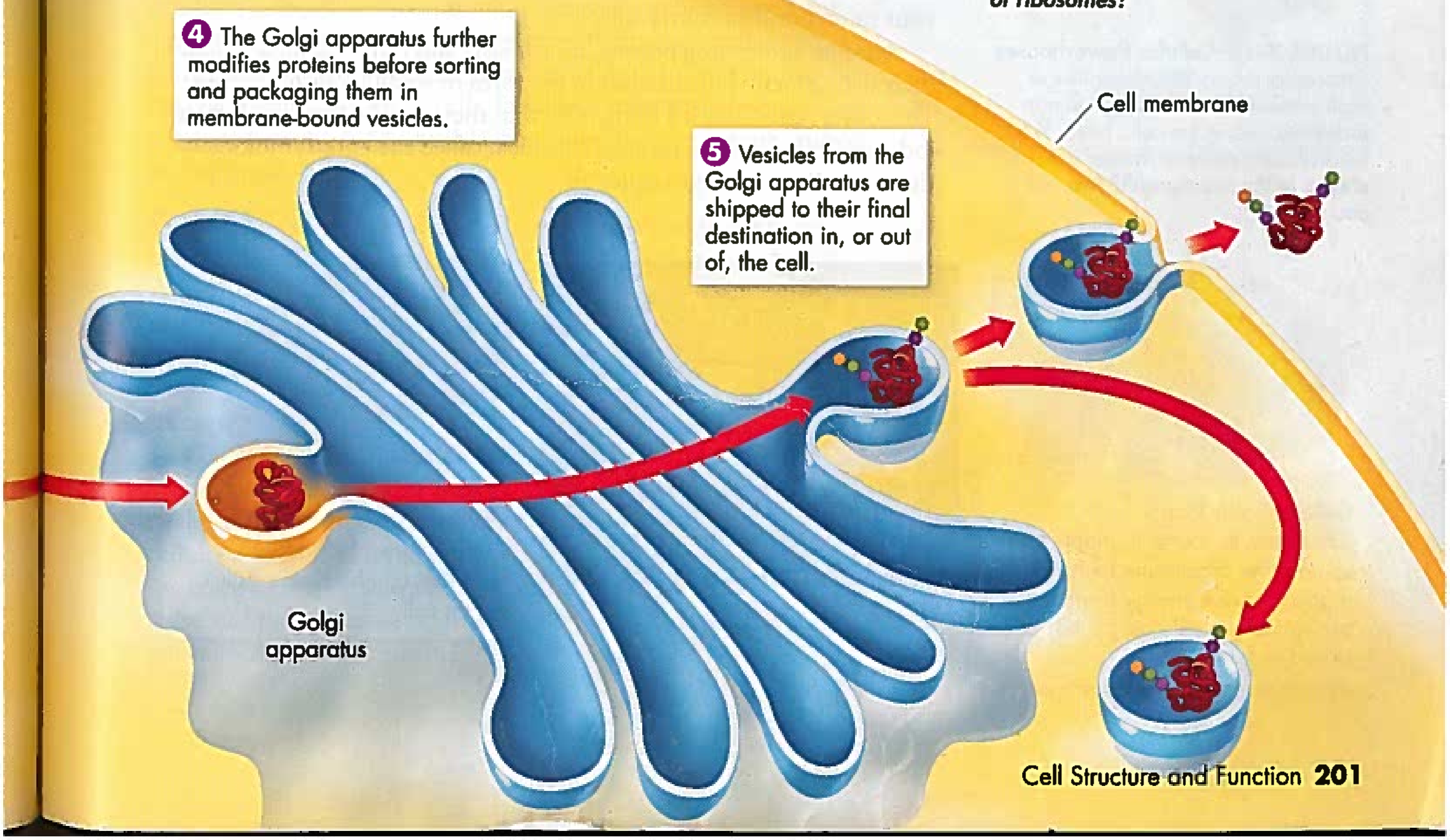
Golgi Apparatus In eukaryotic cells, proteins produced in the rough ER move next into an organelle called the **Golgi apparatus,** which appears as a stack of flattened membranes. As proteins leave the rough ER, molecular "address tags" get them to the right destinations. As these tags are "read" by the cell, the proteins are bundled into tiny vesicles that bud from the ER and carry them to the Golgi apparatus. **The Golgi apparatus modifies, sorts, and packages proteins and other materials from the endoplasmic reticulum for storage in the cell or release outside the cell.** The Golgi apparatus is somewhat like a customization shop, where the finishing touches are put on proteins before they are ready to leave the "factory." From the Golgi apparatus, proteins are "shipped" to their final destination inside or outside the cell.

In Your Notebook *Make a flowchart that shows how proteins are assembled in a cell.*

VISUAL SUMMARY

MAKING PROTEINS

FIGURE 7–11 Together, ribosomes, the endoplasmic reticulum, and the Golgi apparatus synthesize, modify, package, and ship proteins. **Infer** *What can you infer about a cell that is packed with more than the typical number of ribosomes?*



Organelles That Capture and Release Energy

What are the functions of chloroplasts and mitochondria?

All living things require a source of energy. Factories are hooked up to the local power company, but how do cells get energy? Most cells are powered by food molecules that are built using energy from the sun.

Chloroplasts Plants and some other organisms contain chloroplasts (KLAWR uh plasts). **Chloroplasts** are the biological equivalents of solar power plants. **Chloroplasts capture the energy from sunlight and convert it into food that contains chemical energy in a process called photosynthesis.** Two membranes surround chloroplasts. Inside the organelle are large stacks of other membranes, which contain the green pigment chlorophyll.

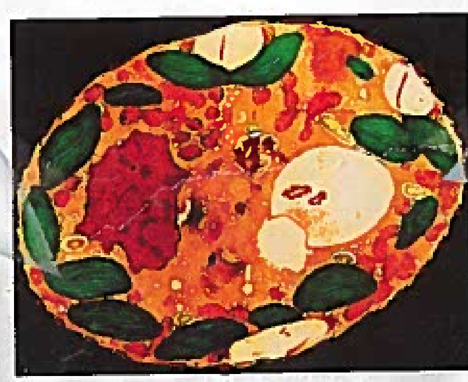
Mitochondria Nearly all eukaryotic cells, including plants, contain mitochondria (myt oh KAHN dree uh; singular: mitochondrion). **Mitochondria** are the power plants of the cell. **Mitochondria convert the chemical energy stored in food into compounds that are more convenient for the cell to use.** Like chloroplasts, two membranes—an outer membrane and an inner membrane—enclose mitochondria. The inner membrane is folded up inside the organelle, as shown in **Figure 7–12.**

One of the most interesting aspects of mitochondria is the way in which they are inherited. In humans, all or nearly all of our mitochondria come from the cytoplasm of the ovum, or egg cell. This means that when your relatives are discussing which side of the family should take credit for your best characteristics, you can tell them that you got your mitochondria from Mom!

Another interesting point: Chloroplasts and mitochondria contain their own genetic information in the form of small DNA molecules. This observation has led to the idea that they may be descended from independent microorganisms. This idea, called the endosymbiotic theory, is discussed in Chapter 19.

FIGURE 7–12 Cellular Powerhouses Chloroplasts and Mitochondia are both involved in energy conversion processes within the cell. **Infer** ***What kind of cell—plant or animal—is shown in the micrograph? How do you know?***

Cellular Solar Plants
Chloroplasts, found in plants and some other organisms such as algae, convert energy from the sun into chemical energy that is stored in food.



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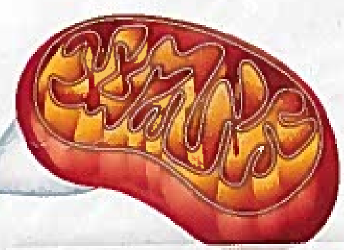


Cellular Power Plants
Mitochondria convert chemical energy stored in food into a form that can be used easily by the cell.

Quick Lab
OPEN-ENDED INQUIRY

Making a Model of a Cell

1. Your class is going to make a model of a plant cell using the whole classroom. Work with a partner or in a small group to decide what cell part or organelle you would like to model. (Use **Figure 7–14** on pages 206–207 as a starting point. It gives you an idea of the relative sizes of various cell parts and their possible positions.)

2. Using materials of your choice, make a three-dimensional model of the cell part or organelle you chose. Make the model as complete and as accurate as you can.

3. Label an index card with the name of your cell part or organelle, and list its main features and functions. Attach the card to your model.

4. Attach your model to an appropriate place in the room. If possible, attach your model to another related cell part or organelle.

Analyze and Conclude

1. Calculate Assume that a typical plant cell is 50 micrometers wide (50×10^{-6} m). Calculate the scale of your classroom cell model. (*Hint:* Divide the width of the classroom by the width of a cell, making sure to use the same units.) MATH

2. Compare and Contrast How is your model cell part or organelle similar to the real cell part or organelle? How is it different?

3. Evaluate Based on your work with this model, describe how you could make a better model. What new information would your improved model demonstrate?

Cellular Boundaries

What is the function of the cell membrane?

A working factory needs walls and a roof to protect it from the environment outside, and also to serve as a barrier that keeps its products safe and secure until they are ready to be shipped out. Cells have similar needs, and they meet them in a similar way. As you have learned, all cells are surrounded by a barrier known as the cell membrane. Many cells, including most prokaryotes, also produce a strong supporting layer around the membrane known as a **cell wall.**

Cell Walls Many organisms have cell walls in addition to cell membranes. The main function of the cell wall is to support, shape, and protect the cell. Most prokaryotes and many eukaryotes have cell walls. Animal cells do not have cell walls. Cell walls lie outside the cell membrane. Most cell walls are porous enough to allow water, oxygen, carbon dioxide, and certain other substances to pass through easily.

Cell walls provide much of the strength needed for plants to stand against the force of gravity. In trees and other large plants, nearly all of the tissue we call wood is made up of cell walls. The cellulose fiber used for paper as well as the lumber used for building comes from these walls. So if you are reading these words off a sheet of paper from a book resting on a wooden desk, you've got cell walls all around you.

BUILD Vocabulary

ACADEMIC WORDS The adjective **porous** means "allowing materials to pass through." A porous cell membrane allows substances like water and oxygen to pass through it.

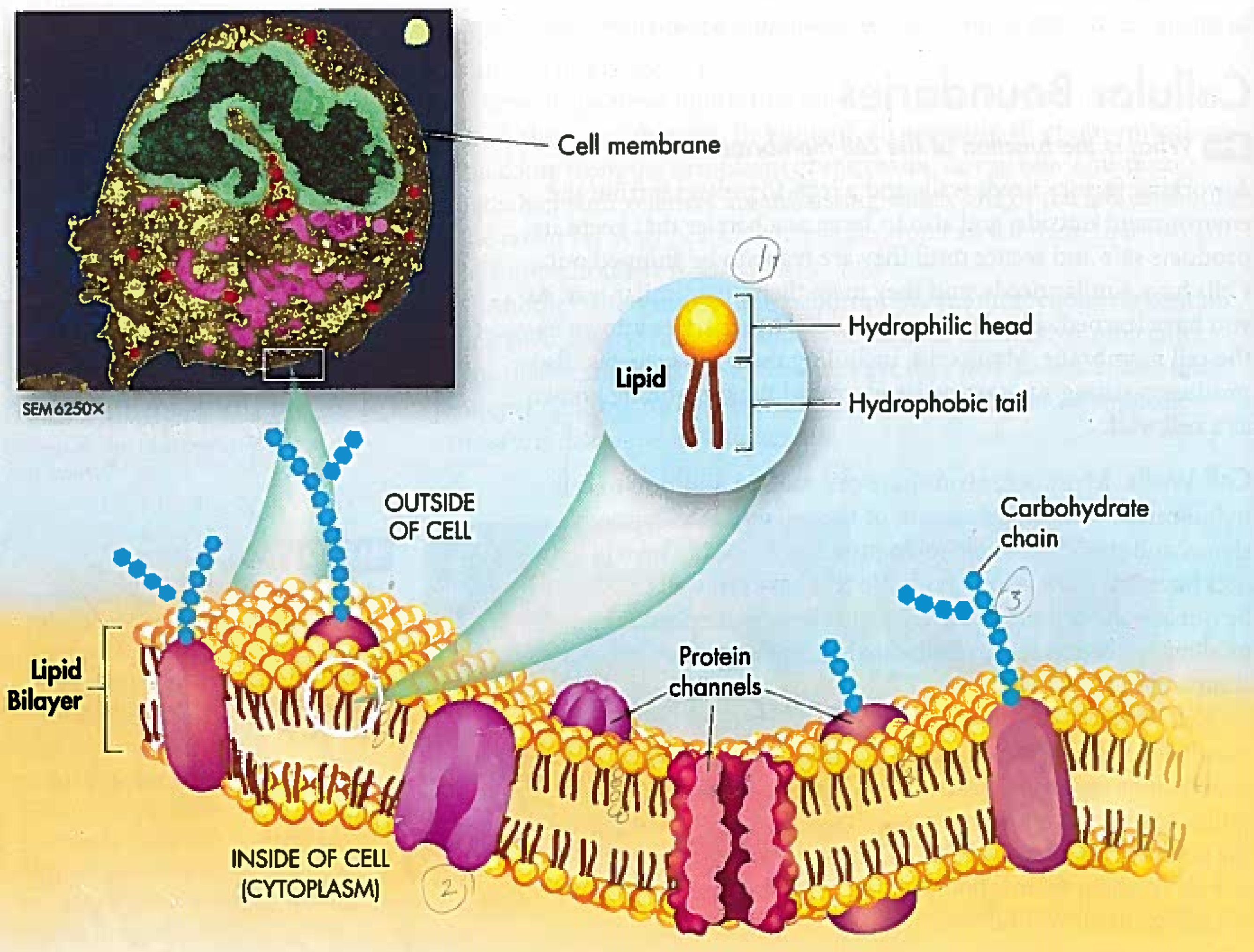
Cell Membranes All cells contain cell membranes, which almost always are made up of a double-layered sheet called a lipid bilayer, as shown in **Figure 7–13.** The **lipid bilayer** gives cell membranes a flexible structure that forms a strong barrier between the cell and its surroundings. **The cell membrane regulates what enters and leaves the cell and also protects and supports the cell.**

▶ ***The Properties of Lipids*** The layered structure of cell membranes reflects the chemical properties of the lipids that make them up. You may recall that many lipids have oily fatty acid chains attached to chemical groups that interact strongly with water. In the language of a chemist, the fatty acid portions of this kind of lipid are hydrophobic (hy druh FOH bik), or "water-hating," while the opposite end of the molecule is hydrophilic (hy druh FIL ik), or "water-loving." When these lipids, including the phospholipids that are common in animal cell membranes, are mixed with water, their hydrophobic fatty acid "tails" cluster together while their hydrophilic "heads" are attracted to water. A lipid bilayer is the result. As you can see in **Figure 7–13,** the head groups of lipids in a bilayer are exposed to the outside of the cell, while the fatty acid tails form an oily layer inside the membrane that keeps water out.

ZOOMING IN

THE CELL MEMBRANE

FIGURE 7–13 Every cell has a membrane that regulates the movement of materials. Nearly all cell membranes are made up of a lipid bilayer in which proteins and carbohydrates are embedded. **Apply Concepts** ***Explain why lipids "self-assemble" into a bilayer when exposed to water.***



▶ ***The Fluid Mosaic Model*** Embedded in the lipid bilayer of most cell membranes are protein molecules. Carbohydrate molecules are attached to many of these proteins. Because the proteins embedded in the lipid bilayer can move around and "float" among the lipids, and because so many different kinds of molecules make up the cell membrane, scientists describe the cell membrane as a "fluid mosaic." A mosaic is a kind of art that involves bits and pieces of different colors or materials. What are all these different molecules doing? As you will see, some of the proteins form channels and pumps that help to move material across the cell membrane. Many of the carbohydrate molecules act like chemical identification cards, allowing individual cells to identify one another. Some proteins attach directly to the cytoskeleton, enabling cells to respond to their environment by using their membranes to help move or change shape.

As you know, some things are allowed to enter and leave a factory, and some are not. The same is true for living cells. Although many substances can cross biological membranes, some are too large or too strongly charged to cross the lipid bilayer. If a substance is able to cross a membrane, the membrane is said to be permeable to it. A membrane is impermeable to substances that cannot pass across it. Most biological membranes are **selectively permeable,** meaning that some substances can pass across them and others cannot. Selectively permeable membranes are also called semipermeable membranes.

MYSTERY CLUE

The cell membrane regulates what enters and leaves the cell, including salts and water. What might have happened that caused the cell membrane to allow too much water into Michelle's cells?

7.2 Assessment

Review Key Concepts

1. a. **Review** What are the two major parts of the cell?
   b. **Use Analogies** How is the role of the nucleus in a cell similar to the role of the captain on a sports team?
2. a. **Review** What is the function of lysosomes?
   b. **Apply Concepts** How do contractile vacuoles help maintain water balance?
3. a. **Review** What is the difference between rough and smooth ER?
   b. **Sequence** Describe the steps involved in the synthesis, packaging, and export of a protein from a cell.
4. a. **Review** What is the function of mitochondria?
   b. **Infer** You examine an unknown cell under a microscope and discover that the cell contains chloroplasts. From what type of organism does the cell likely come?
5. a. **Review** Why is the cell membrane sometimes referred to as a fluid mosaic? What part of the cell membrane acts like a fluid? And what makes it like a mosaic?
   b. **Explain** How do the properties of lipids help explain the structure of a cell membrane?
   c. **Infer** Why do you think it's important that cell membranes are *selectively* permeable?

VISUAL THINKING

6. Using the cells on the next page as a guide, draw your own models of a prokaryotic cell, a plant cell, and an animal cell. Then use each of the vocabulary words from this lesson to label your cells.

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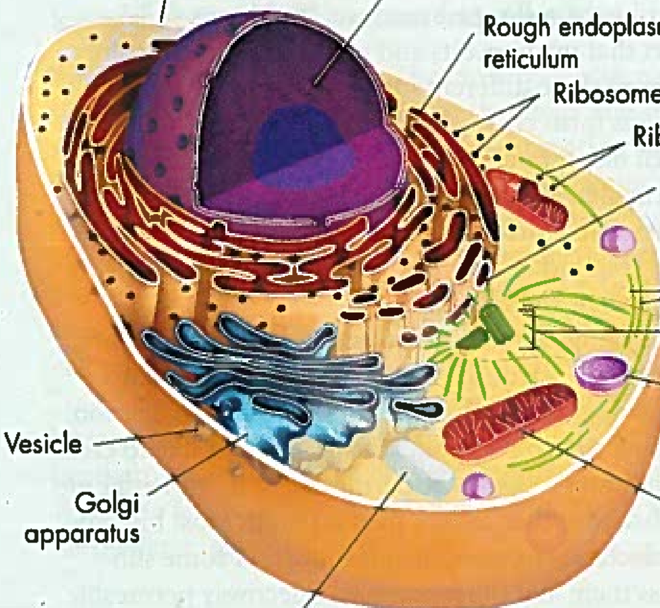
VISUAL SUMMARY

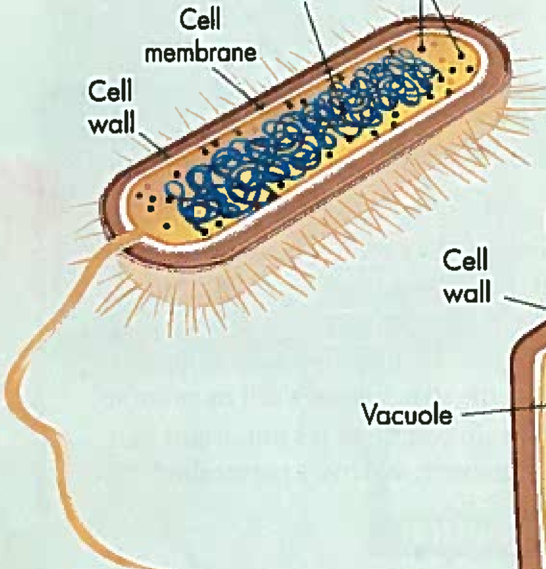
TYPICAL CELLS

FIGURE 7–14 Eukaryotic cells contain a variety of organelles, a few of which they have in common with prokaryotic cells. Note in the table on the facing page that while prokaryotic cells lack cytoskeleton and chloroplasts, they accomplish their functions in other ways as described. **Interpret Visuals** ***What structures do prokaryotic cells have in common with animal cells? With plant cells?***

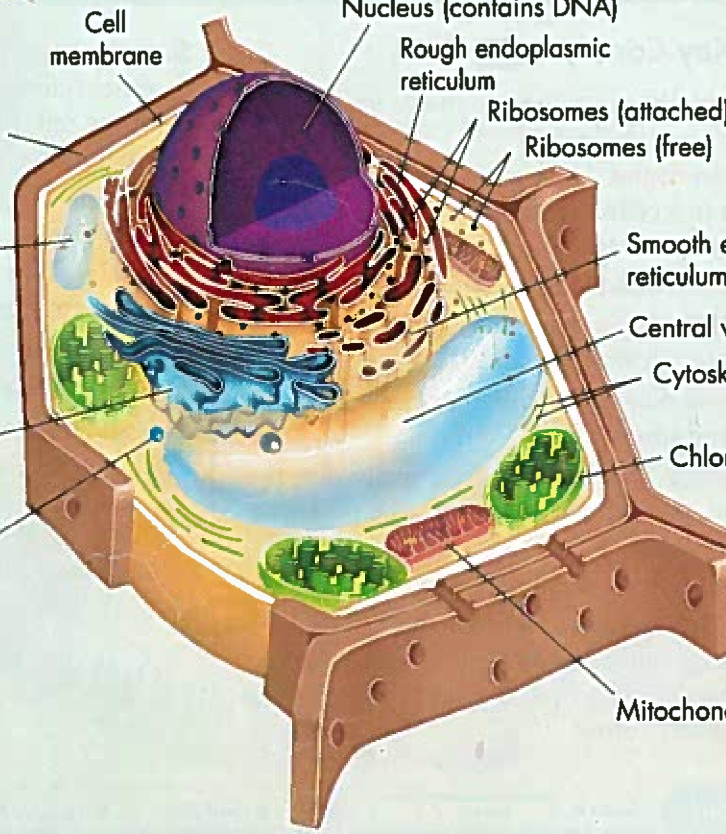
ANIMAL CELL



PROKARYOTIC CELL



PLANT CELL



	Structure	Function	Prokaryote	Eukaryote: Animal	Eukaryote: Plant
Cellular Control Center	Nucleus	Contains DNA	*Prokaryote DNA is found in cytoplasm.*	✓	✓
Organelles That Store, Clean-Up, and Support	Vacuoles and vesicles	Store materials		✓	✓
	Lysosomes	Break down and recycle macromolecules		✓	✓ (rare)
	Cytoskeleton	Maintains cell shape; moves cell parts; helps cells move	*Prokaryotic cells have protein filaments similar to actin and tubulin.*	✓	✓
	Centrioles	Organize cell division		✓	
Organelles That Build Proteins	Ribosomes	Synthesize proteins	✓	✓	✓
	Endoplasmic reticulum	Assembles proteins and lipids		✓	✓
	Golgi apparatus	Modifies, sorts, and packages proteins and lipids for storage or transport out of the cell		✓	✓
Organelles That Capture and Release Energy	Chloroplasts	Convert solar energy to chemical energy stored in food	*In some prokaryotic cells, photosynthesis occurs in association with internal photosynthetic membranes.*		✓
	Mitochondria	Convert chemical energy in food to usable compounds		✓	✓
Cellular Boundaries	Cell wall	Shapes, supports, and protects the cell	✓		✓
	Cell membrane	Regulates materials entering and leaving cell; protects and supports cell	✓	✓	✓

7.3 Cell Transport

Key Questions

What is passive transport?

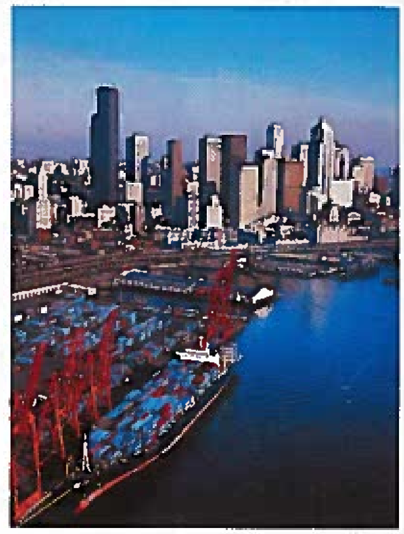
What is active transport?

Vocabulary

diffusion • facilitated diffusion • aquaporin • osmosis • isotonic • hypertonic • hypotonic • osmotic pressure

Taking Notes

Compare/Contrast Table As you read, create a compare/contrast table for passive and active transport.



THINK ABOUT IT In the previous lesson, cell walls and cell membranes were compared to the roof and walls of a factory. When you think about how cells move materials in and out, it can be helpful to think of a cell as a nation. Before you can learn anything about a nation, it's important to understand where it begins and where it ends. The boundaries of a nation are its borders, and nearly every country tries to regulate and control the goods that move across those borders, like the shipping containers seen here entering and leaving the port of Seattle. Each cell has its own border, which separates the cell from its surroundings and also determine what comes in and what goes out. How can a cell separate itself from its environment and still allow material to enter and leave? That's where transport across its border, the cell membrane, comes in.

MYSTERY CLUE

As Michelle ran, she perspired, losing salts from her bloodstream. And as she drank more and more water during the race, the concentration of dissolved salts and minerals in her bloodstream decreased. How do you think these phenomena contributed to Michelle's condition?

Passive Transport

What is passive transport?

Every living cell exists in a liquid environment. One of the most important functions of the cell membrane is to keep the cell's internal conditions relatively constant. It does this by regulating the movement of molecules from one side of the membrane to the other.

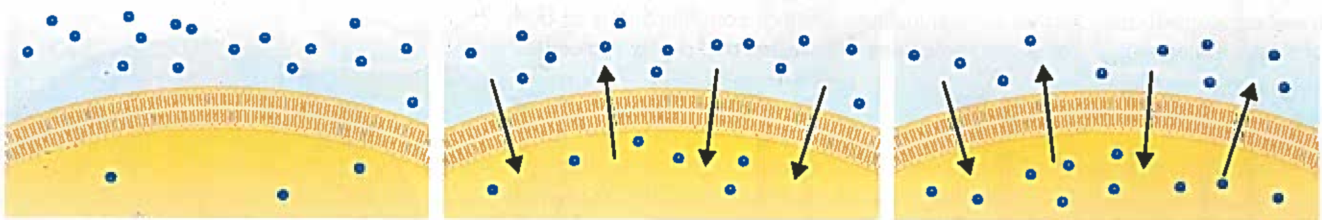
Diffusion Cellular cytoplasm consists of many different substances dissolved in water. In any solution, solute particles move constantly. They collide with one another and tend to spread out randomly. As a result, the particles tend to move from an area where they are more concentrated to an area where they are less concentrated. When you add sugar to coffee or tea, for example, the sugar molecules move away from their original positions in the sugar crystals and disperse throughout the hot liquid. The process by which particles move from an area of high concentration to an area of lower concentration is known as **diffusion** (dih FYOO zhun). Diffusion is the driving force behind the movement of many substances across the cell membrane.

What does diffusion have to do with the cell membrane? Suppose a substance is present in unequal concentrations on either side of a cell membrane, as shown in **Figure 7–15.** If the substance can cross the cell membrane, its particles will tend to move toward the area where it is less concentrated until it is evenly distributed. Once the concentration of the substance on both sides of the cell membrane is the same, equilibrium is reached.

Even when equilibrium is reached, particles of a solution continue to move across the membrane in both directions. However, because almost equal numbers of particles move in each direction, there is no further net change in the concentration on either side.

Diffusion depends on random particle movements. Therefore, substances diffuse across membranes without requiring the cell to use additional energy. **The movement of materials across the cell membrane without using cellular energy is called passive transport.**

FIGURE 7–15 Diffusion Diffusion is the process by which molecules of a substance move from an area of higher concentration to an area of lower concentration. It does not require the cell to use energy. **Predict** ***How would the movement of solute particles seen here be different if the initial area of high concentration had been on the inside of the cell instead of the outside?***



There is a higher concentration of solute on one side of the membrane than on the other.

Diffusion causes a net movement of solute particles from the side of the membrane with the higher solute concentration to the side with the lower solute concentration.

Once equilibrium is reached, solute particles continue to diffuse across the membrane in both directions but at approximately equal rates, so there is no net change in solute concentration.

Facilitated Diffusion Since cell membranes are built around lipid bilayers, the molecules that pass through them most easily are small and uncharged. These properties allow them to dissolve in the membrane's lipid environment. But many ions, like Cl^-, and large molecules, like the sugar glucose, seem to pass through cell membranes much more quickly than they should. It's almost as if they have a shortcut across the membrane.

How does this happen? Proteins in the cell membrane act as carriers, or channels, making it easy for certain molecules to cross. Red blood cells, for example, have protein carriers that allow glucose to pass through them in either direction. Only glucose can pass through these protein carriers. These cell membrane channels facilitate, or help, the diffusion of glucose across the membrane. This process, in which molecules that cannot directly diffuse across the membrane pass through special protein channels, is known as **facilitated diffusion.** Hundreds of different proteins have been found that allow particular substances to cross cell membranes. Although facilitated diffusion is fast and specific, it is still diffusion, so it does not require any additional use of the cell's energy.

In Your Notebook *Explain how you can demonstrate diffusion by spraying air freshener in a large room.*

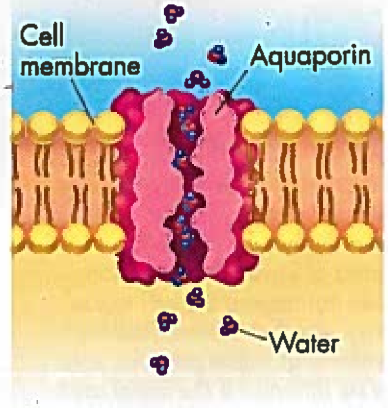


FIGURE 7–16 An Aquaporin

Osmosis: An Example of Facilitated Diffusion Surprising new research has added water to the list of molecules that enter cells by facilitated diffusion. Recall that the inside of a cell's lipid bilayer is hydrophobic, or "water-hating." Because of this, water molecules have a tough time passing through the cell membrane. However, many cells contain water channel proteins, known as **aquaporins** (ak wuh PAWR inz), that allow water to pass right through them, as shown in **Figure 7–16.** The movement of water through cell membranes by facilitated diffusion is an extremely important biological process—the process of osmosis.

Osmosis is the diffusion of water through a selectively permeable membrane. In osmosis, as in other forms of diffusion, molecules move from an area of higher concentration to an area of lower concentration. The only difference is that the molecules that move in the case of osmosis are water molecules, not solute molecules. The process of osmosis is shown in **Figure 7–17.**

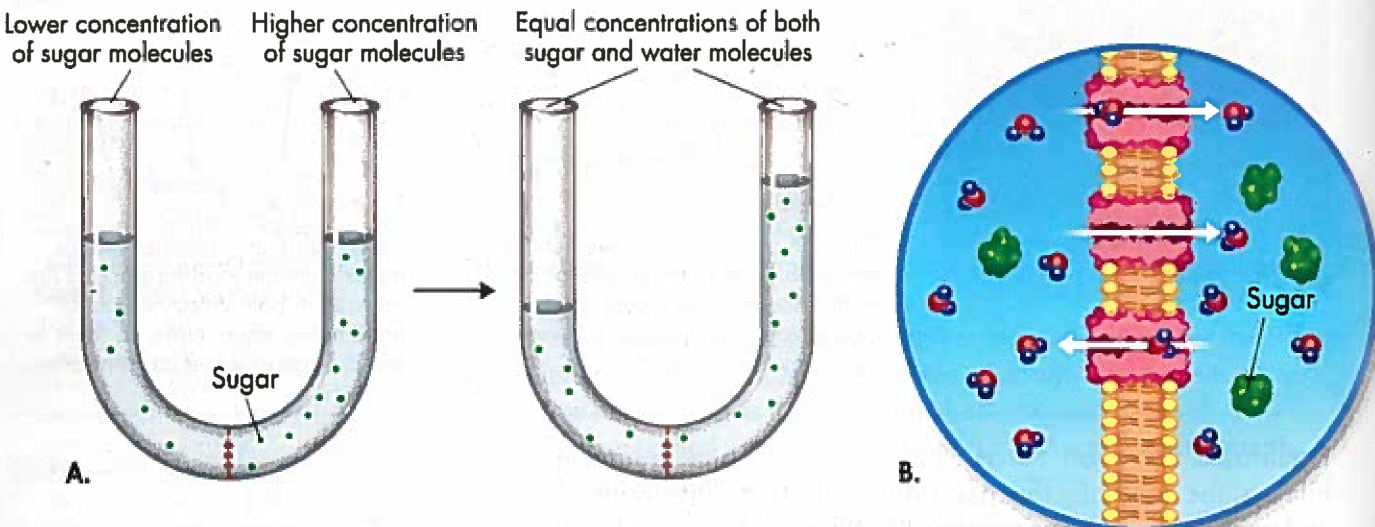


FIGURE 7–17 Osmosis Osmosis is a form of facilitated diffusion. **A.** In a laboratory experiment, water moves through a selectively permeable barrier from an area of lower to higher solute concentration until equilibrium is reached. **B.** In the cell, water passes in through aquaporins embedded in the cell membrane. Although water moves in both directions through aquaporins, there is a net movement of water from an area of lower to higher sugar concentration. **Apply Concepts** ***Does osmosis require the cell to use energy?***

▶ ***How Osmosis Works*** Look at the experimental setup in **Figure 7–17A.** The barrier is permeable to water but not to sugar. This means that water can cross the barrier in both directions, but sugar cannot. To start, there are more sugar molecules on the right side of the barrier than on the left side. Therefore, the concentration of water is lower on the right, where more of the solution is made of sugar. Although water molecules move in both directions across the membrane, there is a net movement of water toward the concentrated sugar solution.

Water will tend to move across the membrane until equilibrium is reached. At that point, the concentrations of water and sugar will be the same on both sides of the membrane. When this happens, the two solutions will be **isotonic,** which means "same strength." Note that "strength" refers to the amount of solute, not water. When the experiment began, the more concentrated sugar solution (right side of the tube) was **hypertonic,** or "above strength," compared to the left side. So the dilute sugar solution (left side of the tube) was **hypotonic,** or "below strength," compared to the right side. **Figure 7–17B** shows how osmosis works across a cell membrane.

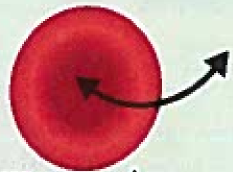
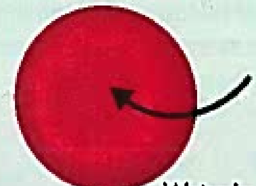
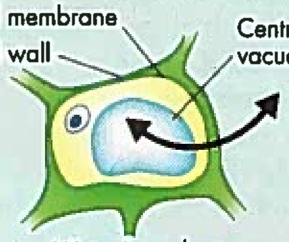
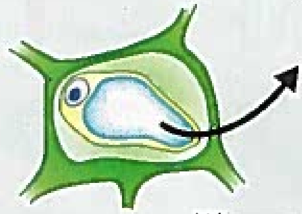
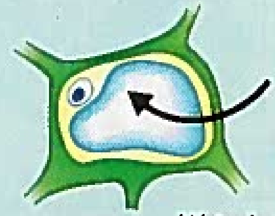
The Effects of Osmosis on Cells			
Solution	**Isotonic:** The concentration of solutes is the same inside and outside the cell. Water molecules move equally in both directions.	**Hypertonic:** The solution has a higher solute concentration than the cell. A net movement of water molecules out of the cell causes it to shrink.	**Hypotonic:** The solution has a lower solute concentration than the cell. A net movement of water molecules into the cell causes it to swell.
Animal Cell	 Water in and out	 Water out	 Water in
Plant Cell	 Water in and out	 Water out	 Water in

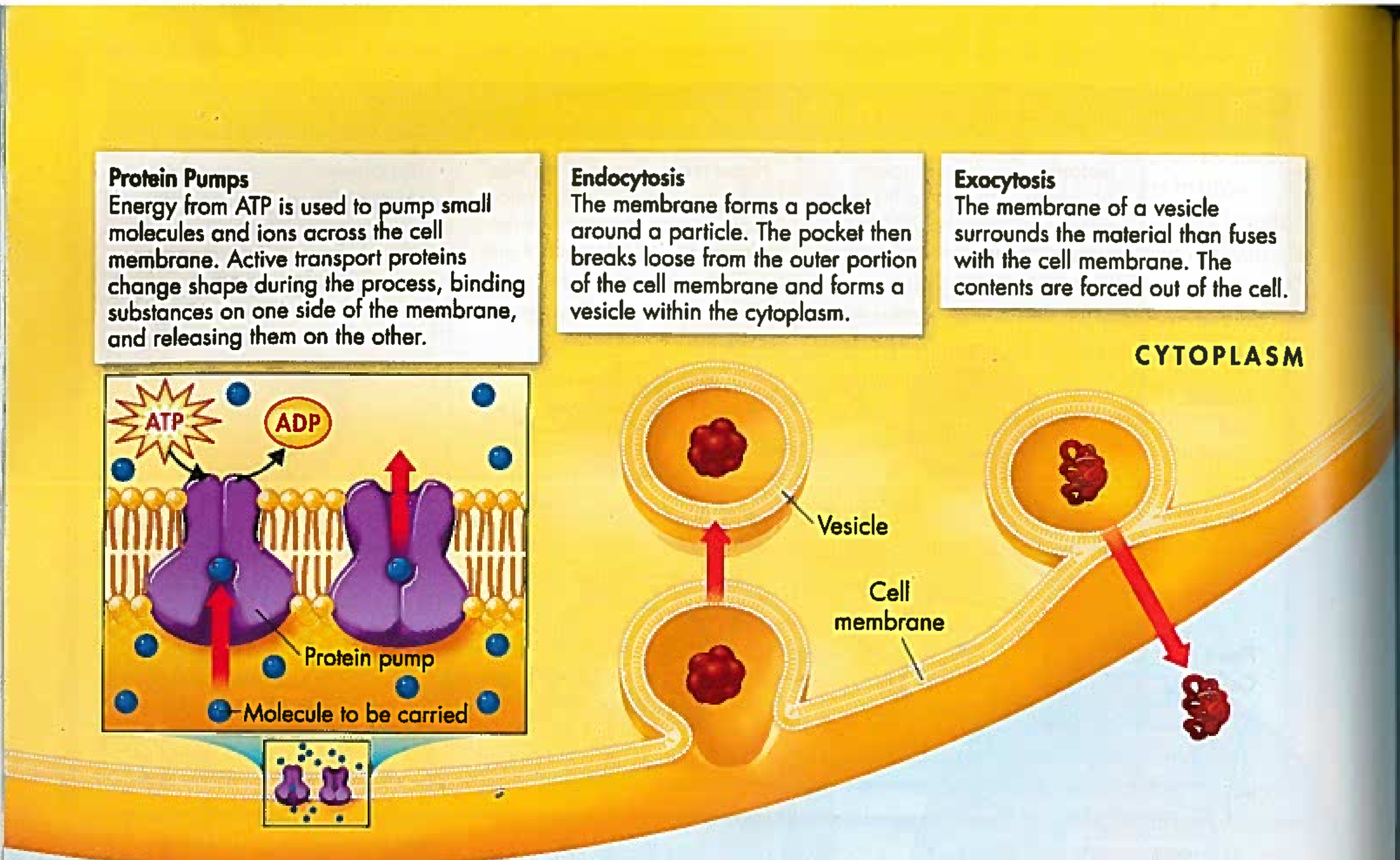
FIGURE 7–18 Osmotic Pressure Water molecules move equally into and out of cells placed in an isotonic solution. In a hypertonic solution, animal cells, like the red blood cell shown, shrink, and plant cell central vacuoles collapse. In a hypotonic solution, animal cells swell and burst. The central vacuoles of plant cells also swell, pushing the cell contents out against the cell wall. **Predict** ***What would happen to the cells of a saltwater plant if the plant were placed in fresh water?***

▶ ***Osmotic Pressure*** Driven by differences in solute concentration, the net movement of water out of or into a cell produces a force known as **osmotic pressure.** As shown in **Figure 7–18,** osmotic pressure can cause an animal cell in a hypertonic solution to shrink, and one in a hypotonic solution to swell. Because cells contain salts, sugars, proteins, and other dissolved molecules, they are almost always hypertonic to fresh water. As a result, water tends to move quickly into a cell surrounded by fresh water, causing it to swell. Eventually, the cell may burst like an overinflated balloon. In plant cells, osmotic pressure can cause changes in the size of the central vacuole, which shrinks or swells as water moves into or out of the cell.

Fortunately cells in large organisms are not in danger of bursting because most of them do not come in contact with fresh water. Instead, the cells are bathed in blood or other isotonic fluids. The concentrations of dissolved materials in these isotonic fluids are roughly equal to those in the cells themselves.

What happens when cells do come in contact with fresh water? Some, like the eggs laid in fresh water by fish and frogs, lack water channels. As a result, water moves into them so slowly that osmotic pressure is not a problem. Others, including bacteria and plants cells, are surrounded by tough walls. The cell walls prevent the cells from expanding, even under tremendous osmotic pressure. Notice how the plant cell in **Figure 7–18** holds its shape in both hypertonic and hypotonic solutions while the animal red blood cell does not. However, increased osmotic pressure makes plant cells extremely vulnerable to cell wall injuries.

In Your Notebook *In your own words, explain why osmosis is really just a special case of facilitated diffusion.*



VISUAL SUMMARY

ACTIVE TRANSPORT

FIGURE 7–19 Energy from the cell is required to move particles against a concentration gradient. **Compare and Contrast** ***What are the similarities and differences between facilitated diffusion and active transport by protein pump?***

Active Transport

What is active transport?

As powerful as diffusion is, cells sometimes must move materials against a concentration difference. **The movement of materials against a concentration difference is known as active transport. Active transport requires energy.** The active transport of small molecules or ions across a cell membrane is generally carried out by transport proteins—protein pumps—that are found in the membrane itself. Larger molecules and clumps of material can also be actively transported across the cell membrane by processes known as endocytosis and exocytosis. The transport of these larger materials sometimes involves changes in the shape of the cell membrane. The major types of active transport are shown in **Figure 7–19.**

Molecular Transport Small molecules and ions are carried across membranes by proteins in the membrane that act like pumps. Many cells use protein pumps to move calcium, potassium, and sodium ions across cell membranes. Changes in protein shape seem to play an important role in the pumping process. A considerable portion of the energy used by cells in their daily activities is spent providing the energy to keep this form of active transport working. The use of energy in these systems enables cells to concentrate substances in a particular location, even when the forces of diffusion might tend to move these substances in the opposite direction.

Bulk Transport Larger molecules and even solid clumps of material can be transported by movements of the cell membrane known as bulk transport. Bulk transport can take several forms, depending on the size and shape of the material moved into or out of the cell.

▶ ***Endocytosis*** Endocytosis (en doh sy TOH sis) is the process of taking material into the cell by means of infoldings, or pockets, of the cell membrane. The pocket that results breaks loose from the outer portion of the cell membrane and forms a vesicle or vacuole within the cytoplasm. Large molecules, clumps of food, even whole cells can be taken up in this way.

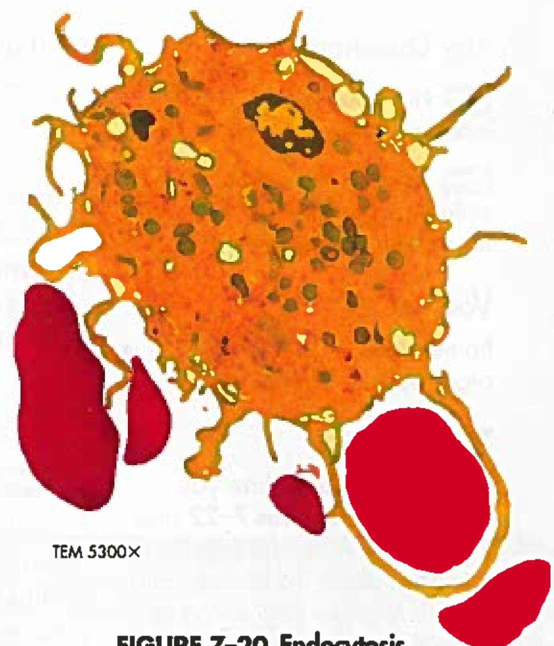
Phagocytosis (fag oh sy TOH sis) is a type of endocytosis, in which extensions of cytoplasm surround a particle and package it within a food vacuole. The cell then engulfs it. Amoebas use this method for taking in food, and white blood cells use phagocytosis to "eat" damaged cells, as shown in **Figure 7–20.** Engulfing material in this way requires a considerable amount of energy and is considered a form of active transport.

In a process similar to phagocytosis, many cells take up liquid from the surrounding environment. Tiny pockets form along the cell membrane, fill with liquid, and pinch off to form vacuoles within the cell. This type of endocytosis is known as pinocytosis (py nuh sy TOH sis).

▶ ***Exocytosis*** Many cells also release large amounts of material, a process known as exocytosis (ek soh sy TOH sis). During exocytosis, the membrane of the vacuole surrounding the material fuses with the cell membrane, forcing the contents out of the cell. The removal of water by means of a contractile vacuole is one example of this kind of active transport.

BUILD Vocabulary

PREFIXES The prefix *endo-* in *endocytosis* comes from a Greek word meaning "inside" or "within." The prefix *exo-* in *exocytosis* means "outside."



TEM 5300×

FIGURE 7–20 Endocytosis The white blood cell seen here is engulfing a damaged red blood cell by phagocytosis—a form of endocytosis. Extensions, or "arms," of the white blood cell's cell membrane have completely surrounded the red blood cell.

7.3 Assessment

Review Key Concepts

1. a. **Review** What happens during diffusion?
   b. **Explain** Describe the process of osmosis.
   c. **Compare and Contrast** What is the difference between diffusion and facilitated diffusion?
2. a. **Review** How is active transport different from passive transport?
   b. **Explain** Describe the two major types of active transport.
   c. **Compare and Contrast** How is endocytosis different from exocytosis?

BUILD VOCABULARY

3. Based on the meanings of *isotonic, hypertonic,* and *hypotonic,* write definitions for the prefixes *iso-*, *hyper-*, and *hypo-*. Then come up with another set of words that uses these prefixes (the words do not need to have the same suffixes).
4. The prefix *phago-* means "to eat." The prefix *pino-* means "to drink." Look up the definition of *-cytosis,* and write definitions for *phagocytosis* and *pinocytosis.*

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7.4 Homeostasis and Cells

Key Questions

How do individual cells maintain homeostasis?

How do the cells of multicellular organisms work together to maintain homeostasis?

Vocabulary

homeostasis • tissue • organ • organ system • receptor

Taking Notes

Preview Visuals Before you read, look at **Figures 7–22** and **7–23.** Then write two questions you have about the micrographs. As you read, write answers to your questions.

THINK ABOUT IT From its simple beginnings, life has spread to every corner of our planet, penetrating deep into the earth and far beneath the surface of the seas. The diversity of life is so great that you might have to remind yourself that all living things are composed of cells, have the same basic chemical makeup, and even contain the same kinds of organelles. This does not mean that all living things are the same: Differences arise from the ways in which cells are specialized and the ways in which cells associate with one another to form multicellular organisms.

The Cell as an Organism

How do individual cells maintain homeostasis?

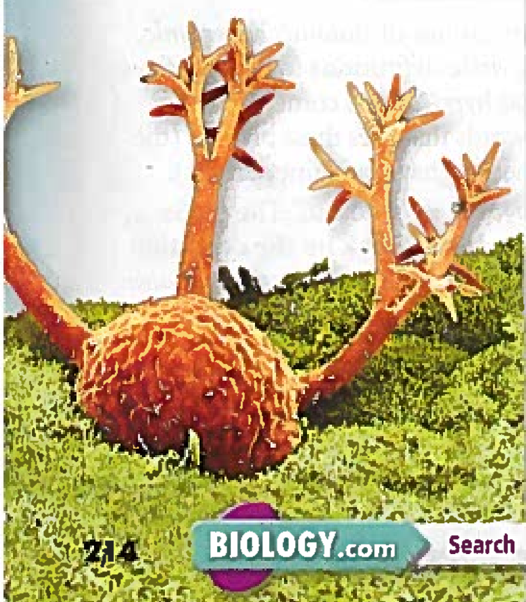
Cells are the basic living units of all organisms, but sometimes a single cell is the organism. In fact, in terms of their numbers, unicellular organisms dominate life on Earth. A single-celled organism does everything you would expect a living thing to do. Just like other living things, unicellular organisms must maintain **homeostasis,** relatively constant internal physical and chemical conditions. **To maintain homeostasis, unicellular organisms grow, respond to the environment, transform energy, and reproduce.**

Unicellular organisms include both prokaryotes and eukaryotes. Prokaryotes, especially bacteria, are remarkably adaptable. Bacteria live almost everywhere—in the soil, on leaves, in the ocean, in the air, even within the human body.

Many eukaryotes, like the protozoan in **Figure 7–21,** also spend their lives as single cells. Some types of algae, which contain chloroplasts and are found in oceans, lakes, and streams around the world, are single celled. Yeasts, or unicellular fungi, are also widespread. Yeasts play an important role in breaking down complex nutrients, making them available for other organisms. People use yeasts to make bread and other foods.

Don't make the mistake of thinking that single-celled organisms are always simple. Prokaryote or eukaryote, homeostasis is still an issue for each unicellular organism. That tiny cell in a pond or on the surface of your pencil still needs to find sources of energy or food, to keep concentrations of water and minerals within certain levels, and to respond quickly to changes in its environment. The microscopic world around us is filled with unicellular organisms that are successfully maintaining that homeostatic balance.

FIGURE 7–21 Unicellular Life Single-celled organisms, like this freshwater protozoan, must be able to carry out all of the functions necessary for life (SEM 600×).



Multicellular Life

How do the cells of multicellular organisms work together to maintain homeostasis?

Unlike most unicellular organisms, the cells of human beings and other multicellular organisms do not live on their own. They are interdependent; and like the members of a winning baseball team, they work together. In baseball, each player plays a particular position: pitcher, catcher, infielder, outfielder. And to play the game effectively, players and coaches communicate with one another, sending and receiving signals. Cells in a multicellular organism work the same way. **The cells of multicellular organisms become specialized for particular tasks and communicate with one another to maintain homeostasis.**

BUILD Vocabulary

PREFIXES The prefix *homeo-* in **homeostasis** means "the same." Organisms are constantly trying to maintain homeostasis, to keep their internal physical and chemical conditions relatively constant despite changes in their internal and external environments.

Cell Specialization The cells of a multicellular organism are specialized, with different cell types playing different roles. Some cells are specialized to move; others, to react to the environment; still others, to produce substances that the organism needs. No matter what its role, each specialized cell, like the ones in **Figures 7–22** and **7–23**, contributes to homeostasis in the organism.

In Your Notebook *Where in the human body do you think you would find cells that are specialized to produce enzymes? Why?*

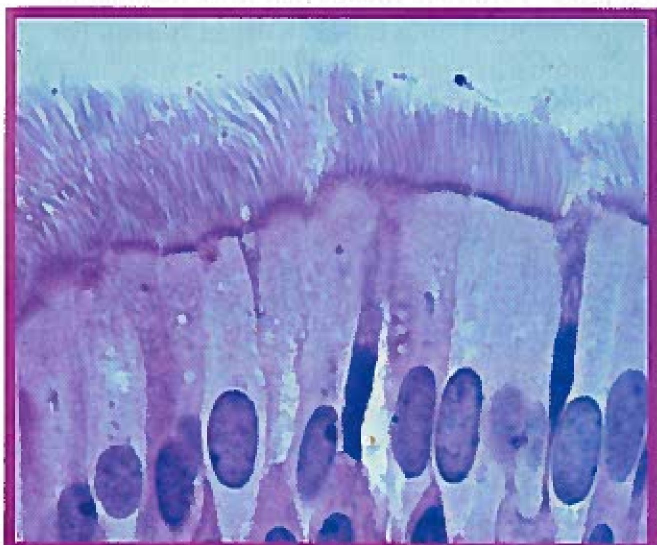


FIGURE 7–22 Specialized Animal Cells: Human Trachea Epithelium (LM 1000×)

FIGURE 7–23 Specialized Plant Cells: Pine Pollen (LM 430×)

▶ ***Specialized Animal Cells*** Even the cleanest, freshest air is dirty, containing particles of dust, smoke, and bacteria. What keeps this bad stuff from getting into your lungs? That's the job of millions of cells that work like street sweepers. These cells line the upper air passages. As you breathe, they work night and day sweeping mucus, debris, and bacteria out of your lungs. These cells are filled with mitochondria, which produce a steady supply of the ATP that powers the cilia on their upper surfaces to keep your lungs clean.

▶ ***Specialized Plant Cells*** How can a pine tree, literally rooted in place, produce offspring with another tree hundreds of meters away? It releases pollen grains, some of the world's most specialized cells. Pollen grains are tiny and light, despite tough walls to protect the cells inside. In addition, pine pollen grains have two tiny wings that enable them to float in the slightest breeze. Pine trees release millions of pollen grains like these to scatter in the wind, land on seed cones, and begin the essential work of starting a new generation.

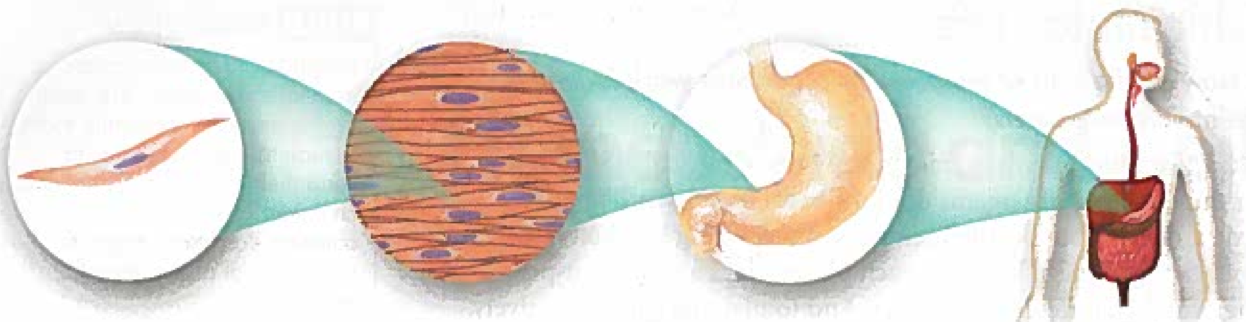


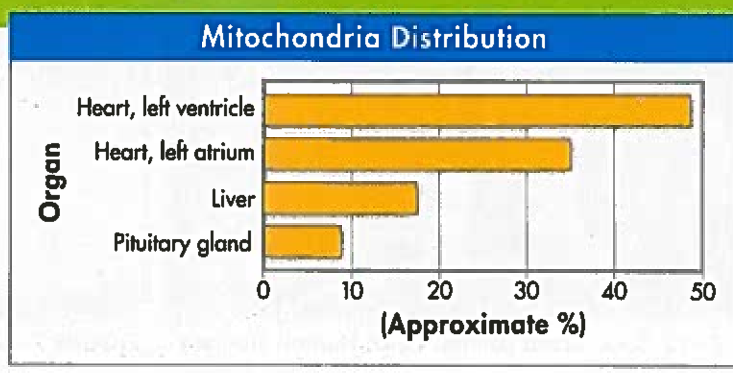
FIGURE 7–24 Levels of Organization From least complex to most complex, the levels of organization in a multicellular organism include cells, tissues, organs, and organ systems.

Levels of Organization The specialized cells of multicellular organisms are organized into tissues, then into organs, and finally into organ systems, as shown in **Figure 7–24.** A **tissue** is a group of similar cells that performs a particular function. Many tasks in the body are too complicated to be carried out by just one type of tissue. In these cases, many groups of tissues work together as an **organ.** For example, each muscle in your body is an individual organ. Within a muscle, however, there is much more than muscle tissue. There are nervous tissues and connective tissues too. Each type of tissue performs an essential task to help the organ function. In most cases, an organ completes a series of specialized tasks. A group of organs that work together to perform a specific function is called an **organ system.** For example, the stomach, pancreas, and intestines work together as the digestive system.

Analyzing Data

Mitochondria Distribution in the Mouse

Scientists studied the composition of several organs in the mouse. They found that some organs and tissues contain more mitochondria than others. They described the amount of mitochondria present as a percentage of total cell volume. The higher the percentage volume made up of mitochondria, the more mitochondria present in the cells of the organ. The data are shown in the graph.



1. **Interpret Graphs** What approximate percentage of cell volume in the mouse liver is composed of mitochondria?

2. **Calculate** Approximately how much more cellular volume is composed of mitochondria in the left ventricle than in the pituitary gland? MATH

3. **Infer** There are four chambers in the mouse heart, the right and left ventricles, and the right and left atria. Based on the data given, which chamber, the left ventricle or left atrium, do you think pumps blood from the heart to the rest of the body? Explain your answer.

The organization of the body's cells into tissues, organs, and organ systems creates a division of labor among those cells that allows the organism to maintain homeostasis. Specialization and interdependence are two of the remarkable attributes of living things. Appreciating these characteristics is an important step in understanding the nature of living things.

Cellular Communication Cells in a large organism communicate by means of chemical signals that are passed from one cell to another. These cellular signals can speed up or slow down the activities of the cells that receive them and can even cause a cell to change what it is doing in a most dramatic way.

Certain cells, including those in the heart and liver, form connections, or cellular junctions, to neighboring cells. Some of these junctions, like those in **Figure 7–25,** hold cells together firmly. Others allow small molecules carrying chemical messages or signals to pass directly from one cell to the next. To respond to one of these chemical signals, a cell must have a **receptor** to which the signaling molecule can bind. Some receptors are on the cell membrane; receptors for other types of signals are inside the cytoplasm. The chemical signals sent by various types of cells can cause important changes in cellular activity. For example, the electrical signal that causes heart muscle cells to contract begins in a region of the muscle known as the pacemaker. Ions carry that electrical signal from cell to cell through a special connection known as a gap junction, enabling millions of heart muscle cells to contract as one in a single heartbeat. Other junctions hold the cells together, so the force of contraction does not tear the muscle tissue. Both types of junctions are essential for the heart to pump blood effectively.

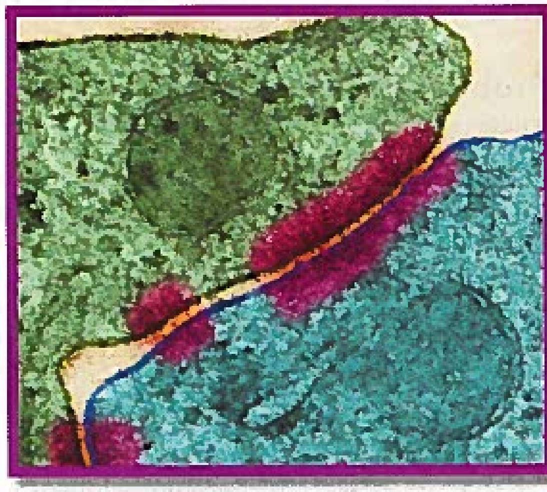


FIGURE 7–25 Cellular Junctions Some junctions, like those seen in dark pink in this micrograph of epithelial cells in the central nervous system (blue and green), hold cells together in tight formations (TEM 21,600×).

7.4 Assessment

Review Key Concepts

1. a. **Review** What is homeostasis?

   b. **Explain** What do unicellular organisms do to maintain homeostasis?

   c. **Apply Concepts** The contractile vacuole is an organelle found in paramecia, a group of unicellular organisms. Contractile vacuoles pump out fresh water that accumulates in the organisms by osmosis. Explain how this is an example of the way paramecia maintain homeostasis.

2. a. **Review** What is cellular specialization?

   b. **Explain** How do cellular junctions and receptors help an organism maintain homeostasis?

   c. **Predict** Using what you know about the ways muscles move, predict which organelles would be most common in muscle cells.

WRITE ABOUT SCIENCE

Description

3. Use an area in your life—such as school, sports, or extracurricular activities—to construct an analogy that explains why specialization and communication are necessary for you to function well.

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