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Phloem of Douglas fir (Pseudotsuga menziesii), ×500. (Polarized light photomicrograph by G. S. Ellmore.)

Cells
All living organisms, from alfalfa and aardvarks to zinnias and zebras, are composed of cells, and all living organisms, including each of us, also generally begin life as a single cell. This single cell divides repeatedly until it develops into an organism often consisting of billions of cells. During the first few hours of any organism’s development, the cells all look alike, but changes soon take place, not only in the appearance of the cells but also in their function. Some modifications, for example, equip cells to transport food and water, while other cells become modified for secretion of various fluids such as resin or nectar, and still others give strength to tissues such as wood. Some cells may live and function for many years; others mature and degenerate in just a few days. Even as you read this, millions of new cells are being produced in your body. Some cells add to your total body mass (if you have not yet stopped growing), but most replace the millions of older cells that are destroyed every second you remain alive. The variety and form of cells seem almost infinite, but certain features are shared by most of them. A discussion of these features forms the body of this chapter.

Overview

This chapter gives a brief review of the history of the discovery of cells and the development of the cell theory. Differences between prokaryotic and eukaryotic cells are mentioned, and observations on cell size and structure follow. Each of a cell’s particulates are discussed, beginning with the cell wall. Included are the nucleus, cytoskeleton, plasma membrane, endoplasmic reticulum, ribosomes, dictyosomes, mitochondria, plastids, other organelles, vacuoles, and vacuolar membranes. Distinctions between plant and animal cells are then given. The chapter next discusses mitosis and cytokinesis and concludes with a brief review of intercellular communication.

Some Learning Goals

1. Trace the development of modern cell theory and show how the advances of early researchers have led us to our current understanding.
2. Know the following cell structures and organelles and indicate the function of each: plasma membrane, nucleus, mitochondria, plastids, ribosomes, endoplasmic reticulum, dictyosomes, vacuoles.
3. Describe the components of a nucleus and understand the function of each component.
4. Contrast plant cells with animal cells.
5. Understand the cell cycle and the events that take place in each phase of mitosis.

Cells

History

The discovery of cells is associated with the development of the microscope in the 17th century. In 1665, the English physicist Robert Hooke, using a primitive microscope (Fig. 3.1), examined thin slices of cork he had cut with a sharp penknife. Hooke compared the boxlike compartments he saw to the surface of a honeycomb and is credited with applying the term cell to those compartments. He also estimated that a cubic inch of cork would contain approximately 1,259 million such cells. What Hooke saw in the cork were really only the walls of dead cells, but he also saw “juices” in living cells of elderberry plants and thought he had found something similar to the veins and arteries of animals.

Two physicians, Marcello Malpighi in Italy and Hooke’s compatriot Nehemiah Grew in England, along with Anton van Leeuwenhoek, reported for 50 years on the organization of cells in a variety of plant tissues. In the 1670s, they also reported on the form and structure of single-celled organisms, which they referred to as “animalcules.”

After this period, little more was reported on cells until the early 1800s. This lack of progress was due in large part to the imperfections of the primitive microscopes and also to the...
crude methods of tissue preparation used. However, both microscopes and tissue preparations slowly improved, and by 1809, the famous French biologist Jean Baptiste de Lamarck had seen a wide enough variety of cells and tissues to conclude that “no body can have life if its constituent parts are not cellular tissue or are not formed by cellular tissue.” In 1824, Rene J. H. Dutrochet, also of France, reinforced Lamarck’s conclusions that all animal and plant tissues are composed of cells of various kinds. Neither of them, however, realized that each cell could, in many cases, reproduce itself and exist independently.

In 1831, the English botanist Robert Brown discovered that all cells contain a relatively large body that he called the nucleus. Soon after the discovery of the nucleus, the German botanist Matthias Schleiden observed a smaller body within the nucleus that he called the nucleolus. Schleiden and a German zoologist, Theodor Schwann, were not the first to understand the significance of cells, but they explained them more clearly and with greater insight than others before them had done. They are generally credited with developing the cell theory, beginning with their publications of 1838 to 1839. This theory, in essence, holds that all living organisms are composed of cells and that cells form a unifying structural basis of organization.

In 1858, another German scientist, Rudolf Virchow, argued persuasively in a classic textbook that every cell comes from a preexisting cell (“omnis cellula e cellula”) and that there is no spontaneous generation of cells. Virchow’s publication stirred up a great controversy, because there had previously been a widespread belief among scientists and nonscientists alike that animals could originate spontaneously from dust. Many who had microscopes were thoroughly convinced they could see “animalcules” appearing in decomposing substances.

The controversy became so heated that in 1860, the Paris Academy of Sciences offered a prize to anyone who could experimentally either prove or disprove spontaneous generation. Just two years later, the brilliant scientist Louis Pasteur of France was awarded the prize. Pasteur, using swan-necked flasks, demonstrated convincingly that boiled media remained sterile indefinitely if microorganisms from the air were excluded from the media.

In 1871, Pasteur proved that natural alcoholic fermentation always involves the activity of yeast cells. In 1897, the German scientist Eduard Buchner accidentally discovered that the yeast cells did not need to be alive for fermentation to occur. He found that extracts from the yeast cells would convert sugar to alcohol. This discovery was a big surprise to the biologists of the time and quickly led to the identification and description of enzymes (discussed in Chapter 2), the organic catalysts (substances that aid chemical reactions without themselves being changed) found in all living cells; it also led to the belief that cells were little more than miniature packets of enzymes. During the first half of the 20th century, however, great advances were made in the refinement of microscopes and in tissue preparation techniques. Many structures and bodies, besides the nucleus, were observed in cells, and the relationship between structure and function came to be realized and understood on a much broader scale than previously had been possible.

**Modern Microscopes**

Without microscopes, very little would be known about cells. Our present vast knowledge of cells and all aspects of biological investigations associated with them is directly related to the development of these instruments.

Light microscopes increase magnification as light passes through a series of transparent lenses, presently made of various types of glass or calcium fluoride crystals. The curvatures of the lens materials and their composition are designed to minimize distortion of image shapes and colors.

Light microscopes are of two basic types: compound microscopes, which require the material being examined to be sliced thinly enough for light to pass through, and dissecting microscopes (stereomicroscopes), which allow three-dimensional viewing of opaque objects. The best compound microscopes in use today can produce useful magnifications of up to 1,500 times under ideal conditions. Many dissecting microscopes used in teaching laboratories magnify up to 30 times, but higher magnifications are possible with both types of microscopes. Magnifications of more than 1,500 times, however, are considered “empty” because resolution (the capacity of lenses to aid in separating closely adjacent tiny objects) does not improve with magnification beyond a certain point. Light microscopes will continue to be useful, particularly for observing living cells, into the foreseeable future (Fig. 3.2).

Since the 1950s, the development of high-resolution electron microscopes has resulted in observation of much greater detail than is possible with light microscopes. Instead of light, electron microscopes use a beam of electrons produced when high-voltage electricity is passed through a wire. This electron beam is directed through a vacuum in a large tube or column. When the beam passes through a specimen, an image is formed on a plate. Magnification is controlled by powerful electromagnetic lenses located on the column.

Like light microscopes, electron microscopes are of two basic types. Transmission electron microscopes (Fig. 3.3 A) can produce magnifications of 200,000 or more times, but the material to be viewed must be sliced extremely thin and introduced into the column’s vacuum, so that living objects can’t be observed.

Scanning electron microscopes (Fig. 3.3 B) usually do not attain such high magnifications (3,000 to 10,000 times...
is the usual range), but thick objects can be observed when a scanner makes the object visible on a cathode tube like a television screen. The techniques for observation with electron microscopes have become so refined that even preserved material can appear exceptionally lifelike, and high-resolution three-dimensional images can be obtained.

In 1986, the Nobel Prize in physics was awarded to two IBM scientists, Gerd Binnig and Heinrich Rohrer, for their invention in 1982 of a scanning tunneling microscope. This microscope uses a minute probe instead of electrons or light to scan across a surface, and then without doing any damage to the probed area, it reproduces an image of such high magnification that even atoms can become discernible. The probe can scan areas barely twice the width of an atom and theoretically could be used to print on the head of an ordinary pin the words contained in more than 50,000 single-spaced pages of books.

Early in 1989, the first picture of a segment of DNA showing its helical structure was taken with a scanning tunneling microscope by an undergraduate student associated with the Lawrence Laboratories in northern California. Several variations of this microscope, each using a slightly different type of probe, have now been produced. Significant new discoveries by cell biologists using one or more of all three types of microscopes in their research have become frequent events.

**EUKARYOTIC VERSUS PROKARYOTIC CELLS**

Nearly all higher plant and animal cells share most of the various features that are discussed in the sections that follow. The cells of some very primitive organisms, such as bacteria, however, don’t have a number of these features (e.g., nuclei, plastids). Such cells are called prokaryotic to distinguish them from the typical eukaryotic cells discussed here. Prokaryotic cells are covered in more detail in Chapter 17.

**CELL SIZE AND STRUCTURE**

The living part of a cell, which in plants is surrounded by a nonliving wall, consists of a souplike fluid called cytosol and various bodies called organelles distributed throughout it. The combination of organelles and cytosol, which contains dissolved substances such as salts, is referred to as
**cytoplasm.** Organelles are persistent structures of various shapes and sizes with specialized functions in the cell; most, but not all, are bounded by membranes. The organelles are the sites of many different activities that take place within the cell, with the most conspicuous organelle, the nucleus, controlling those activities. A brief examination of each of the various cell components follows (Figs. 3.4 and 3.5).

**Cell Size**

Most plant and animal cells are so tiny they are invisible to the unaided eye. Cells of higher plants generally vary in length between 10 and 100 micrometers. Since there are roughly 25,000 micrometers to the inch, it would take about 500 average-sized cells to extend across 2.54 centimeters (1 inch) of space; 30 of them could easily be placed across the head of a pin. Some prokaryotic (bacterial) cells are less than one-half micrometer wide, while cells of the green alga mermaid’s wineglass (*Acetabularia*) are mostly between 2 and 5 centimeters long, and fiber cells of some nettles are about 20 centimeters long.

Why are cells so small, and why aren’t they larger? Consider that as a cell increases in size, its volume grows much more than its surface area. The increase in volume of a spherical cell, for example, is equal to the cube of the increase in diameter, while the increase in surface area is equal to the square of the increase in diameter. This means that a cell whose diameter increases 10 times would increase in volume 1,000 times (10 cubed) but in surface area only 100 times (10 squared). Since all substances entering or leaving cells do so through the surface and the surfaces are the cells’ only contact with their surroundings, larger cells are at a distinct disadvantage. Furthermore, since the nucleus regulates all aspects of a cell’s activities, the greater the volume of the cell, the longer it takes for instructions to reach the surface.

Because cells are so minute, full-grown organisms have astronomical numbers of them. For example, it has been calculated that a single mature leaf of a pear tree contains 50 million cells and that the total number of cells in the roots, stem, branches, leaves, and fruit of a full-grown pear tree exceeds 15 trillion. Can you imagine how many cells there are in a 3,000-year-old redwood tree of California, which may reach heights of 90 meters (300 feet) and measure up to 4.5 meters (15 feet) in diameter near the base?

Some cells are boxlike with six walls, but others assume a wide variety of shapes, depending on their location and function. The most abundant cells in the younger parts of plants and fruits may be more or less spherical, like bubbles, when they are first formed, but as they press against each other, they commonly end up with an average of 14 sides by the time they are mature. These cell types are discussed in the next chapter.

**The Cell Wall**

A novelty song of several verses that was popular more than 50 years ago listed food items the writer said he disliked. Each verse ended, however, with the line, “But I like bananas because they have no bones!” Indeed, bananas and all plant parts differ from animals in having no bones or similar internal skeletal structures. Yet large trees support branches and leaves weighing many tons. They are able to do this because most plant cells have semirigid or rigid walls that perform the functions of bones; that is, they provide

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1. See Appendix 5 for metric conversion tables.
FIGURE 3.4  A cross section of a root cap cell of tobacco. V = vacuole; N = nucleus; A = amyloplast; G = dictyosomes; M = mitochondria; ER = endoplasmic reticulum; CW = cell wall. The cell wall has a thickness of about 0.1–0.4 micrometer; the nucleus is 3 micrometers in diameter, and the cell itself is about 8 micrometers long.

(Transmission electron micrograph courtesy John Z. Kiss)
strength and support for the plants (and also protect the delicate cell contents within). When millions of these cells function together as a tissue, their collective strength is enormous. The largest trees alive today, the redwoods, exceed the mass, or volume, of the largest land animals, the elephants, by more than a hundred times. The wood of one tree could support the combined weight of a thousand elephants.

The principal structural component of cell walls is cellulose, the most abundant polymer on earth. Cellulose polymers are made up of 100 to 15,000 glucose monomers attached end to end in long chains. Other cell wall components include the polysaccharide pectin (the complex organic material that gives stiffness to fruit jellies); another polysaccharide known as hemicellulose (a gluelike substance unrelated to cellulose that holds cellulose fibrils together); and glycoproteins (proteins that have sugars associated with their molecules). The long cellulose molecules are grouped together in bundles known as microfibrils, which, in turn, are held together by pectin and related substances and make up the bulk of the cell wall.

A middle lamella, which consists of a layer of pectin, is first produced when new cell walls are formed. This middle lamella is normally shared by two adjacent cells and is so thin that it may not be visible with an ordinary light microscope unless it is specially stained. A flexible primary wall, consisting of a fine network of cellulose, hemicellulose, pectin, and glycoproteins, is laid down on either side of

FIGURE 3.5  A. A leaf cell diagrammed with the aid of a light microscope. B. The same cell greatly enlarged to show submicroscopic features. The nucleus of the enlarged cell would be about 10 micrometers in diameter and the cell itself would be about 60 micrometers long.
the middle lamella (Fig. 3.6). Sometimes the cellulose is deposited in two stages, forming first the primary cell wall and then a secondary cell wall inside the primary wall. When this happens, the secondary cell wall is usually the more extensive of the two structures. Depending on the type of cell involved, the wall may become impregnated with other substances, such as sugars and lignin (a complex organic substance that adds mechanical strength to cell walls).

The thickness of the wall can also vary, occupying as little as 5% to more than 95% of the volume of the cells. Cells that store or manufacture food have thin walls, while those involved in support usually have relatively thick walls. Fluids and dissolved substances usually can pass rapidly from cell to cell via plasmodesmata (singular: plasmodesma), which are tiny strands of cytoplasm that extend between adjacent cells through minute holes in the walls. The middle lamellae and most cell walls are, however, permeable and permit slower movement of water and dissolved substances between cells.

**Cytoplasm**

**The Nucleus**

The nucleus is the control center of the cell. In some ways it functions like a combination of a DNA-programmed computer and a dispatcher. The rest of the cell receives coded messages, or “blueprints,” from the nucleus and assembles items called for from the raw materials available to it. These raw materials are either absorbed by the plant from the soil or recycled from other areas. The nucleus not only directs the myriad activities of the complex cell “factory” but also stores hereditary information, which is passed from cell to cell as new cells are formed.

The nucleus is often the most conspicuous organelle in a living cell, although in green cells, chloroplasts may obscure it. In living cells without chloroplasts, the nucleus may appear as a grayish, spherical to ellipsoidal lump, sometimes lying against the plasma membrane to one side of the cell, or toward a corner. Some nuclei are irregular in form and, like most other organelles, they can vary greatly in size. They are, however, generally from 2 to 15 micrometers or larger in diameter. Certain fungi and algae have numerous nuclei within a single extensively branched cell, but the cells of more complex plants usually have a single nucleus located within the cytoplasm.

Each nucleus is bounded by two membranes, which together constitute the nuclear envelope. The nuclear envelope, which originates from the endoplasmic reticulum after a nucleus divides, appears to be a specialized part of the endoplasmic reticulum and is continuous with it. Structurally complex pores, about 50 to 75 nanometers apart, occupy up to one-third of the total surface area of the nuclear envelope (Fig. 3.7). Proteins, which act as channels for molecules, are embedded within the pores, which...
apparently permit only certain kinds of molecules (for example, proteins being carried into the nucleus and RNA being carried out) to pass between the nucleus and the cytosol.

The nucleus contains a granular-appearing fluid called chromatin. When a nucleus divides, the chromatin strands coil, becoming shorter and thicker, and in their condensed condition, they are called chromosomes. Chromatin is composed of protein and DNA (discussed in Chapters 2 and 13). Ribosomal RNA is exported outside the nucleus where, with proteins, it forms ribosomes.

Other important nuclear structures, which are not apparent with light microscopy unless the cell is stained or fixed, include thin strands of chromatin. When a nucleus divides, the chromatin strands coil, becoming shorter and thicker, and in their condensed condition, they are called chromosomes. Chromatin is composed of protein and DNA (discussed in Chapters 2 and 13). Each cell of a given plant or animal species has its own fixed number and composition of chromosomes; the cells involved in sexual reproduction have half the number found in other cells of the same organism. The number of chromosomes present in a nucleus normally bears no relation to the size and complexity of the organism. Each body cell of a radish, for example, has 18 chromosomes in its nucleus, while a cell of one species of goldenweed has 4, and a cell of a tropical adder's tongue fern has over 1,000. Humans have 46 chromosomes in each body cell.

Plastids

Most living plant cells have several kinds of plastids, with the chloroplasts (Fig. 3.8A) of green organisms usually being the most conspicuous. They occur in a variety of shapes and sizes, such as the beautiful corkscrewlike ribbons found in cells of the green alga Spirogyra (see Fig. 18.6), and the bracelet-shaped chloroplasts of other green algae, such as Ulothrix (see Figs. 18.2D and 18.5). The chloroplasts of higher plants, however, tend to be shaped somewhat like two frisbees glued together along their edges, and when they are sliced in median section, they resemble the outline of a football.

Although several algae and a few other plants have only one or two chloroplasts per cell, the number of chloroplasts is usually much greater in a green cell of higher plants. Seventy-five to 125 is quite common, with the green cells of a few plants having up to several hundred. The chloroplasts may be from 2 to 10 micrometers in diameter, and each is bounded by an envelope consisting of two delicate membranes. The outer membrane apparently is derived from endoplasmic reticulum, while the inner membrane is believed to have originated from the cell membrane of a cyanobacterium (discussed in Chapter 17). Within is a colorless fluid matrix, the stroma, which contains enzymes. Most of the activities of chloroplasts are dictated by genes in the nucleus, but each chloroplast contains a small circular molecule of DNA that encodes a few of the many photosynthetic and other activities within the chloroplast itself.

Grana (singular: granum) have the appearance of independent stacks of double-membraned coins within each chloroplast. There are usually about 40 to 60 grana linked together by arms in each chloroplast, and each granum may contain from 2 or 3 to more than 100 stacked thylakoids. In reality, thylakoids are part of an overlapping and continuous membrane system suspended in the stroma (Fig. 3.8B, C). The thylakoid membranes contain green chlorophyll and other pigments. These “coin stacks” of grana are vital to life as we know it, for it is within the thylakoids that the first steps of the important process of photosynthesis (see Chapter 10) occurs. In photosynthesis, green plants convert water and carbon dioxide (from the air) to simple food substances, harnessing energy from the sun in the process. The existence of human and all other animal life depends on the activities of the chloroplasts.

There are usually four or five starch grains in the stroma, as well as oil droplets and enzymes. Some plastids (e.g., those of tobacco) store proteins. The stroma, like the matrix fluid in mitochondria, contains ribosomes in addition to the DNA molecule.

Chromoplasts are a second type of plastid found in some cells of more complex plants. Although chromoplasts are similar to chloroplasts in size, they vary considerably in shape, often being somewhat angular. They sometimes develop from chloroplasts through internal changes, including the disappearance of chlorophyll. Chromoplasts are yellow, orange, or red in color due to the presence of carotenoid pigments, which they synthesize and accumulate. They are most abundant in the yellow, orange, or some red parts of plants, such as ripe tomatoes, carrots, or red peppers (Fig. 3.9). These carotenoid pigments, which are lipid soluble, are not, however, the predominant pigments in most red flower petals. The anthocyanin pigments of most red flower petals are water soluble.

Leucoplasts are a third type of plastid common to cells of higher plants. They are essentially colorless and include amyloplasts, which are known to synthesize starches, and elaioplasts, which synthesize oils. If exposed to light, some leucoplasts will develop into chloroplasts, and vice versa.

Plastids of all types develop from proplastids, which are small, pale green or colorless organelles having roughly the size and form of mitochondria. They are simpler in internal structure than plastids and have fewer thylakoids, the thylakoids not being arranged in grana stacks. Proplastids frequently divide and become distributed throughout the cell; after a cell itself divides, each daughter cell has a proportionate share. Plastids also arise through the division of existing mature plastids.
The Cytoskeleton

The **cytoskeleton**, which is involved in movement within a cell and in a cell’s architecture, is an intricate network constructed mainly of two kinds of fibers—**microtubules** and **microfilaments**.

**Microtubules** apparently control the addition of cellulose to the cell wall (Fig. 3.10). Other functions of microtubules include the steering to the cell wall of vesicles containing cell wall components synthesized by dictyosomes and aiding movement of the tiny whiplike **flagella** and **cilia** possessed by some cells (see section on plant movements in Chapter 11).

Microtubules are unbranched, thin, hollow, tubelike structures that resemble tiny straws. They are composed of proteins called **tubulins** and are of varying lengths, most being between 15 and 25 nanometers in diameter. They are most commonly found just inside the plasma membrane. Microtubules are also found in the special fibers that form the **spindles** and **phragmoplats** of dividing cells discussed later in this chapter.

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**FIGURE 3.8**  A. A chloroplast ×10,000. G = granum; T = thylakoid; L = lipid bodies. B. Grana ×40,000. C. Thylakoids. Each thylakoid is about 25 nanometers wide.

(A. Electron micrograph courtesy John Z. Kiss; B. Electron micrograph courtesy Blake Rowe)
Nearly all cells have microfilaments, which play a major role in the contraction and movement of cells in multicellular animals. They are three or four times thinner than microtubules and consist of long, fine threads of protein with an average diameter of 6 nanometers. They are often in bundles and appear to play a role in cytoplasmic streaming (sometimes referred to as cyclosis), which occurs in all living cells. Microscopic examination of such cells reveals that the organelles appear to be moving, as a current within the cytosol carries them around within the walls. This streaming probably facilitates exchanges of materials within the cell and plays a role in the movement of substances from cell to cell. The precise nature and origin of cytoplasmic streaming is still not known, but there is evidence that bundles of microfilaments may be responsible for it. Other evidence suggests that it may be related to the transport of cellular substances by microtubules.

The Plasma Membrane
The outer boundary of the living part of the cell, the plasma membrane, is roughly eight-millionths of a millimeter thick. To get an idea of how incredibly thin that is, consider that it would take 12,500 such membranes neatly stacked in a pile to achieve the thickness of an ordinary piece of writing paper. Yet this delicate, semipermeable structure is of vital importance in regulating the movement of substances into and out of the cell. Some substances are prevented from entering or leaving the cell, the passage of other substances is controlled, and some substances migrate freely through the plasma membrane. As a result, the proportions and makeup of chemicals within a cell are quite different from those outside the cell. The plasma membrane is also involved in the production and assembly of cellulose for cell walls.

Evidence obtained since the early 1970s indicates that the plasma membrane and other cell membranes are mosaics composed of lipids arranged in two layers, with proteins interspersed throughout (Fig. 3.11). Covalent bonds link carbohydrates to both the lipids and the proteins on the outer surfaces of the membranes. Some proteins extend across the entire width of the membrane, while others are embedded or apparently are loosely bound to the outer surface.

The remainder of the cell contents usually push the plasma membrane up against the cell wall because of pressures developed by osmosis (see Chapter 9), but the membrane is quite flexible and often forms folds, which may in turn become little hollow spheres or vesicles that float off into the cell. In fact, experiments have shown that by adding detergents to a unit membrane, it can be broken up and dispersed, yet it can partially reform when the detergents are

**FIGURE 3.9** Chromoplasts in the flesh of a red pepper, ×100.

**FIGURE 3.10** A small portion of a plant cell wall with microtubules more or less perpendicular to it, ×100,000.
(Electron micrograph courtesy John Z. Kiss)
removed. The membrane may even shrink away from the wall temporarily, but if it ever ruptures, the cell soon dies.

**The Endoplasmic Reticulum**

The outer membrane of the nucleus is connected to and continuous with the endoplasmic reticulum, which is also connected to the plasma membrane. Many important activities, such as the synthesis of membranes for other organelles and the synthesis of proteins from components assembled from elsewhere within the cell, occur either on the surface of the endoplasmic reticulum or within its compartments.

The endoplasmic reticulum (often referred to simply as ER) is an enclosed space consisting of a network of flattened sacs and tubes that form channels throughout the cytosol, the amount and form varying considerably from cell to cell. In section, it looks like a series of parallel membranes that resemble long, narrow tubes or sacs, creating subcompartments within the cell.

Ribosomes (discussed in the section that follows) may line the outer surfaces of the endoplasmic reticulum. Such endoplasmic reticulum is said to be rough and is primarily associated with the synthesis, secretion, or storage of proteins (Fig. 3.12; see also Chapter 13). This contrasts with smooth endoplasmic reticulum, which has few, if any, ribosomes lining the surface, and is associated with lipid secretion. Both types of endoplasmic reticulum can occur in the same cell, and can be interconverted depending on the demands of the cell. Many enzymes involved in the process of respiration are synthesized on the surface of the endoplasmic reticulum. However, they enter other organelles (primarily mitochondria) without passing through the endoplasmic reticulum. The endoplasmic reticulum also appears to be the primary site of membrane synthesis within the cell.
Ribosomes

Ribosomes are tiny bodies that, under instructions from DNA in the nucleus, assemble proteins. They may line the endoplasmic reticulum, but they may also occur unattached in the cytosol, nucleus, chloroplasts, or other organelles. They average only about 20 nanometers in diameter in most plant cells. The unattached ribosomes often occur in clusters of 5 to 100, particularly when they are involved in linking amino acids together in the construction of the large, complex protein molecules that are a basic part of all living organisms.

Ribosomes are roughly ellipsoidal in shape although recent evidence suggests their surfaces are varied and complex. Each ribosome is composed of two subunits, which in turn are made up of RNA and proteins. About 55 kinds of protein are found in each ribosome of prokaryotic cells and a slightly higher number in those of eukaryotic cells (see the discussion of various types of RNA in Chapter 13). Unlike other organelles, ribosomes have no bounding membranes, and because of this, some scientists prefer not to call them organelles.

Dictyosomes

Cells may contain from several to hundreds of groups of roundish sacs, which appear flattened, scattered throughout the cytosol. These sacs, which in plant cells are known as dictyosomes (Golgi bodies in animal cells), are often bounded by branching tubules that originate from the endoplasmic reticulum but are not directly connected to it (Fig. 3.13). The dictyosomes are often organized into stacks of 5 to 8, but up to 30 or more are common in simpler organisms.

Dictyosomes are involved in the modification of carbohydrates attached to proteins, which are synthesized in the endoplasmic reticulum. Complex polysaccharides are also assembled within the dictyosomes and collect in small vesicles (tiny blisterlike bodies) that are pinched off from the margins. These vesicles migrate to the plasma membrane or other parts of the cell. There they discharge their contents to the outside, where they become a part of the cell wall. Proteins are also packaged within dictyosomes. The enzymes needed for the packaging process are produced in the endoplasmic reticulum and further modified within the dictyosomes. One might describe dictyosomes as collecting, packaging, and delivery centers.

Mitochondria

Mitochondria are often referred to as the powerhouses of the cell, for it is within them that energy is released from organic molecules by the process of respiration (the role of mitochondria in respiration is further discussed in Chapter 10). This energy is needed to keep the individual cells and the plant functioning as a whole. Carbon skeletons and fatty acid chains are also rearranged within mitochondria, allowing for the building of a wide variety of organic molecules. Mitochondria are numerous and tiny, typically measuring from 1 to 3 or more micrometers in length and having a width of roughly one-half micrometer; they are barely visible with light microscopes. They are in constant motion in living cells and tend to accumulate in groups where energy is needed. They often divide in two; in fact, they all originate from the division of existing mitochondria.

Mitochondria typically are shaped like gherkins, paddles, rods, or balls. A sectioned mitochondrion resembles a scooped-out watermelon with inward extensions of the rind forming mostly incomplete partitions perpendicular to the surface (Fig. 3.14). The appearance of incomplete partitions results from the fact that each mitochondrion is bounded by two membranes, with the inner membrane forming numerous platelike folds called cristae, which greatly increase the surface area available to the enzymes contained in a matrix fluid. The number of cristae, as well as the number of mitochondria themselves, can change over time, depending on the activities taking place within the cell. The matrix fluid also contains DNA, RNA, ribosomes, proteins, and dissolved substances.

Other Organelles

Various small bodies distributed throughout the cytoplasm tend to give it a granular appearance. Examples of such components include types of small, spherical organelles called microbodies, which contain enzymes and are bounded by a single membrane. One type of microbody contains enzymes involved in a phase of photosynthesis and photorespiration (discussed in Chapter 10); another contains enzymes that aid in the conversion of fats to carbohydrates. At one time, lipid, fat, or wax droplets, which are common...
in cytoplasm, were believed to be bounded by a membrane; recent evidence suggests no membrane is present, and some, therefore, do not consider them true organelles. One organelle, called a lysosome, stores enzymes that digest proteins and certain other large molecules but is apparently confined to animal cells. The digestive activities of lysosomes are similar to those of the vacuoles of plant cells.

**Vacuoles**

In a mature living plant cell, as much as 90% or more of the volume may be taken up by one or two large central vacuoles that are bounded by vacuolar membranes (tonoplasts) (Fig. 3.15). The vacuolar membranes, which constitute the inner boundaries of the living part of the cell, are similar in structure and function to plasma membranes.

**FIGURE 3.14** A mitochondrion greatly enlarged and cut away to show the cristae (folds of the inner membrane). A mitochondrion is about 2 micrometers long.

**FIGURE 3.15** A small portion of a root cap cell of tobacco ×100,000. V = vacuole; T = vacuolar membrane (tonoplast); G = dictyosome with vesicles (arrows); M = mitochondrion; ER = endoplasmic reticulum; PM = plasma membrane; CW = cell wall.
(Electron micrograph courtesy John Z. Kiss)
The vacuole evidently received its name because of a belief that it was just an empty space; hence its name has the same Latin root as the word vacuum (from vacuus—meaning “empty”). Vacuoles, however, are filled with a watery fluid called cell sap, which is slightly to significantly acidic. Cell sap, which helps to maintain pressures within the cell (see the discussion of osmosis in Chapter 9), contains dissolved substances, such as salts, sugars, organic acids, and small quantities of soluble proteins. It also frequently contains water-soluble pigments. These pigments, called anthocyanins, are responsible for many of the red, blue, or purple colors of flowers and some reddish leaves. In some instances, anthocyanins accumulate to a greater extent in response to cold temperatures in the fall. They should not be confused, however, with the red and orange carotenoid pigments confined to the chromoplasts. Yellow carotenoid pigments (carotenes) also play a role in fall leaf coloration (discussed in Chapter 7).

Sometimes, large crystals of waste products form within the cell sap after certain ions have become concentrated there. Vacuoles in newly formed cells are usually tiny and numerous. They increase in size and unite as the cell matures. In addition to accumulating the various substances and ions mentioned above, vacuoles are apparently also involved in the recycling of certain materials within the cell and even aid in the breakdown and digestion of organelles, such as mitochondria and plastids.

**CELLULAR REPRODUCTION**

**The Cell Cycle**

When cells divide, they go through an orderly series of events known as the cell cycle (Fig. 3.16). This cycle is usually divided into interphase and mitosis, mitosis itself being subdivided into four phases. The length of the cell cycle varies with the kind of organism involved, the type of cell within an organism, and with temperature and other environmental factors. In most instances, however, interphase may occupy up to 90% or more of the time it takes to complete the cycle.

**Interphase**

Living cells that are not dividing are said to be in interphase, a period during which chromosomes are not visible with light microscopes. It is such cells that have been discussed up to this point.

For many years, immature cells were considered to be “resting” when they were not actually dividing, but we know now that three consecutive periods of intense activity take place during interphase. These intervals are designated as gap (or growth) 1, synthesis, and gap (or growth) 2 periods, usually referred to as G1, S, and G2, respectively.

The G1 period, which is relatively lengthy, begins immediately after a nucleus has divided. During this period, the cell increases in size. Also, ribosomes, RNA, and substances that either inhibit or stimulate the S period that follows are produced. During the S period, the unique process of DNA replication (duplication) takes place. Details of this process and of DNA structure are discussed in Chapter 13. In the G2 period, mitochondria and other organelles divide, and microtubules and other substances directly involved in mitosis are produced. Coiling and condensation of chromosomes also begin during G2.

**Mitosis**

All organisms begin life as a single cell. This cell usually divides almost immediately, producing two new cells. These two cells, in turn, divide, with each of them producing two more cells. This process, called mitosis (see Fig. 3.17), ensures that two new cells (daughter cells) resulting from each cell undergoing mitosis have precisely equal amounts of DNA and certain other substances duplicated during interphase. Mitosis occurs in an organism until it dies. Strictly speaking, mitosis refers to the division of the nucleus alone, but with a few exceptions seen in algae and fungi (discussed in Chapters 18 and 19), the division of the remainder of the cell, called cytokinesis, normally accompanies or follows mitosis. Both processes will be considered together here.

In higher plants, such as conifers and flowering plants, mitosis occurs in specific regions, or tissues, called meristems (see Fig. 4.1). Meristems are found in the root and stem tips and also in a thin, perforated, and branching cylinder of tissue called the vascular cambium (often referred to simply as the cambium), located in the interior of some stems and roots a short distance from the surface. In some herbaceous
FIGURE 3.17 The phases of mitosis as seen in onion root-tip cells. These chromosomes are about 4 micrometers long. 
A. Cell (center) in prophase. B. Cell (center) in metaphase.

and most woody plants, a second meristem similar in form to the cambium lies between the cambium and the outer bark. This second meristem is called the cork cambium. These specific tissues are discussed in Chapters 4, 5, and 6.

When mitosis takes place, it makes no difference how many chromosomes are in the nucleus. The daughter cells that result from the process each have exactly the same number of chromosomes and DNA distribution as the parent cell. It is a continuous process, which may take as little as 5 minutes or as long as several hours from start to finish. Typically, however, it takes from 30 minutes to 2 or 3 hours. The process, which is initiated with the appearance of a ringlike preprophase band of microtubules just beneath the plasma membrane, is usually divided into four arbitrary phases, primarily for convenience. Descriptions of the phases follow.

**Prophase**
The main features of prophase (Fig. 3.17 A) are (1) the chromosomes become shorter and thicker, and their two-stranded nature becomes apparent; (2) the nuclear envelope fragments and the nucleolus disintegrates.

Prophase takes up about as much time as the remaining three phases combined. Before prophase begins, a preprophase band, formed from microtubules and microfilaments inside the plasma membrane, develops in a narrow bundle around the nucleus. The beginning of prophase is marked by the appearance of the chromosomes as faint threads in the nucleus. These chromosomes gradually coil or fold into thicker and shorter structures, and soon two strands, or chromatids, can be distinguished for each chromosome. The chromatids, which are identical to each other, are
themselves independently coiled. These coils appear to tighten and condense until the chromosomes have become relatively short, thick, and rodlike, with areas called centromeres holding each pair of chromatids together.

The centromere is located at a constriction on the chromosome (Fig. 3.18). A dense granule called a kinetochore, to which spindle fibers become attached, is located near each centromere. When examined with the aid of a light microscope, the centromeres appear to be single structures, but they actually have become double by the $G_2$ stage of interphase and simply function as a single unit at this point. They may be located almost anywhere on a chromosome but tend to be toward the middle. Sometimes, other constrictions may appear on individual chromosomes, usually toward one end, giving them the appearance of having extra knobs; these

![FIGURE 3.17 continued. C. Cell (center) in anaphase. D. Cell (center) in telophase.](image)

![FIGURE 3.18 Parts of a chromosome.](image)
Scientists use the scanning electron microscope (SEM) to study the details of many different types of surfaces. Unlike the light microscope or even a transmission electron microscope that form images by passing either a beam of light or electrons through a thin slice of fixed tissue, the SEM’s great advantage is its ability to look at surfaces of specimens and provide topographical detail not possible with other types of microscopy.

The basic concept of a scanning electron microscope is that a finely focused beam of electrons is scanned across the surface of the specimen. The high velocity electrons from the beam create an energetic interaction with the surface layers. These electron-specimen interactions generate particles that are emitted from the specimen and can be collected with a detector and sent to a TV screen (cathode ray tube). Particles that form the typical scanning electron image are called secondary electrons because they come from the electrons in the specimen itself. The more electrons a particular region emits, the brighter the image will be on the TV screen. The end result, therefore, is brightness associated with surface characteristics and an image that looks very much like a normally illuminated subject. SEM images typically contain a good deal of topographical detail because the electrons that are emitted and produced on the TV screen represent a one-for-one correspondence with the contours of the specimen.

All scanning electron images have one very distinctive characteristic because of this feature of electron emission and display—the images are three dimensional rather than the flat 2-dimensional images obtained from other types of microscopes. The images can be understood even by the lay person because the eye is accustomed to interpreting objects that are in three dimensions.

Take, for instance, a leaf surface, which looks smooth with an ordinary light microscope. But with a scanning electron microscope, the leaf surface is a rich composition of undulating cell walls, cells joined together like pieces of a jigsaw puzzle, squiggly ridges of waxes that look like frosting decorations on a cake, and lens-shaped stomatal pores (Box Figure 3.1A). The stomatal knobs are referred to as satellites. The constrictions at the base of the satellites have no known function, but the satellites themselves are useful in helping to distinguish certain chromosomes from others in a nucleus.

As prophase progresses, the nucleolus gradually becomes less distinct and eventually disintegrates. By the end of prophase, spindle fibers, which consist of microtubules, have developed and extend in arcs between two invisible poles located toward the ends of the cell. The tips of the spindle fibers become anchored at the poles. An additional spindle fiber appears to grow out from opposite sides of each centromere until the tips reach the poles. At the conclusion of prophase, the nuclear envelope has been reabsorbed into the endoplasmic reticulum and has totally fragmented.

In certain simpler organisms, such as fungi and algae, and in virtually all animal cells, the cytoplasm just outside the nucleolus contains dual pairs of tiny keg-shaped structures called centrioles. The centrioles are surrounded by microtubules, which radiate out from them and arrange cytoplasmic particles in the vicinity into starlike rays, collectively called an aster. At the beginning of prophase, the aster divides into two parts; one part remains at its original location, while the other part migrates around the nuclear envelope to the opposite side. Centrioles and asters have not been detected in the cells of most of the more complex members of the Plant Kingdom.

**Metaphase**

The main feature of metaphase (Fig. 3.17B) is the alignment of the chromosomes in a ring around the circumference of the cell. The ring is more or less perpendicular to the axis of the prophase band and spindle fibers, like the equator of a globe.
Cells

As indicated in our discussion of prophase, spindle fibers can be seen in the area previously occupied by the nucleus after the nuclear envelope has disassociated. They form a structure that looks like an old-fashioned spinning top made of fine threads. Collectively, the spindle fibers are referred to as the spindle. The chromosomes become aligned so that their centromeres are in a plane roughly in the center of the cell. This invisible circular plate, called the equator, is analogous to the equator of the earth. At the end of metaphase, the centromeres holding the two strands (sister chromatids) of each chromosome together split lengthwise.

**Anaphase**
The main feature of anaphase—the briefest of the phases—is that the sister chromatids of each chromosome separate and are pulled to opposite poles (Fig. 3.17C).

Until the end of metaphase, the sister chromatids of each chromosome have been united at their centromeres. Anaphase begins with all the sister chromatids separating in unison and moving toward the poles. The chromatids, which after separation at their centromeres are called daughter chromosomes, are pulled toward the poles as their spindle fibers gradually shorten. The shortening occurs as a result of material continuously being removed from the polar ends of the spindle fibers. If the centromere is in the center of the daughter chromosome, it leads the way, with the rest of the chromosome assuming a V shape as it appears to drag in the cytoplasm.

All of the chromosomes separate and move at the same time. Although experiments have shown that a chromosome will not migrate to a pole if the fiber attached to its centromere is severed, other experiments have shown that the chromosomes will separate from one another but not move to the poles, even if no spindle is present. The force

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As the beauty of nature becomes seen for the first time in startling detail, micrographs do indeed become "microscapes."
or forces involved in the latter phenomenon has not yet been identified.

**Telophase**
The five main features of telophase (Fig. 3.17D) are (1) each group of daughter chromosomes becomes surrounded by a reformed nuclear envelope; (2) the daughter chromosomes become longer and thinner and are finally indistinguishable; (3) nucleoli reappear; (4) many of the spindle fibers disintegrate; and (5) a cell plate forms.

The transition from anaphase to telophase is not distinct, but telophase is definitely in progress when elements of new nuclear envelopes appear around each group of daughter chromosomes at the poles. These elements gradually form intact envelopes as the daughter chromosomes return to the diffuse, indistinct threads seen at the onset of prophase. The new nucleoli appear on specific regions of certain chromosomes.

During telophase, the spindle microtubules gradually break down and a set of shorter fibers (fibrils), composed of microtubules, develops in the region of the equator between the daughter nuclei. This set of fibrils, which appears somewhat keg-shaped, is called a *phragmoplast*. Dictyosomes produce small vesicles containing raw materials for the cell wall and membranes. Some of these vesicles, which resemble tiny droplets of fluid when viewed with a light microscope, are directed toward the center of the spindle (equator) by the remaining spindle fibers.

The microtubules apparently trap the dictyosome-derived vesicles, which then fuse together into one large, flattened but hollow structure called a *cell plate* (Fig. 3.19). Carbohydrates in the vesicles are synthesized into two new primary cell walls and a *middle lamella*. The middle lamella is shared by what now have become two new *daughter cells*. The cell plate grows outward until it contacts and unites with the plasma membrane of the mother cell. *Plasmodesmata* (tiny strands of protoplasm that extend through the walls between cells—see Fig. 3.5) are apparently formed as portions of the endoplasmic reticulum are trapped between fusing vesicles of the cell plate.

New plasma membranes develop on either side of the cell plate as it forms, and new cell wall materials are deposited between the middle lamella and the plasma membranes. These new walls are relatively flexible and remain so until the cells increase to their mature size. At that time, additional cellulose and other substances may be added, forming a secondary cell wall interior to the primary wall. In some instances, cell plate formation does not accompany division of the nucleus.

**COMMUNICATION BETWEEN CELLS**

Although each living cell is capable of independently carrying on complex activities, it is essential that these activities be coordinated through some means of communication among all the living cells of an organism. Living plant cells are in contact with each other via the plasmodesmata. A plasmodesma extends through a minute hole in the walls of two adjacent cells. The hole is located within a pair of more or less circular depressions (one in each wall) where the adjacent secondary walls are very thin or nonexistent. These paired areas, where little more than the middle lamella and a small amount of primary wall separates abutting cells, are called *pits* (see Fig. 4.7). Although most pit pairs are relatively simple in structure, some, called *bordered pits*, have blisterlike, arched secondary wall “covers” over the thin areas, giving them the appearance of tiny doughnuts in surface view. The translocation of sugars, amino acids, ions, and other substances occurs through the plasmodesmata.

**HIGHER PLANT CELLS VERSUS ANIMAL CELLS**

All animals have either internal or external support for their tissues from a skeleton of some kind. Animal cells do not have cell walls; instead, the plasma membrane, called the *cell mem-
brane} by most zoologists (animal scientists), forms the outer boundary of animal cells. Higher plant cells have walls that are thickened and rigid to varying degrees, with a framework of cellulose fibrils. Higher plant cells also have plasmodesmata connecting the protoplasts with each other through microscopic holes in the walls. Animal cells lack plasmodesmata since they have no walls. When higher plant cells divide, a cell plate is formed during the telophase of mitosis, but cell plates do not form in animal cells, which divide by pinching in two.

Other differences pertain to the presence or absence of certain organelles. Centrioles, for example, the tiny paired keg-shaped structures found just outside the nucleus, occur in all animal cells but are generally absent from higher plant cells. Plastids, common in plant cells, are not found in animal cells. Vacuoles, which are often large in plant cells, are either small or absent in animal cells.

Visit the accompanying web site to this textbook at http://www.mhhe.com/botany/stern for hyperlinks to additional web sites with appropriate material supporting the content of this chapter.

Summary

1. All living organisms are composed of cells. Cells are modified according to the functions they perform; some live for a few days while others live for many years.

2. The discovery of cells is associated with the development of the microscope. Robert Hooke coined the word cells for boxlike compartments he saw in cork in 1665. Leeuwenhoek and Grew reported frequently during the next 50 years on the existence of cells in a variety of tissues.

3. In 1809, Lamarck concluded that all living tissue is composed of cells, and in 1824, Dutrochet reinforced Lamarck’s conclusions. In 1833, Brown discovered that all cells contain a nucleus, and shortly thereafter Schleiden saw a nucleolus within a nucleus. Schleiden and Schwann are credited with developing the cell theory in 1838 to 1839. The theory holds that all living organisms are composed of cells and that cells form a unifying structural basis of organization.

4. In 1858, Virchow contended that every cell comes from a preexisting cell and that there is no spontaneous generation of cells from dust. In 1862, Pasteur experimentally confirmed Virchow’s contentions and later proved that fermentation involves activity of yeast cells. In 1897, Buchner found that yeast cells do not need to be alive for fermentation to occur. This led to the discovery of enzymes.

5. Light microscopes can magnify up to 1,500 times. Thinly sliced materials can be viewed with compound microscopes. Opaque objects can be viewed with stereomicroscopes; most magnify up to 30 times.

6. Electron microscopes utilize electromagnetic lenses and a beam of electrons within a vacuum to achieve magnification. Transmission electron microscopes magnify up to 200,000 or more times. Scanning electron microscopes, which can be used with opaque objects, usually magnify up to 10,000 times.

7. Scanning tunneling microscopes use a minute probe to scan surfaces at a width as narrow as that of two atoms.

8. Eukaryotic cells are the subject of this chapter. Prokaryotic cells, which lack some of the features of eukaryotic cells, are discussed in Chapter 17.

9. Cells are minute, varying in diameter between 10 and 100 micrometers. They number into the billions in larger organisms, such as trees. Plant cells are bounded by walls. The living part of the cell within the walls—cytoplasm—consists of fluid cytosol and various organelles, the most important of which is the nucleus.

10. A pectic middle lamella is sandwiched between the primary cell walls of adjacent cells. The primary wall and also the secondary cell wall, often added inside the primary wall, are composed mostly of cellulose polymers, with hemicelluloses and glycoproteins. Secondary cell walls may also contain lignin and other substances.

11. The nucleus is bounded by a nuclear envelope consisting of two membranes that are perforated by numerous pores. Within the nucleus are a fluid called nucleoplasm, one or more spherical nucleoli, and thin strands of chromatin, which condense and become chromosomes when nuclei divide. Each species of organism has a specific number of chromosomes in each cell.

12. The cytoskeleton, which is involved in the architecture of cells and internal movement, is composed of microtubules and microfilaments. Microfilaments are associated with cytoplasmic streaming.

13. Plastids are larger green, orange or red, or colorless organelles. Chloroplasts contain enzymes, in a matrix called the stroma, and grana, which are stacks of coin-shaped membranes (thylakoids) containing green chlorophyll pigments; photosynthesis occurs in the thylakoids. Plastids develop from proplastids, which divide frequently, and also arise from the division of mature plastids.

14. A flexible plasma membrane, which is sandwichlike and often forms folds, constitutes the outer boundary of the cytoplasm. It regulates the substances that enter and leave the cell.

15. The endoplasmic reticulum is a system of flattened sacs and tubes associated with the storing and transporting of protein and other cell products. Granular particles called ribosomes, which function in protein synthesis, may line the outer surfaces of the endoplasmic reticulum. Ribosomes also occur independently in the cytosol.

16. Dictyosomes are structures that appear as stacks of sacs and function as collecting and packaging centers for the cell.
17. Mitochondria are tiny, numerous organelles that are bounded by two membranes with inner platelike folds called cristae; they are associated with respiration.

18. One or more vacuoles may occupy 90% or more of the volume of a mature cell. Vacuoles are bounded by a vacuolar membrane (tonoplast) and contain a watery fluid called cell sap. Cell sap contains dissolved substances and sometimes water-soluble red or blue anthocyanin pigments.

19. Cells that are not dividing are in interphase, which is subdivided into three periods of intense activity that precede mitosis or division of the nucleus. Mitosis is usually accompanied by division of the rest of the cell and takes place in meristems.

20. Mitosis is arbitrarily divided into four phases: (1) prophase, in which the chromosomes and their two-stranded nature become apparent and the nuclear envelope breaks down; (2) metaphase, in which the chromosomes become aligned at the equator of the cell; a spindle composed of spindle fibers is fully developed, with some spindle fibers being attached to the chromosomes at their centromeres; (3) anaphase, in which the sister chromatids of each chromosome (now called daughter chromosomes) separate lengthwise, with each group of daughter chromosomes migrating to opposite poles of the cell; and (4) telophase, in which each group of daughter chromosomes becomes surrounded by a nuclear envelope, thus becoming new nuclei, and a wall dividing the daughter nuclei forms, creating two daughter cells.

21. The development of the dividing wall is initiated by the appearance of a set of short fibrils constituting the phragmoplast. Droplets, or vesicles, of pectin merge, forming a cell plate that grows to become the middle lamella of the new cell wall.

22. Living cells are in contact with one another via fine strands of cytoplasm called plasmodesmata, which often extend through minute holes in paired wall depressions called pits.

23. Animal cells differ from those of higher plants in not having a wall, plastids, or large vacuoles. Also, they have keg-shaped centrioles in pairs just outside the nucleus and pinch in two instead of forming a cell plate when they divide.

Review Questions

1. How is cellular structure beneficial to plants and animals?
2. Of what importance to the plant cell is the wall?
3. What is the difference between cytosol and cytoplasm?
4. How can you distinguish between cytoplasm and vacuoles?
5. What is the function of a cell nucleus? How does it perform its function?
6. Of what are chloroplasts composed? What is the function of each component?
7. What are plasmodesmata, and what is their importance to living plants?
8. What are pits? Where are they located?
9. What are the differences and similarities between plant and animal cells?
10. Are prophase and telophase of mitosis exactly the reverse of one another? Explain.

Discussion Questions

1. Would you consider any one type of cell more useful than another? Why?
2. After you have completed your introductory plant science course, do you believe you would be able to determine the function of each of a cell’s organelles in a laboratory? Explain.

Additional Reading