Guide for Reading

Focus on this question as you read.

- *What is the cell theory?*

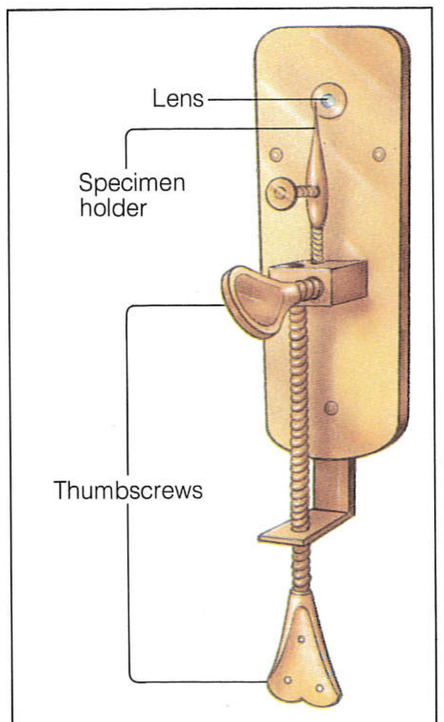
2–1 The Cell Theory

The basic units of structure and function of living things are **cells.** Most cells are too small to be seen with the unaided eye. As a result, many of the even smaller structures that make up a cell remained a mystery to scientists for hundreds of years. The structures that make up a cell are called **organelles,** which means tiny organs. The organelles were not revealed until the seventeenth century, when the first microscopes were invented.

In 1665, while looking at a thin slice of cork through a compound microscope, the English scientist Robert Hooke observed tiny roomlike structures. He called these structures cells. But the cells that Hooke saw in the slice of cork were not alive. What Hooke saw were actually the outer walls of dead plant cells.

At about the same time, Anton van Leeuwenhoek (LAY-vuhn-hook), a Dutch fabric merchant and amateur scientist, used a simple microscope to examine materials such as blood, rainwater, and scrapings from his teeth. In each material, van Leeuwenhoek observed living cells. He even found tiny living things in a drop of rainwater. Van Leeuwenhoek called these living things "animalcules." The smallest of the animalcules observed by van Leeuwenhoek are today known as bacteria. Bacteria are single-celled organisms. These discoveries made van Leeuwenhoek famous all over the world.

During the next two hundred years, new and better microscopes were developed. Such microscopes made it possible for the German botanist Matthias Schleiden to view different types of plant parts. Schleiden discovered that all the plant parts he examined were made of cells. One year later, the German zoologist Theodor Schwann made similar observations using animal parts. About twenty years later, a German physician named Rudolph Virchow discovered that all living cells come only from other living cells.



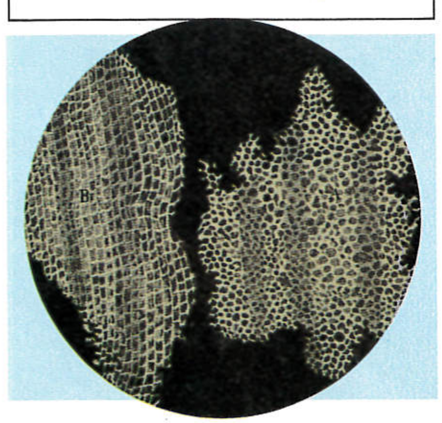


Figure 2–1 *Van Leeuwenhoek's simple microscope (top) could magnify objects a few hundred times. Robert Hooke made this drawing of cork cells (bottom) using a microscope he built. Hooke was not looking at living cells, but rather at the cell walls that surround living cork cells.*

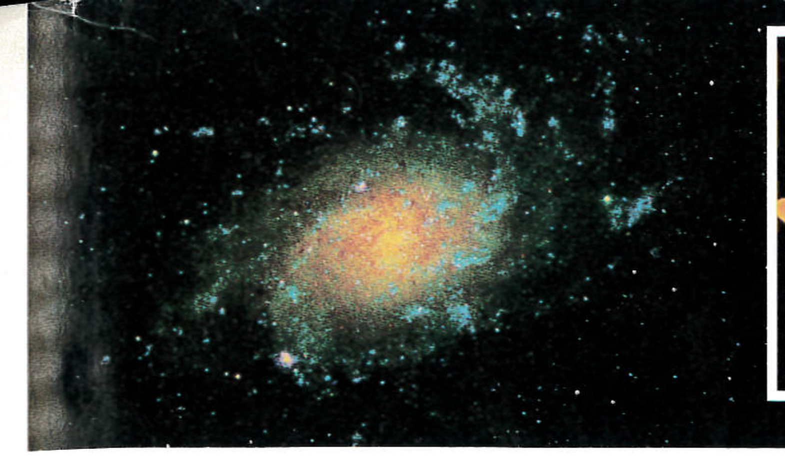


Figure 2–2 *The invention of the telescope enabled astronomers to study distant objects such as this spiral galaxy. The microscope opened up the world of the very small to biologists. Before the invention of the microscope, microscopic organisms such as these yeast cells could not have been observed.*

The work of Schleiden, Schwann, Virchow, and other biologists led to the development of the **cell theory,** which is one of the cornerstones of modern biology. **The cell theory states that**

- **All living things are made of cells.**
- **Cells are the basic units of structure and function in living things.**
- **Living cells come only from other living cells.**

2–1 Section Review

1. What is the cell theory?
2. What term is used for the structures that make up a cell?

Connection—*Science and Technology*

3. Discuss the relationship between technology and the development of the cell theory.

Guide for Reading

Focus on these questions as you read.

- *What structures are found within a typical cell and what function do they serve?*
- *What are the five levels of organization in multicellular organisms?*

2–2 Structure and Function of Cells

You are about to take an imaginary journey. It will be quite an unusual trip because you will be traveling inside a living organism, visiting its tiny cells. On your trip you will be observing some of the typical structures found in plant and animal cells.

All living things are made of one or more cells. As you have just learned, cells are the basic units of structure and function in living things. Most cells are much too small to be seen without the aid of a

ACTIVITY DOING

Plant Cells

1. To view a plant cell, remove a very thin transparent piece of tissue from an onion.

2. Place the onion tissue on a glass slide.

3. Add a drop of iodine stain to the tissue and cover with a coverslip.

4. Observe the onion tissue under low power and under high power of your microscope.

Draw a diagram of an onion cell and label its parts.

Figure 2–3 *The cell wall gives support and protection to plant cells, enabling giant redwoods to grow tall and straight.*

microscope. In fact, most cells are smaller than the period at the end of this sentence. (One exception is the yolk of an egg, which is actually a large single cell.) Within a cell are even smaller structures called organelles. **The structures within a cell function in providing protection and support, forming a barrier between the cell and its environment, building and repairing cell parts, transporting materials, storing and releasing energy, getting rid of waste materials, and increasing in number.**

Whether found in an animal or in a plant, most cells share certain similar characteristics. It is these characteristics that you are going to learn about. So hop aboard your imaginary ship and prepare to enter a typical plant cell. You will begin by sailing up through the trunk of an oak tree. Your destination is that box-shaped structure directly ahead. See Figure 2–4.

Cell Wall: Support and Protection

Entering the cell of an oak tree is a bit difficult. First you must pass through the **cell wall.** Strong and stiff, the cell wall is made of cellulose, a nonliving material. Cellulose is a long chain of sugar molecules that the cell manufactures. (The stringy part of celery is cellulose found in the cell walls of the celery stalk.)

The rigid cell wall is found in plant cells, but not in animal cells. The cell wall helps to protect and support the plant so that it can grow tall. Think for a moment of grasses, trees, and flowers that support themselves upright. No doubt you can appreciate the important role the cell wall plays for the individual cell and for the entire plant.

Although the cell wall is stiff, it does allow water, oxygen, carbon dioxide, and certain dissolved materials to pass into and out of the cell. So sail on through the cell wall and enter the cell.

Cell Membrane: Doorway of the Cell

As you pass through the cell wall, the first structure you encounter is the **cell membrane.** In a plant cell, the cell membrane is just inside the cell wall. In an animal cell (which has no cell wall), the cell membrane forms the outer covering of the cell.

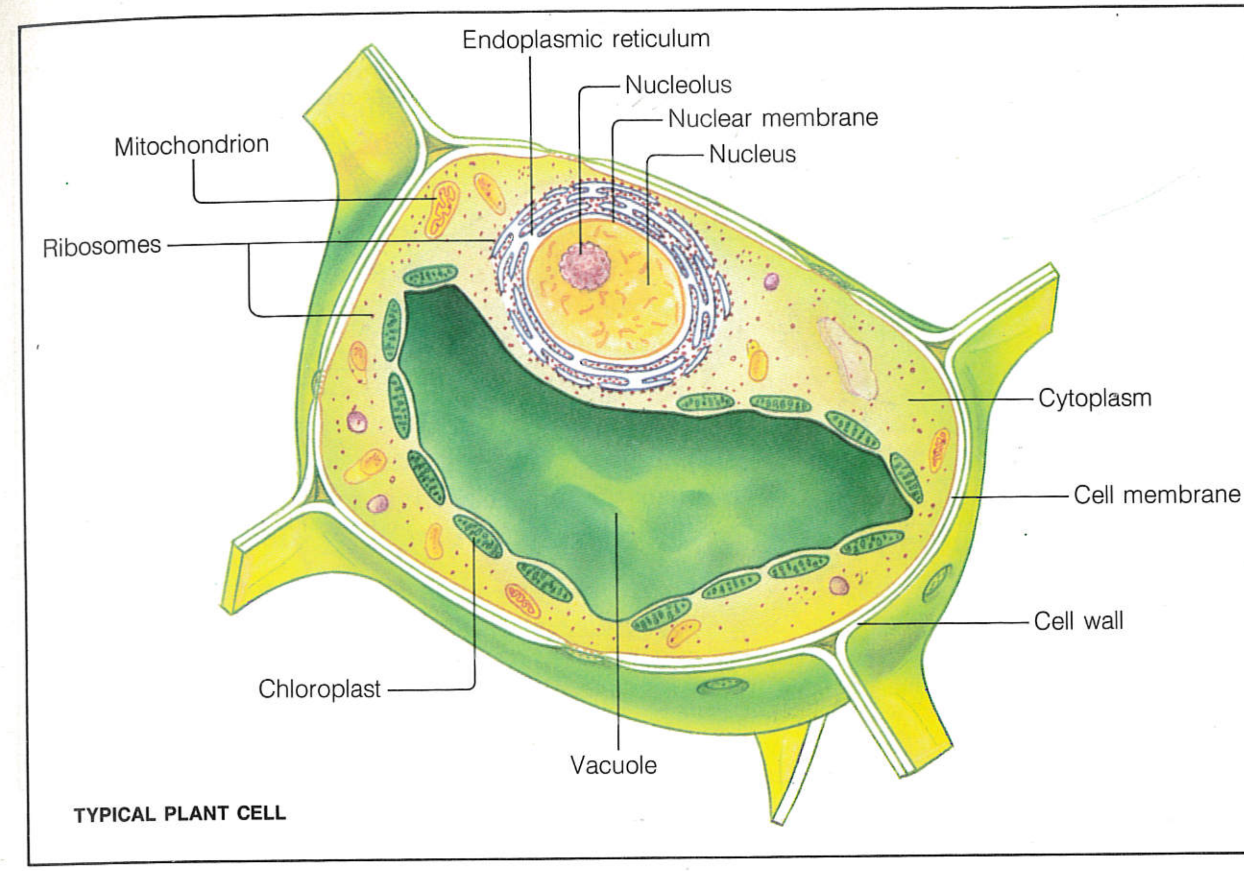


Figure 2–4 *A typical plant cell contains many different structures, each having a characteristic shape and function. What is the outer barrier surrounding a plant cell called?*

The cell membrane has several important jobs. One of these important jobs is to provide protection and support for the cell. Unlike a plant cell, an animal cell does not have a rigid cell wall. Instead, an animal's cell membrane contains a substance called cholesterol that strengthens the cell membrane. As you might expect, a plant's cell membrane does not contain cholesterol.

As your ship nears the edge of the cell membrane, you notice that there are tiny openings, or pores, in the membrane. You steer toward an opening. Suddenly your ship narrowly misses being struck by a chunk of floating waste material passing out of the cell. You have discovered another job of the cell membrane. This membrane helps to control the movement of materials into and out of the cells. You will learn more about how materials pass through the cell membrane in Chapter 3.

In a sense, the cell membrane is like the walls that surround your house or your apartment. Just as the walls of your home form a barrier between you and the outside world, the cell membrane forms a barrier between the living material inside the cell

Activity Bank

Now You See It—Now You Don't, p. 107

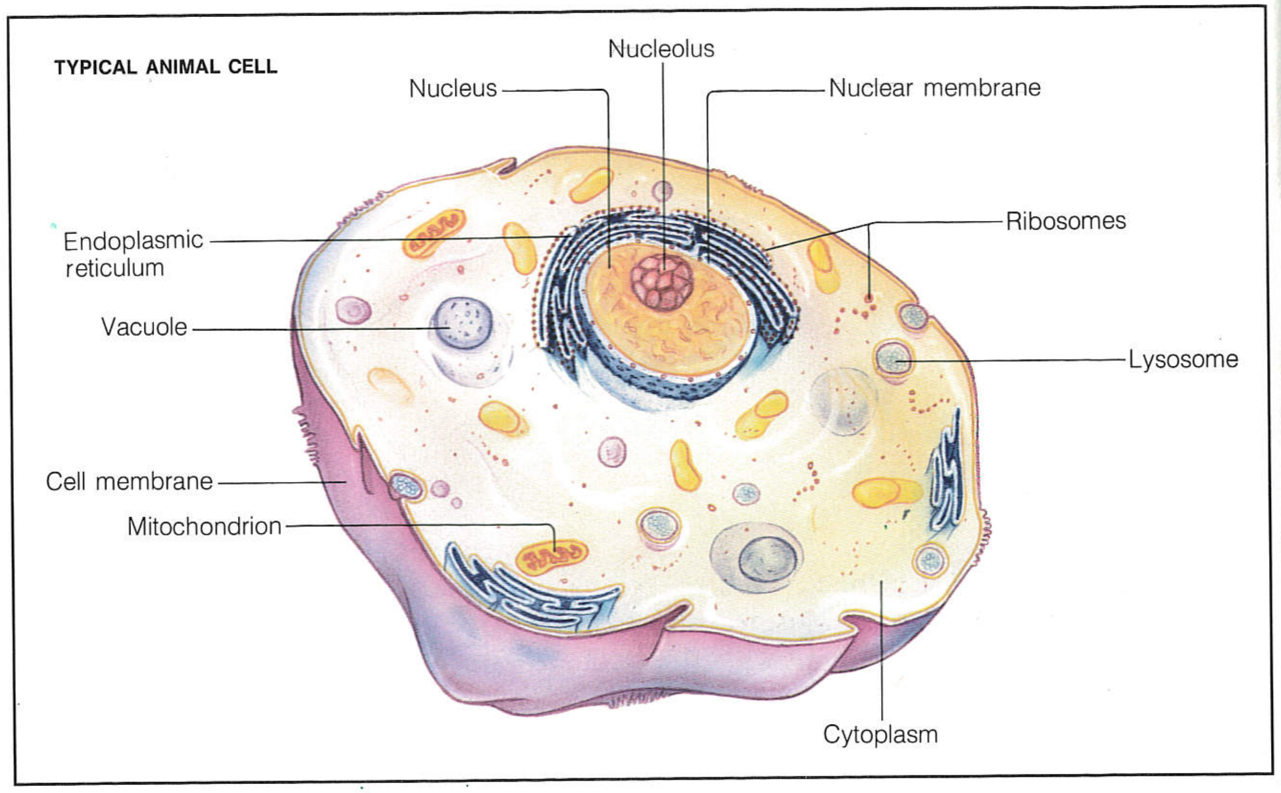


Figure 2–5 *An animal cell has many of the same structures as a plant cell. What is the outer barrier surrounding an animal cell called?*

ACTIVITY CALCULATING

Small and Smallest

Cells come in a variety of sizes. The smallest cells belong to a group of organisms called *Mycoplasma*. *Mycoplasma* are only about 0.2 micrometer in diameter. (A micrometer is equal to one-millionth of a meter.) Larger cells include the giant ameba *Chaos chaos*, which is about 1000 micrometers in diameter. How much larger is *Chaos chaos* than a *mycoplasma*?

and the outside environment of the cell. No doubt you would be quite unhappy if nothing could get into and out of your home. After all, you need to have food, water, and electricity come into your home. And you need to have waste products removed from your home before they build up. To ensure the survival of the cell, the cell membrane must allow materials to pass into and out of the cell. So you can think of the cell membrane as a barrier with doorways.

Everything the cell needs, from food to oxygen, enters the cell through the cell membrane. And harmful waste products exit through the cell membrane as well. In this way, the cell stays in smooth-running order, keeping conditions inside the cell the same even though conditions outside the cell may change. As you may recall from Chapter 1, the ability to maintain a stable internal environment, or homeostasis, is one of the important needs of all living things. Now sail on through a doorway in the cell membrane and enter a living cell.

Nucleus: Control Center of the Cell

As you sail inside the cell, a large, oval structure comes into view. This structure is the control center of the cell, or the **nucleus** (NOO-klee-uhs). The nucleus acts as the "brain" of the cell, regulating or controlling all the activities of the cell. See Figure 2–7.

NUCLEAR MEMBRANE Like the cell itself, the nucleus is also surrounded by a membrane. As you might expect, it is called the nuclear membrane. This membrane is similar to the cell membrane in that it allows materials to pass into or out of the nucleus. Small openings, or pores, are spaced regularly around the nuclear membrane. Each pore acts as a passageway. So set your sights for that pore just ahead and carefully glide into the nucleus.

CHROMOSOMES Those thick, rodlike objects floating directly ahead in the nucleus are **chromosomes.** Steer carefully to avoid colliding with the delicate chromosomes. For it is the chromosomes that direct all the activities of the cell, including growth and reproduction. In addition, chromosomes are responsible for passing on the traits of the cell to new cells. Chromosomes, for example, make sure that skin cells grow and divide into more skin cells.

The large, complex molecules that make up the chromosomes are compounds called nucleic acids. Nucleic acids store the information that helps a cell make the proteins it requires. And proteins are necessary for life. Some proteins are used to form parts of the cell, such as the cell membrane. Other

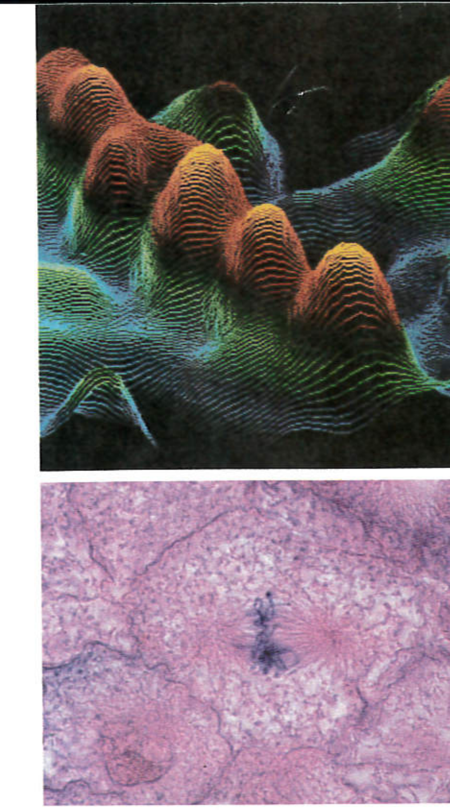


Figure 2–6 *Notice the rodlike chromosomes in the nucleus (bottom). This unusual photograph is an image of DNA in a chromosome, produced by a scanning electron microscope (top). The colors have been added by a computer.*

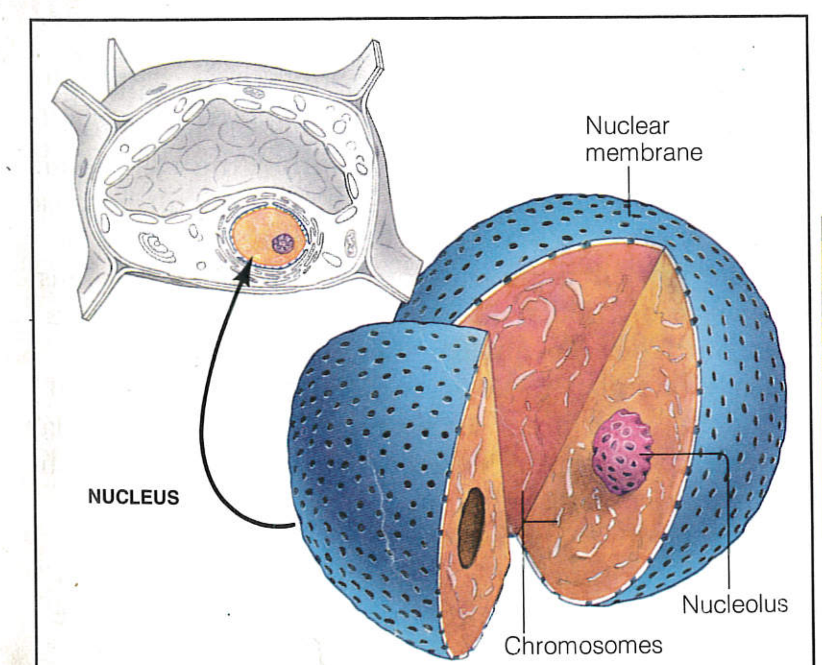


Figure 2–7 *The nucleus directs all the activities of a cell. Notice the various structures that make up the nucleus and the appearance of the nucleus in a liver cell viewed through an electron microscope.*

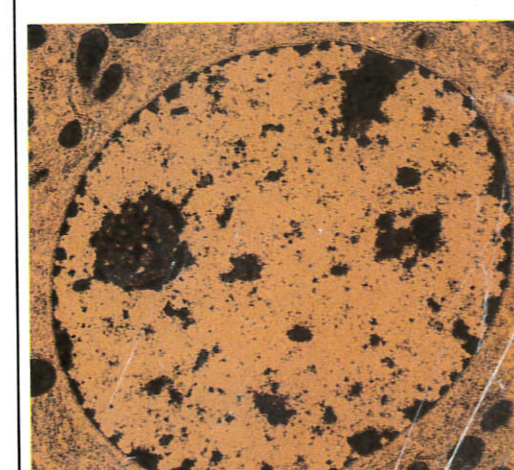


Figure 2–8 *As you read about the structures in a typical cell, keep in mind that organisms do differ in cell structure. Bacteria, members of the kingdom Monera, do not contain a distinct nucleus (top). Fungi, which look similar to plants, have nuclei but do not always have cells separated by a cell wall. For this reason, fungi are placed in the kingdom Fungi (bottom).*

proteins make up different enzymes and hormones used inside and outside the cell. Enzymes and hormones regulate cell activities.

The two nucleic acids found in cells are DNA and RNA. In Chapter 1 we called the nucleic acids the carriers of the blueprints of life. Working together, DNA and RNA store the information and carry out the steps in the protein-making process necessary for life. The DNA remains in the nucleus. But the RNA, carrying its protein-building instructions, leaves the nucleus through pores in the nuclear membrane. So hitch a ride on the RNA leaving the nucleus and continue your exploration of the cell.

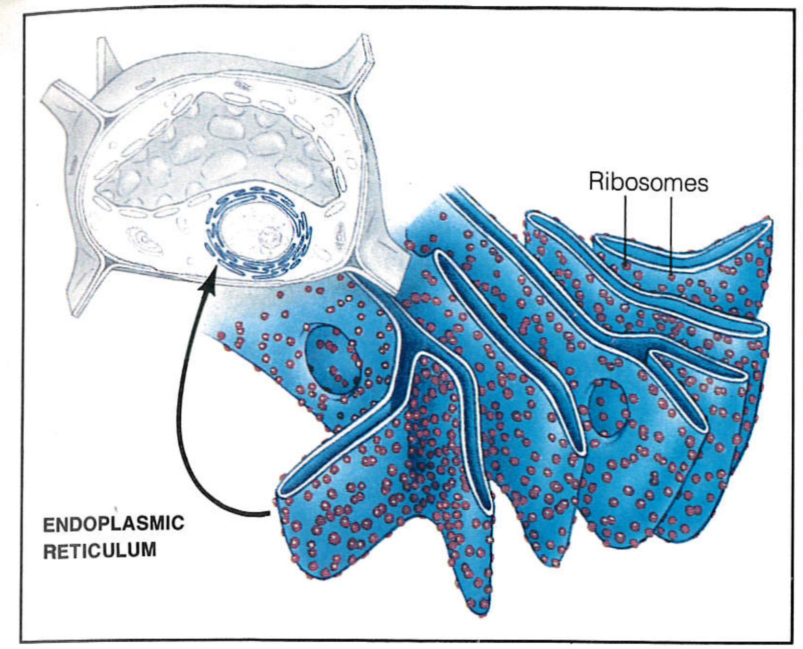
NUCLEOLUS As you prepare to leave the nucleus, you spot a small object floating past. It is the nucleolus (noo-KLEE-uh-luhs), or "little nucleus." For many years the function of the nucleolus remained something of a mystery to scientists. Today it is believed that the nucleolus is the site of ribosome production. Ribosomes, as you will soon learn, are involved in the protein-making process in the cell.

Endoplasmic Reticulum: Transportation System of the Cell

As you leave the nucleus, you find yourself floating in a clear, thick, jellylike substance called the **cytoplasm.** The cytoplasm is the term given to the region between the nucleus and the cell membrane. While you are in the cytoplasm your ship needs no propulsion. For the cytoplasm is constantly moving, streaming throughout the cell. Many of the important cell organelles are located within the cytoplasm.

Steering in the cytoplasm is a bit difficult because of the organelles scattered throughout. The first organelle you encounter as you sail out of the nucleus is a maze of tubular passageways. These passageways lead out from the nuclear membrane. Some of the passageways lead to the cell membrane. Others lead to all the other areas of the cell. These clear, tubular passageways form the **endoplasmic reticulum** (en-doh-PLAZ-mihk rih-TIHK-yuh-luhm).

The endoplasmic reticulum is a transportation system. Its network of passageways spreads throughout the cell, carrying proteins from one part of the



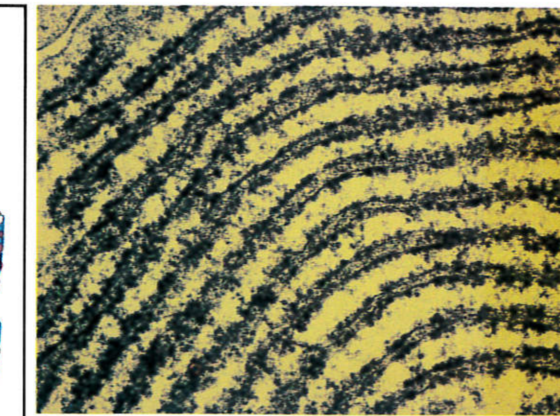


Figure 2–9 *The endoplasmic reticulum is a canal system that can transport proteins throughout the cell. In this photograph of the endoplasmic reticulum, the dark spots are ribosomes, the sites of protein production.*

cell to another—or from the cell through the cell membrane and out the cell. If you look at Figure 2–9, you will see that the endoplasmic reticulum is well suited for its transportation job.

Ribosomes: Protein Factories of the Cell

Steer your ship directly into the endoplasmic reticulum passageways. From here you can travel anywhere you want in the cell. Before moving on, however, look closely at the inner surface of the endoplasmic passageways. Attached to the surface are grainlike bodies called **ribosomes.** Recall that ribosomes are produced in the nucleolus. From the nucleolus they pass out of the nucleus. Many of them end up attached to the inner lining of the endoplasmic reticulum.

Ribosomes, which are made primarily of the nucleic acid RNA, are the protein-making sites of the cell. The RNA in the ribosomes, along with the RNA sent out from the nucleus, directs the production of proteins. (Keep in mind that the production of RNA is controlled by the DNA in the chromosomes. So the DNA in the chromosomes is the real control center of the cell.)

It is no surprise that many ribosomes are found in the endoplasmic reticulum. This is a perfect location for them. For, once the ribosomes have made

ACTIVITY DOING

Observing Cells

1. Obtain a thin piece of cork and a few drops of rainwater.

2. Place each sample on a different glass slide and cover with a coverslip.

3. Obtain a prepared slide of human blood.

4. Observe each slide under low power and under high power of your microscope.

5. Make a labeled diagram of what you see on each slide.

Compare how cells appear under low power and under high power.

Using reference books, find diagrams of these materials as seen by Hooke and van Leeuwenhoek. How do your diagrams compare with theirs?

the proteins needed by the cell, they can immediately drop them off into the passageways of the endoplasmic reticulum. From there the proteins can be transported to any part of the cell where they are needed—or out of the cell if necessary.

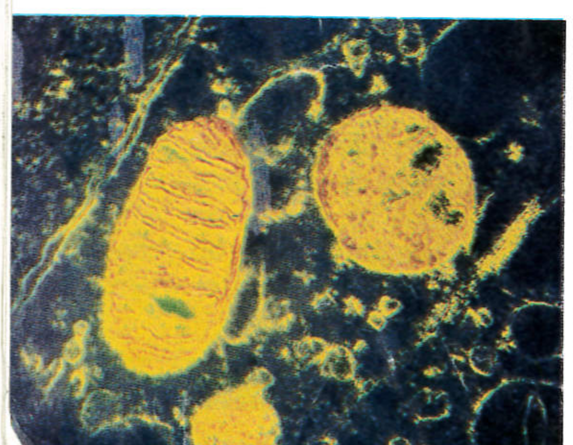
As you leave the endoplasmic reticulum, you notice that not all ribosomes are attached to the endoplasmic reticulum. Some float freely in the cytoplasm. Watch out! There go a few passing by. The cell you are in seems to have many ribosomes. What might this tell you about its protein-making activity?

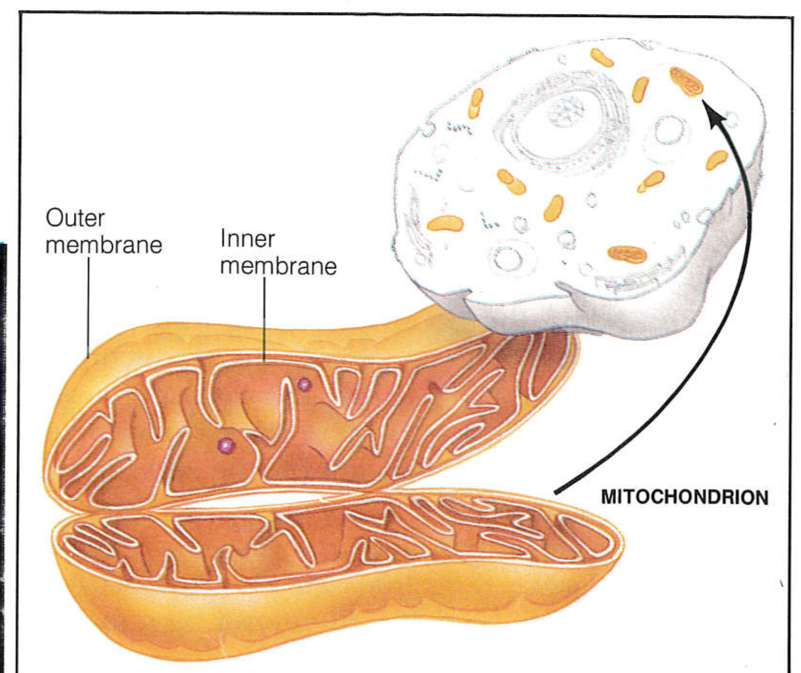
Mitochondria: Powerhouses of the Cell

As you pass by the ribosomes, you see other structures looming ahead. These structures are called **mitochondria** (might-oh-KAHN-dree-uh; singular: mitochondrion). Mitochondria supply most of the energy for the cell. Somewhat larger than the ribosomes, these rod-shaped structures are often referred to as the "powerhouses" of the cell. See Figure 2–10.

Inside the mitochondria, simple food substances such as sugars are broken down into water and carbon dioxide gas. Large amounts of energy are released during the breakdown of sugars. The mitochondria gather this energy and store it in special energy-rich molecules. These molecules are convenient energy packages that the cell uses to do all its work. The more active the cell, the more mitochondria it has. Some cells, such as human liver cells, contain more than 1000 mitochondria. You will read more about mitochondria and energy in Chapter 4.

Figure 2–10 *Mitochondria are the powerhouses of the cell. They provide the cell with the energy it needs to survive. Note the structure of the mitochondrion in the diagram and in the electron micrograph.*





Because mitochondria have a small amount of their own DNA, scientists hypothesize that mitochondria were once tiny living organisms. These organisms, it is believed, invaded other cells millions of years ago. The DNA molecules in the mitochondria were passed from one generation of cells to the next as less complex organisms evolved into more complex organisms. (Keep in mind that even the smallest cells are still quite complex.) Now all living cells contain mitochondria. No longer invaders, mitochondria are an important part of living cells.

Figure 2–11 *Before they became permanent members of living cells, ancient mitochondria may have been similar in structure to these rickettsia. Mitochondria are no longer outside invaders. The rickettsia shown here, however, cause a serious disease called Rocky Mountain Spotted Fever.*

Vacuoles: Storage Tanks for Cells

Steer past the mitochondria and head for that large, round, water-filled sac floating in the cytoplasm. This sac is called a **vacuole** (VA-kyoo-ohl). Most plant cells and some animal cells have vacuoles. Plant cells often have one very large vacuole. Animal cells, if they contain any vacuoles, generally have a few small ones.

Vacuoles act like storage tanks. Food and other materials needed by the cell are stored inside the vacuoles. Vacuoles can also store waste products. In plant cells, vacuoles are the main water-storage areas. When water vacuoles in plant cells are full, they swell and make the cell plump. This plumpness keeps a plant firm.

Figure 2–12 *The large, roundish, empty spaces in these plant cells are vacuoles. What materials do vacuoles store?*

Lysosomes: Cleanup Crews for the Cell

If you carefully swing your ship around the vacuole, you may be lucky enough to see a **lysosome** (LIGH-suh-sohm). Lysosomes are common in animal cells but are not often observed in plant cells.

Lysosomes are small, round structures involved with the digestive activities of the cell. See Figure 2–13 on page 54. Lysosomes contain enzymes that break down large food molecules into smaller ones. These smaller food molecules are then passed on to the mitochondria, where they are "burned" to provide energy for the cell.

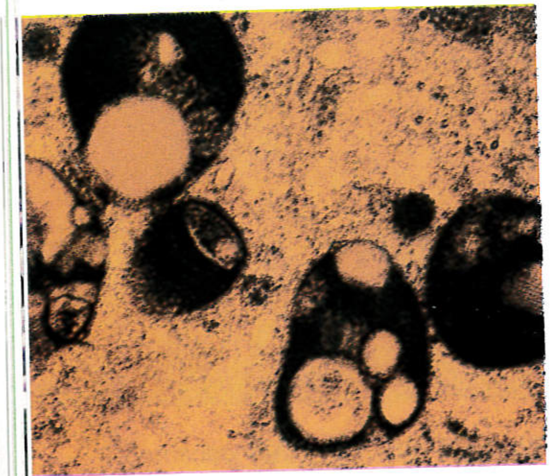


Figure 2–13 *These spherical organelles are lysosomes that have been magnified approximately 95,000 times. Lysosomes contain enzymes that can digest other organelles that have outlived their usefulness.*

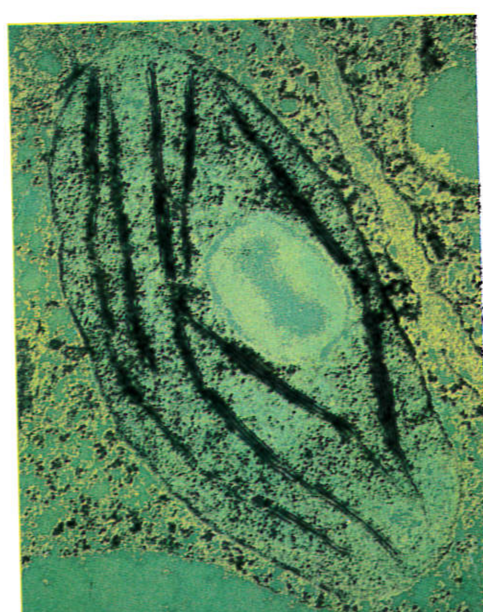
Lysosomes are not involved just in digesting food. Many parts of the cell age and outlive their usefulness. One task of lysosomes is to digest old cell parts, releasing the substances in those aging cell parts so that they can be used again to build new parts. In this sense, you can think of lysosomes as the cell's cleanup crew.

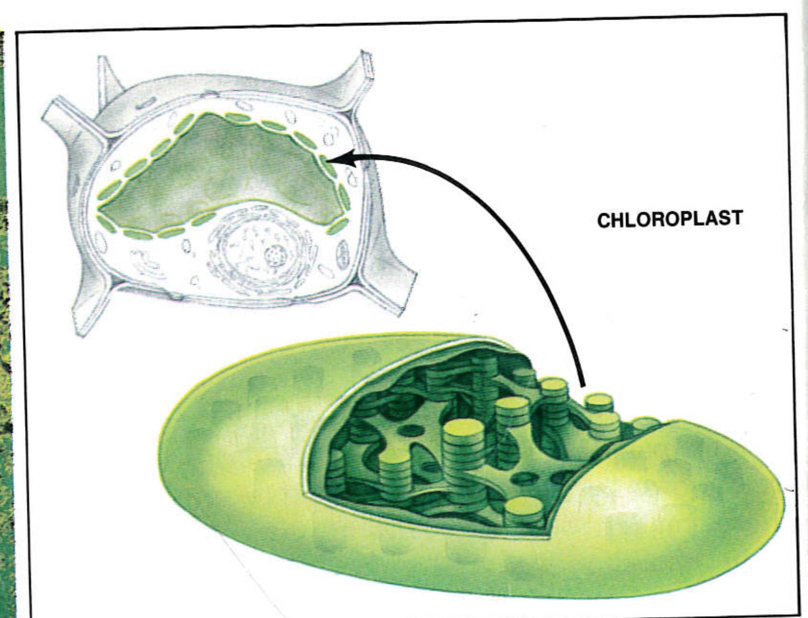
Although lysosomes contain powerful digestive enzymes, you need not worry about your ship's safety. The membrane surrounding a lysosome keeps the enzymes from escaping and digesting the entire cell! Lysosomes can, however, digest whole cells when the cells are injured or dead. In an interesting process in the growth and development of a tadpole into a frog, lysosomes in the tadpole's tail cells digest the tail. Then the material is reused to make new body parts for the frog.

Chloroplasts: Energy Producers for the Cell

Your journey through the cell is just about over. But before you leave, look around you once again. Have you noticed any large, irregularly shaped green structures floating in the cytoplasm? If so, you have observed **chloroplasts.** Chloroplasts are green because they contain a green pigment called chlorophyll. Chlorophyll captures the energy of sunlight, which can then be used to help produce food for the plant cell. This process is called photosynthesis. You will read more about chloroplasts and photosynthesis in Chapter 4.

Figure 2–14 *Chloroplasts are organelles that use sunlight to produce food in a process called photosynthesis. Would you be likely to find a chloroplast in an animal cell?*





Cell Specialization

You have just read about the structures found in plant and animal cells. These structures help to keep the cell alive and functioning properly. In unicellular organisms such as bacteria, the single cell performs all the functions necessary for life. But, as you know, many organisms (including yourself) are multicellular. In multicellular organisms, each cell may well perform a specialized function for the entire organism. That is, the cell not only completes all its own life activities, it also contributes to the life of the organism. Without cell specialization, the evolution of multicellular organisms could not have occurred.

Tissues, Organs, and Organ Systems

You have just read that cells in multicellular organisms are specialized to perform specific tasks for the organism. So it should not surprise you to learn that cells are often organized in order to better serve the needs of the organism. In other words, within a multicellular organism there is a **division of labor.** Division of labor means that the work of keeping the organism alive is divided among the different parts of the body. Each part has a specific job to do. And as each part does its special job, it works in harmony with all the other parts.

The arrangement of specialized parts within a living thing is sometimes referred to as levels of organization. Cells, of course, are the first level of organization.

TISSUES: LEVEL TWO In any multicellular organism, cells rarely work alone. Cells that are similar in structure and function are usually joined together to form **tissues.** Tissues are the second level of organization. What is the first level of organization?

For example, bone cells in your body form bone tissue, a strong, solid tissue that gives you shape and support. Blood cells in your body are part of blood tissue, a liquid tissue responsible for transporting food and oxygen throughout the body. What other types of tissues are found in your body?

Figure 2–15 *In multicellular organisms, many cells are specialized to perform a specific function for the organism. Here you see nerve cells (neurons) in the part of the brain used for thinking skills such as reading and understanding this textbook.*

ACTIVITY WRITING

Word Clues

The definition of a word can often be determined by knowing the meaning of its prefix. For the following words, look up the prefix in each and tell how it relates to the definition:

chloroplast
mitochondria
chromosome
lysosome
cytoplasm