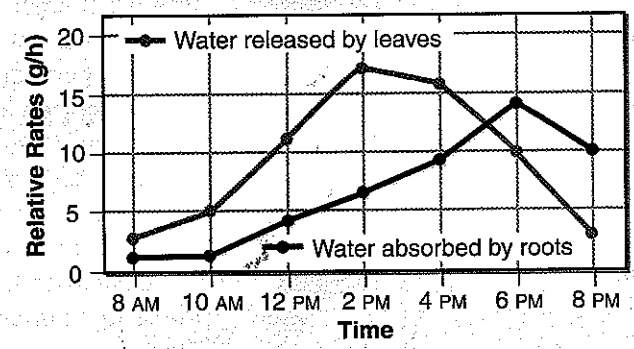
**Water Released and Absorbed by Tree**

| Time | Absorbed by Roots (g/h) | Released by Leaves (g/h) |
|---|---|---|
| 8 AM | 1 | 2 |
| 10 AM | 1 | 5 |
| 12 PM | 4 | 12 |
| 2 PM | 6 | 17 |
| 4 PM | 9 | 16 |
| 6 PM | 14 | 10 |
| 8 PM | 10 | 3 |




▲ **Figure 1–24** One way to record data from an experiment is by using a data table. Then, the data may be plotted on a graph to make it easier to interpret. **Using Tables and Graphs** *At what time of day is the rate of water released by leaves equal to the rate of water absorbed by roots?*

## Analyzing Biological Data

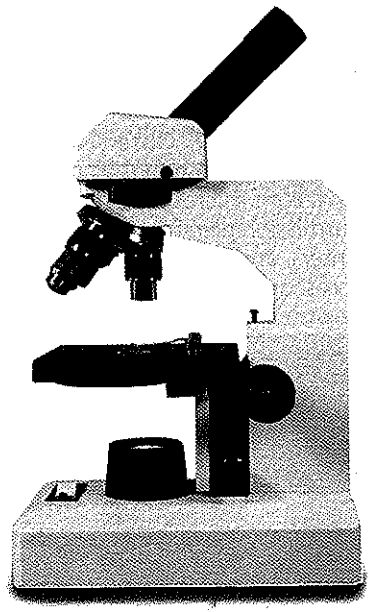
When scientists collect data, they are often trying to find out whether certain factors changed or remained the same. Often, the simplest way to do that is to record the data in a table and then make a graph. Although you may be able to detect a pattern of change from a data table like the one in **Figure 1–24,** a graph of the data can make a pattern much easier to recognize and understand.

The amount of data produced by biologists today is so huge that no individual can look at more than a tiny fraction of it. To make sense of the data, biologists often turn to computers. For example, computers help determine the structure of molecules. They also allow biologists to search through a DNA molecule, find significant regions of the molecule, and discover how organisms are affected by those regions. At the opposite end of the scale, computers are essential to gathering data by satellite, analyzing the data, and presenting the results. Analyses of satellite data are used to make predictions about complex phenomena such as global climate changes.

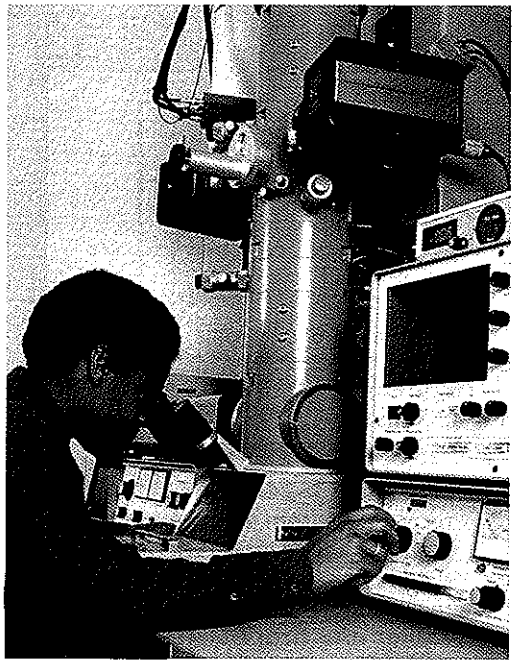
CHECKPOINT *How can a graph help biologists analyze data?*

## Microscopes

When people think of scientific equipment, one of the first tools that comes to mind is the microscope. **Microscopes,** such as the light microscope in **Figure 1–25,** are devices that produce magnified images of structures that are too small to see with the unaided eye. **Light microscopes produce magnified images by focusing visible light rays. Electron microscopes produce magnified images by focusing beams of electrons.** Since the first microscope was invented, microscope manufacturers have had to deal with two problems: What is the instrument's magnification—that is, how much larger can it make an object appear compared to the object's real size? And how sharp an image can the instrument produce?



▲ **Figure 1–25** Light microscopes produce magnified images by focusing visible light rays.



▲ **Figure 1–26** This scientist is using an electron microscope to make observations. **Electron microscopes produce images by focusing beams of electrons.**

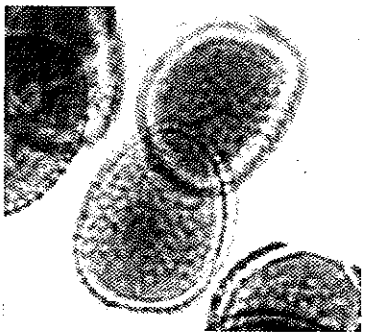
**Light Microscopes** The most commonly used microscope is the light microscope. Light microscopes can produce clear images of objects at a magnification of about 1000 times. **Figure 1–25** shows a compound light microscope similar to those in many high school laboratories. **Compound light microscopes** allow light to pass through the specimen and use two lenses to form an image. Light microscopes make it possible to study dead organisms and their parts, and to observe some tiny organisms and cells while they are still alive. You can refer to Appendix D to learn how to use a compound light microscope.

Biologists have developed techniques and procedures to make light microscopes more useful. Chemical stains, also called dyes, can show specific structures in the cell. Fluorescent dyes have been combined with video cameras and computer processing to produce moving three-dimensional images of processes such as cell movement.

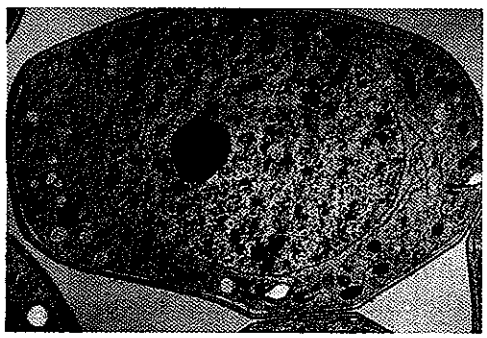
**Electron Microscopes** All microscopes are limited in what they reveal, and light microscopes cannot produce clear images of objects smaller than 0.2 micrometers, or about one-fiftieth the diameter of a typical cell. To study even smaller objects, scientists use electron microscopes. **Electron microscopes,** such as the one shown in **Figure 1–26,** use beams of electrons, rather than light, to produce images. The best electron microscopes can produce images almost 1000 times more detailed than light microscopes can.

Biologists use two main types of electron microscopes. Transmission electron microscopes (TEMs) shine a beam of electrons through a thin specimen. Scanning electron microscopes (SEMs) scan a narrow beam of electrons back and forth across the surface of a specimen. TEMs can reveal a wealth of detail inside the cell. SEMs produce realistic, and often dramatic, three-dimensional images of the surfaces of objects. Because electron microscopes require a vacuum to operate, samples for both TEM and SEM work must be preserved and dehydrated before they are placed inside the microscope. This means that living cells cannot be observed with electron microscopes, only with the light microscope. **Figure 1–27** shows images taken with a light microscope, a transmission electron microscope, and a scanning electron microscope.

▼ **Figure 1–27** Observe the images of pollen grains as seen with a light microscope (left), transmission electron microscope (center), and scanning electron microscope (right). **Interpreting Graphics** *In which image can you see the most detail on the pollen grain's surface?*



(magnification: about 400 ×)



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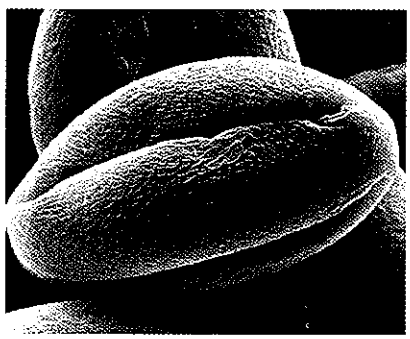


(magnification: about 1000 ×)

# 7–1 Life Is Cellular

Look closely at a part of a living thing, and what do you see? Hold a blade of grass up against the light, and you see tiny lines running the length of the blade. Examine the tip of your finger, and you see the ridges and valleys that make up fingerprints. Place an insect under a microscope, and you see the intricate structures of its wings and the spikes and bristles that protect its body. As interesting as these close-up views may be, however, they're only the beginning of the story. Look closer and deeper with a more powerful microscope, and you'll see that there is a common structure that makes up every living thing—the cell.

## Guide for Reading

**Key Concepts**
- What is the cell theory?
- What are the characteristics of prokaryotes and eukaryotes?

**Vocabulary**
cell
cell theory
nucleus
eukaryote
prokaryote

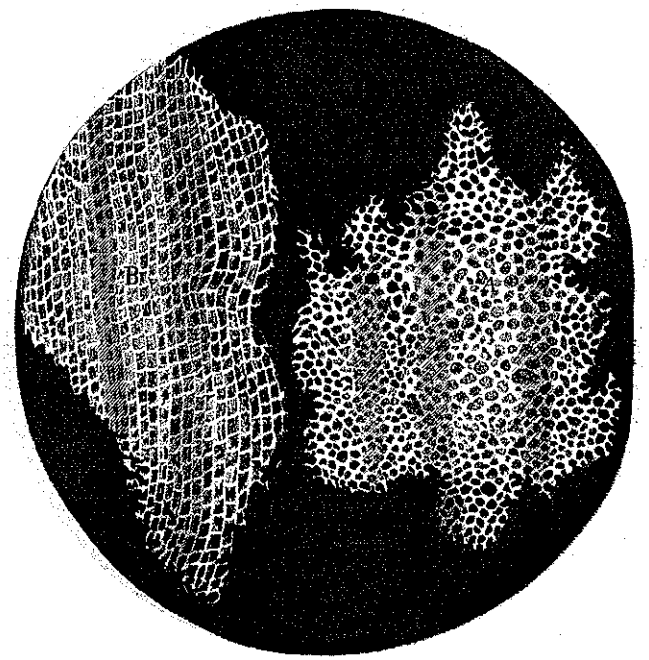
**Reading Strategy: Finding Main Ideas**
As you read, look for evidence to support the statement "The cell theory revolutionized how biologists thought about living things."

## The Discovery of the Cell

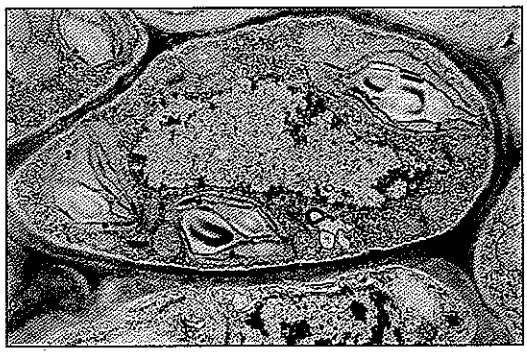
"Seeing is believing," an old saying goes. It would be hard to find a better example of this than the discovery of the cell. Without the instruments to make them visible, cells remained out of sight and, therefore, out of mind for most of human history. All of this changed with a dramatic advance in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

**Early Microscopes** It was not until the mid-1600s that scientists began to use microscopes to observe living things. In 1665, Englishman Robert Hooke used an early compound microscope to look at a 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. One of Hooke's illustrations of cells is shown in **Figure 7–1.** The term *cell* is used in biology to this day. We now know, however, that cells are not empty but contain living matter.

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, even in the very water he and his neighbors drank.



▶ **Figure 7–1** Using an early microscope, Hooke made this drawing of cork cells. In Hooke's drawings, the cells look like empty chambers because he was looking at dead plant matter. Today, we know that living cells are made up of many structures.



(magnification: 12,000×)

▲ **Figure 7–2** **The cell theory states that cells are the basic units of all living things.** This cell is from a plant leaf. Compare this micrograph with Hooke's drawing in which the cells are empty.

**The Cell Theory** Soon, numerous observations made it clear that **cells** were the basic units of life. In 1838, German botanist Matthias Schleiden concluded that all plants were made of cells like the one in **Figure 7–2.** The next year, German biologist Theodor Schwann stated that all animals were made of cells. In 1855, the German physician Rudolf Virchow concluded that new cells could be produced only from the division of existing cells. These discoveries, confirmed by other biologists, are summarized in the **cell theory,** a fundamental concept of biology. **The cell theory states:**

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

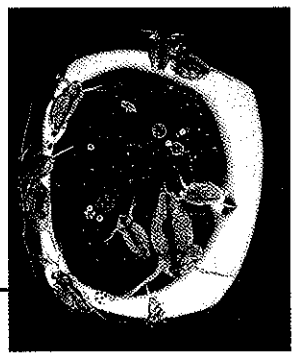
## Exploring the Cell

Following in the footsteps of Hooke, Virchow, and others, modern biologists still use microscopes to explore the cell. However, today's researchers use microscopes and techniques more powerful than the pioneers of biology could have imagined. Researchers can use fluorescent labels and light microscopy to follow molecules moving through the cell. Confocal light microscopy, which scans cells with a laser beam, makes it possible to build three-dimensional images of cells and their parts. High-resolution video technology makes it easy to produce movies of cells as they grow, divide, and develop.

# Biology and History

## A History of the Cell

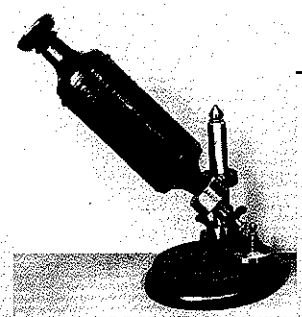
***The observations and conclusions of many scientists helped to develop the current understanding of the cell.***



**1600**

**1607**
English settlers found colony at Jamestown, Virginia

**1665**
**Robert Hooke**
Hooke publishes his book *Micrographia,* which contains his drawings of sections of cork as seen through one of the first microscopes.



**1674**
**Anton van Leeuwenhoek**
Leeuwenhoek observes tiny living organisms in drops of pond water through his simple microscope.

**1700**

These new technologies make it possible for researchers to study the structure and movement of living cells in great detail. Unfortunately, light itself limits the detail, or resolution, of images that can be made with the light microscope. Like all forms of radiation, light waves are diffracted, or scattered, as they pass through matter, making it impossible to visualize tiny structures such as proteins and viruses with light microscopy.

By contrast, electron microscopes are capable of revealing details as much as 1000 times smaller than those visible in light microscopes because the wavelengths of electrons are much shorter than those of light. Transmission electron microscopes (TEMs) make it possible to explore cell structures and large protein molecules. Because beams of electrons can only pass through thin samples, cells and tissues must be cut first into ultrathin slices before they can be examined under a microscope.

With scanning electron microscopes (SEMs), a pencillike beam of electrons is scanned over the surface of a specimen. For SEM images, specimens do not have to be cut into thin slices to be visualized. The scanning electron microscope produces stunning three-dimensional images of cells. Because electrons are easily scattered by molecules in the air, samples examined in both types of electron microscopes must be placed in a vacuum in order to be studied. As a result, researchers chemically preserve their samples first and then carefully remove all of the water before placing them in the microscope. This means that electron microscopy can be used to visualize only nonliving, preserved cells and tissues.

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## Writing Activity

Use the library or the Internet to research a new discovery relating to the cell or its structures. Be sure to include the scientist(s) responsible for the discovery. Then, present your findings in the form of an oral report.

1800 1900 2000

**1838**
**Matthias Schleiden**
Schleiden concludes that all plants are made up of cells.

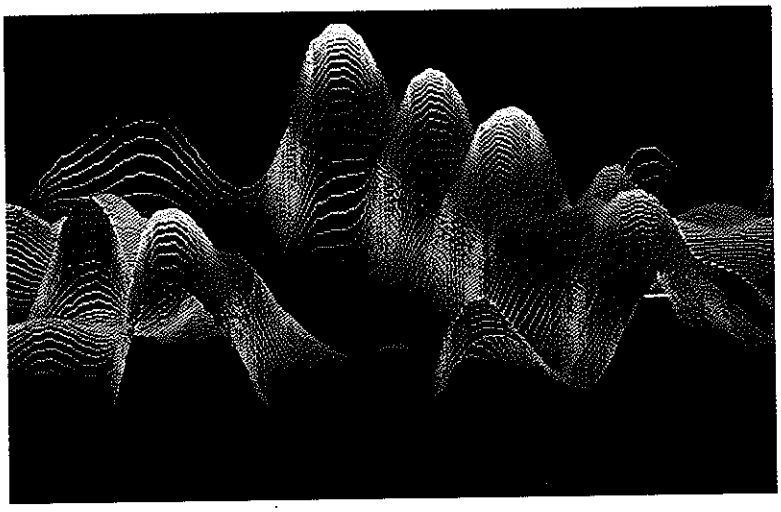
**1839**
**Theodor Schwann**
Schwann concludes that all animals are made up of cells.

**1855**
**Rudolph Virchow**
Virchow proposes that all cells come from existing cells, completing the cell theory.

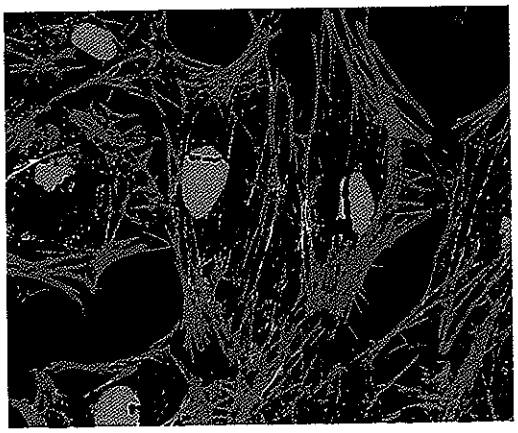
**1931**
**Janet Plowe**
Plowe demonstrates that the cell membrane is a physical structure, not an interface between two liquids.

**1970**
**Lynn Margulis**
Margulis proposes the idea that certain organelles, tiny structures within some cells, were once free-living cells themselves.

Scanning Electron Micrograph



Scanning Probe Micrograph



Fluorescent Confocal Light Micrograph

**Figure 7–3** Different types of microscopes produce a variety of images of cells and cell parts. Scanning electron microscopes produce three-dimensional images of the surfaces of cells and tissues (top left). In order to produce the images, the specimen must be chemically preserved and is, therefore, nonliving. Confocal light microscopes construct images by scanning cells with a computer-controlled laser beam. By attaching fluorescent labels to different molecules, researchers can follow molecules as they move through a living cell (bottom left). A scanning probe microscope scans a fine probe just above the specimen surface and electronically records the position of the probe (top right).

In the 1990s, researchers perfected a new class of microscopes that produce images by tracing the surfaces of samples with a fine probe. These scanning probe microscopes have revolutionized the study of surfaces and made it possible to observe single atoms. Unlike electron microscopes, scanning probe microscopes can operate in ordinary air and can even show samples in solution. Researchers have already used scanning probe microscopes to image DNA and protein molecules as well as a number of important biological structures.

## Prokaryotes and Eukaryotes

Cells come in a great variety of shapes and an amazing range of sizes. Although typical cells range from 5 to 50 micrometers in diameter, the tiniest mycoplasma bacteria are only 0.2 micrometers across, so small that they are difficult to see under even the best light microscopes. In contrast, the giant amoeba *Chaos chaos* may be 1000 micrometers in diameter, large enough to be seen with the unaided eye as a tiny speck in pond water. Despite their differences, all cells have two characteristics in common. They are surrounded by a barrier called a cell membrane; and, at some point in their lives, they contain the molecule that carries biological information—DNA.

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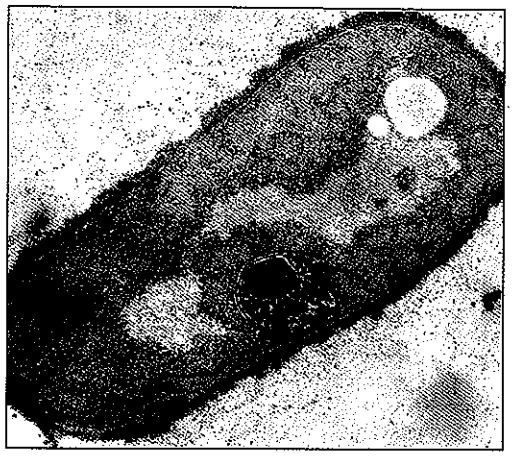
Cells fall into two broad categories, depending on whether they contain a nucleus. The **nucleus** (plural: nuclei) is a large membrane-enclosed structure that contains the cell's genetic material in the form of DNA. (A membrane is a thin layer of material that serves as a covering or lining.) The nucleus controls many of the cell's activities. **Eukaryotes** (yoo-KAR-ee-ohts) are cells that contain nuclei. **Prokaryotes** (pro-KAR-ee-ohts) are cells that do not contain nuclei. Both words derive from the Greek words *karyon,* meaning "kernel," or nucleus, and *eu,* meaning "true," or *pro,* meaning "before." These words reflect the idea that prokaryotic cells evolved before nuclei developed.

**Prokaryotes** Prokaryotic cells are generally smaller and simpler than eukaryotic cells, although there are many exceptions to this rule. **Prokaryotic cells have genetic material that is not contained in a nucleus.** Some prokaryotes contain internal membranes, but prokaryotes are generally less complicated than eukaryotes. Despite their simplicity, prokaryotes carry out every activity associated with living things. They grow, reproduce, respond to the environment, and some can even move by gliding along surfaces or swimming through liquids. The organisms we call bacteria are prokaryotes.

**Eukaryotes** Eukaryotic cells are generally larger and more complex than prokaryotic cells. As you can see in **Figure 7–4,** eukaryotic cells generally contain dozens of structures and internal membranes, and many are highly specialized. **Eukaryotic cells contain a nucleus in which their genetic material is separated from the rest of the cell.** Eukaryotes display great variety. Some eukaryotes live solitary lives as single-celled organisms. Others form large, multicellular organisms. Plants, animals, fungi, and protists are eukaryotes.



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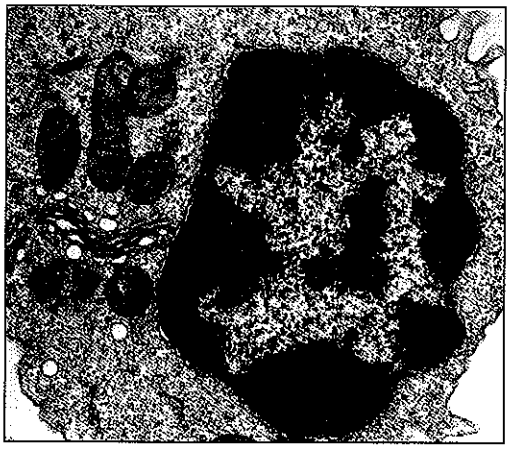


(magnification: 14,400×)

**Figure 7–4 The cells of eukaryotes have a nucleus, but the cells of prokaryotes do not.** Notice how many more structures are located in the eukaryotic cell (bottom) as compared with the prokaryotic cell (top).

## 7–1 Section Assessment

1. **Key Concept** What three statements describe the cell theory?
2. **Key Concept** What are the differences between prokaryotic cells and eukaryotic cells?
3. Compare the processes used to produce a TEM and an SEM.
4. What structures do all cells have?
5. **Critical Thinking Inferring** How did the invention of the microscope help the development of the cell theory?

### Alternative Assessment

**Constructing a Chart**
Make a three-column chart comparing prokaryotes with eukaryotes. In the first column, list the traits found in all cells. In the second column, list the features of prokaryotes. In the third column, list the features of eukaryotes.

# 7–2 Eukaryotic Cell Structure

## *Guide for Reading*

**Key Concept**
- What are the functions of the major cell structures?

**Vocabulary**
organelle
cytoplasm
nuclear envelope
chromatin
chromosome
nucleolus
ribosome
endoplasmic reticulum
Golgi apparatus
lysosome
vacuole
mitochondrion
chloroplast
cytoskeleton
centriole

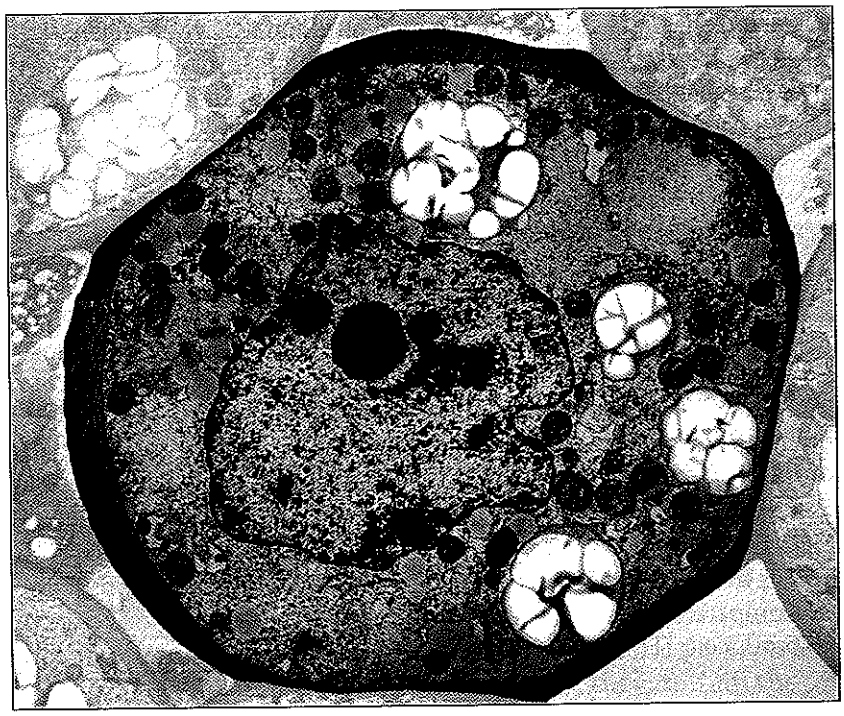
**Reading Strategy: Building Vocabulary**
Before you read, preview the vocabulary by skimming the section and making a list of the boldfaced terms. Leave space to make notes as you read.

At first glance, a factory is a puzzling place. A bewildering variety of machines buzz and clatter, people move quickly in different directions, and the sheer diversity of so much activity can be confusing. However, if you take your time and watch carefully, before long you will begin to identify patterns. What might at first have seemed like chaos begins to make sense.

## Comparing the Cell to a Factory

In some respects, the eukaryotic cell is like a factory. The first time you look at a microscope image of a cell, such as the one in **Figure 7–5,** the cell seems impossibly complex. Look closely at a eukaryotic cell, however, and patterns begin to emerge. To see those patterns more clearly, we'll look at some structures that are common to eukaryotic cells, shown in **Figure 7–6.** Because many of these structures act as if they are specialized organs, these structures are known as **organelles,** literally "little organs."

Cell biologists divide the eukaryotic cell into two major parts: the nucleus and the cytoplasm. The **cytoplasm** is the portion of the cell outside the nucleus. As you will see, the nucleus and cytoplasm work together in the business of life.

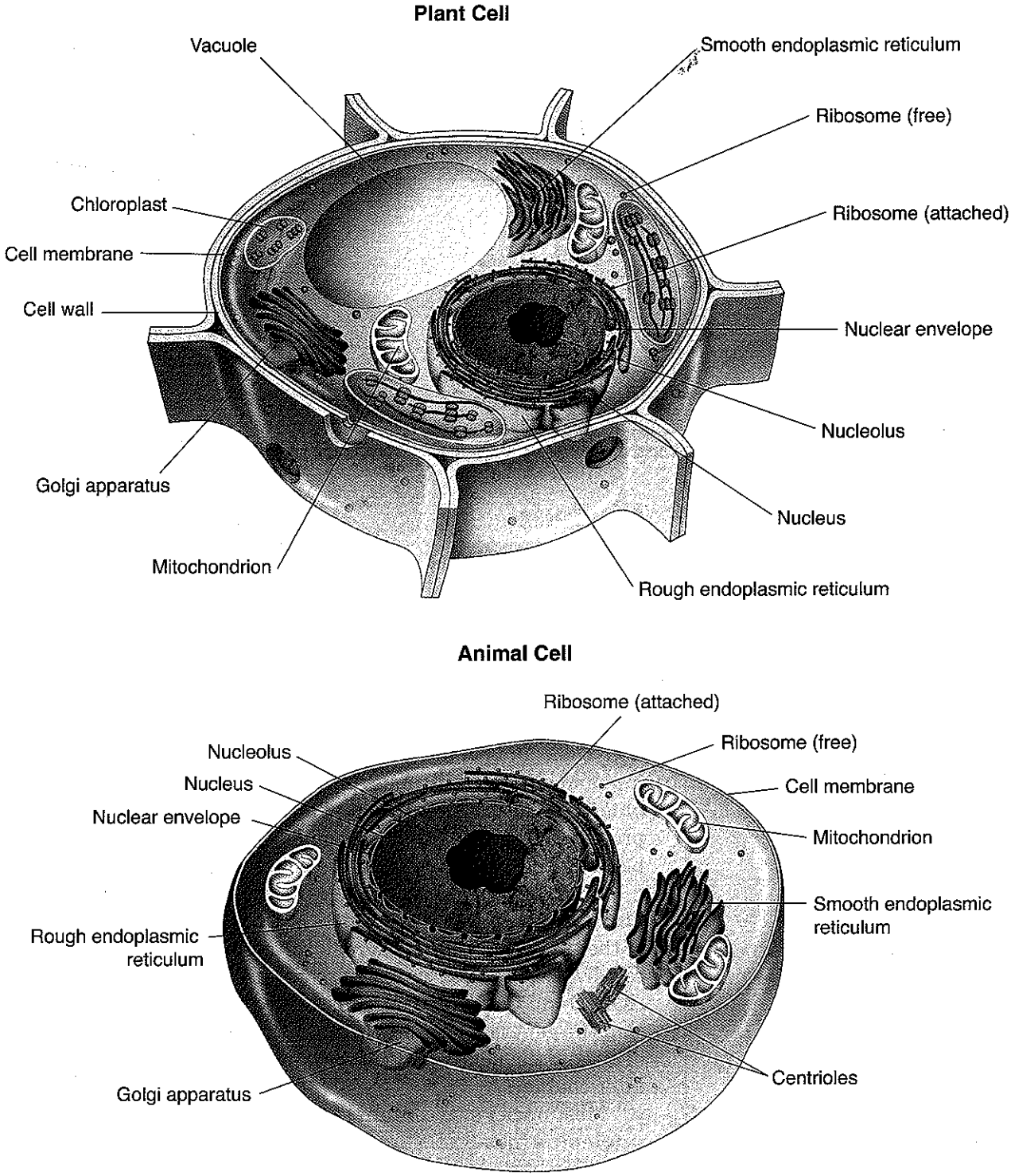


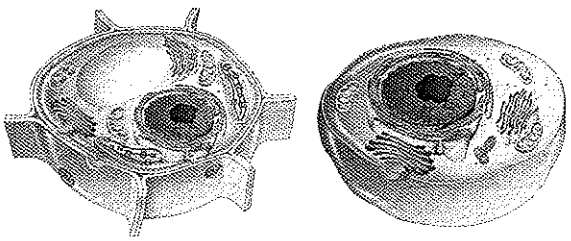
(magnification: 1500×)

▶ **Figure 7–5** This electron micrograph of a plant cell shows many of the different types of structures that are found in eukaryotic cells. The cell has been artificially colored so that you can distinguish one structure from another.

## FIGURE 7–6 PLANT AND ANIMAL CELLS

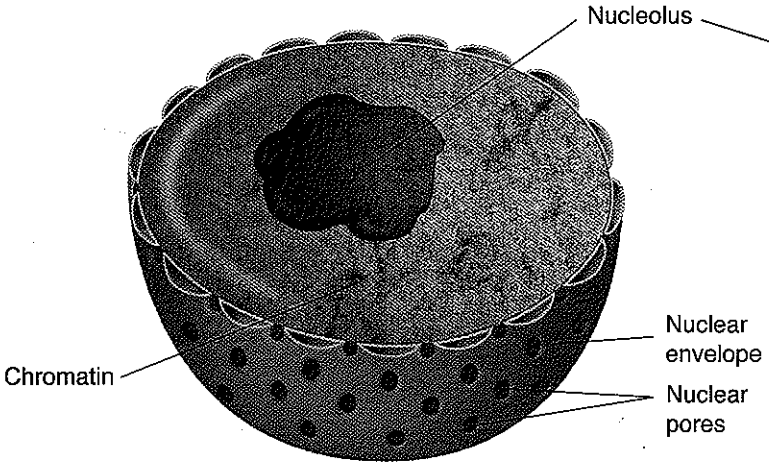
Both plant and animal cells contain a variety of organelles. Some structures are specific to either plant cells or animal cells only. **Interpreting Graphics** *What structures do plant cells have that animal cells do not?*

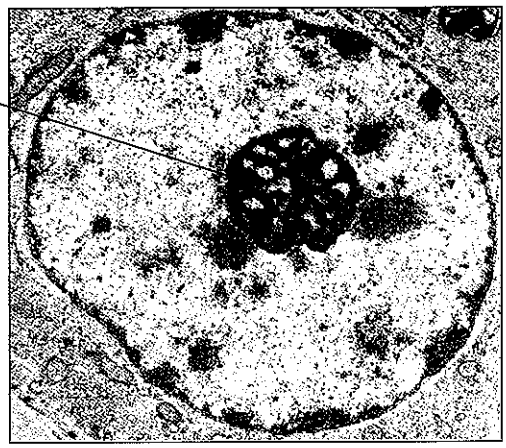




## FIGURE 7–7 THE NUCLEUS

**The nucleus controls most cell processes and contains the hereditary information of DNA.** The DNA combines with protein to form chromatin, which is found throughout the nucleus. The small, dense region in the nucleus is the nucleolus.



# 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.** The structure of the nucleus is shown in **Figure 7–7.**

The nucleus 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 main office, a steady stream of proteins, RNA, and other molecules move through the nuclear pores to and from the rest of the cell.

The granular material you can see in the nucleus is called **chromatin.** Chromatin consists of DNA bound to protein. Most of the time, chromatin is spread throughout the nucleus. When a cell divides, however, chromatin condenses to form **chromosomes** (KROH-muh-sohms). These distinct, threadlike structures contain the genetic information that is passed from one generation of cells to the next. 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.

CHECKPOINT *What kind of information is contained in chromosomes?*

# Appendix D Use of the Microscope

## The Compound Microscope

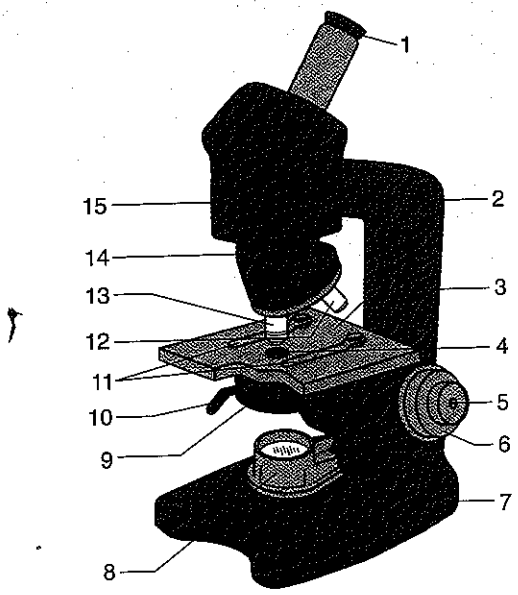
The microscope used in most biology classes, the compound microscope, contains a combination of lenses. The eyepiece lens is located in the top portion of the microscope. This lens usually has a magnification of 10×. Other lenses, called objective lenses, are at the bottom of the body tube on the revolving nosepiece. By rotating the nosepiece, you can select the objective through which you will view your specimen.

The shortest objective is a low-power magnifier, usually 10×. The longer ones are of high power, usually up to 40× or 43×. The magnification is marked on the objective. To determine the total magnification, multiply the magnifying power of the eyepiece by the magnifying power of the objective. For example, with a 10× eyepiece and a 40× objective, the total magnification is 10 × 40 = 400×.

Learning the name, function, and location of each of the microscope's parts is necessary for proper use. Use the following procedures when working with the microscope.

1. Carry the microscope by placing one hand beneath the base and grasping the arm of the microscope with the other hand.
2. Gently place the microscope on the lab table with the arm facing you. The microscope's base should be resting evenly on the table, approximately 10 cm from the table's edge.
3. Raise the body tube by turning the coarse adjustment knob until the objective lens is about 2 cm above the opening of the stage.
4. Rotate the nosepiece so that the low-power objective (10×) is directly in line with the body tube. A click indicates that the lens is in line with the opening of the stage.
5. Look through the eyepiece and switch on the lamp or adjust the mirror so that a circle of light can be seen. This is the field of view. Moving the lever of the diaphragm permits a greater or smaller amount of light to come through the opening of the stage.
6. Place a prepared slide on the stage so that the specimen is over the center of the opening. Use the stage clips to hold the slide in place.
7. Look at the microscope from the side. Carefully turn the coarse adjustment knob to lower the body tube until the low-power objective almost touches the slide or until the body tube can no longer be moved. Do not allow the objective to touch the slide.

## Parts of the Microscope and Their Function

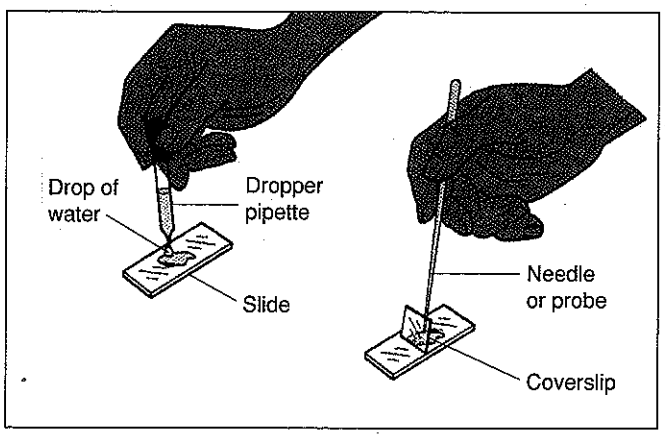



1. **Eyepiece** Contains a magnifying lens
2. **Arm** Supports the body tube
3. **Stage** Supports the slide being observed
4. **Opening of the stage** Permits light to pass up to the eyepiece
5. **Fine adjustment knob** Moves the body tube slightly to sharpen the image
6. **Coarse adjustment knob** Moves the body tube to focus the image
7. **Base** Supports the microscope
8. **Illuminator** Produces light or reflects light up toward the eyepiece
9. **Diaphragm** Regulates the amount of light passing up toward the eyepiece
10. **Diaphragm lever** Opens and closes the diaphragm
11. **Stage clips** Hold the slide in place
12. **Low-power objective** Provides a magnification of 10× and is the shortest objective
13. **High-power objective** Provides a magnification of 40× and is the longest objective
14. **Nosepiece** Holds the objectives and can be rotated to change the magnification
15. **Body tube** Maintains the proper distance between the eyepiece and the objectives

8. Look through the eyepiece and observe the specimen. If the field of view is out of focus, use the coarse adjustment knob to raise the body tube while looking through the eyepiece. **CAUTION:** *To prevent damage to the slide and the objective, do not lower the body tube using the coarse adjustment while looking through the eyepiece.* Focus the image as best you can with the coarse adjustment knob. Then use the fine adjustment knob to focus the image more sharply. Keep both eyes open when viewing a specimen. This helps prevent eyestrain.
9. Adjust the lever of the diaphragm to allow the right amount of light to enter.
10. To change the magnification, rotate the nosepiece until the desired objective is in line with the body tube and clicks into place.
11. Look through the eyepiece and use the fine adjustment knob to bring the image into focus.
12. After every use, remove the slide. Return the low-power objective into place in line with the body tube. Clean the stage of the microscope and the lenses with lens paper. Do not use other types of paper to clean the lenses; they may scratch the lenses.

## Preparing a Wet-Mount Slide

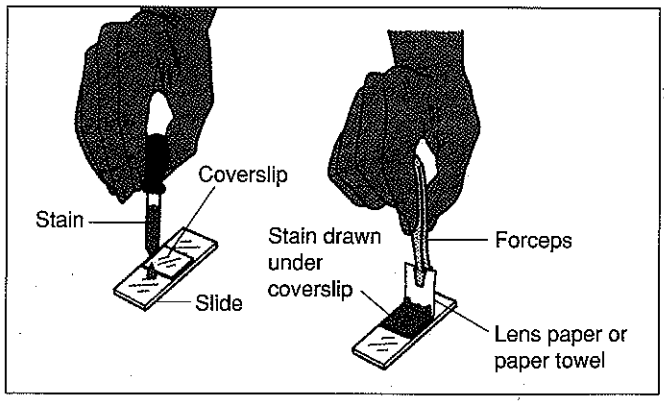
1. Obtain a clean microscope slide and a coverslip. A coverslip is very thin, permitting the objective lens to be lowered very close to the specimen.
2. Place the specimen in the middle of the microscope slide. The specimen must be thin enough for light to pass through it.




3. Using a dropper pipette, place a drop of water on the specimen.
4. Lower one edge of the coverslip so that it touches the side of the drop of water at about a 45° angle. The water will spread evenly along the edge of the coverslip. Using a dissecting needle or probe, slowly lower the coverslip over the specimen and water as shown in the drawing. Try not to trap any air bubbles under the coverslip. If air bubbles are present, gently tap the surface of the coverslip over the air bubble with a pencil eraser.
5. Remove any excess water at the edge of the coverslip with a paper towel. If the specimen begins to dry out, add a drop of water at the edge of the coverslip.

## Staining Techniques

1. Obtain a clean microscope slide and coverslip.
2. Place the specimen in the middle of the microscope slide.
3. Using a dropper pipette, place a drop of water on the specimen. Place the coverslip so that its edge touches the drop of water at a 45° angle. After the water spreads along the edge of the coverslip, use a dissecting needle or probe to lower the coverslip over the specimen.




4. Add a drop of stain at the edge of the coverslip. Using forceps, touch a small piece of lens paper or paper towel to the opposite edge of the coverslip, as shown in the drawing. The paper causes the stain to be drawn under the coverslip and to stain the cells in the specimen.