SECTION 2

CELL DIVISION

OBJECTIVES

- **Describe** the events of cell division in prokaryotes.
- **Name** the two parts of the cell that are equally divided during cell division in eukaryotes.
- **Summarize** the events of interphase.
- **Describe** the stages of mitosis.
- **Compare** cytokinesis in animal cells with cytokinesis in plant cells.
- **Explain** how cell division is controlled.

VOCABULARY

binary fission
mitosis
asexual reproduction
meiosis
gamete
interphase
cytokinesis
prophase
spindle fiber
metaphase
anaphase
telophase
cell plate

Approximately 2 trillion cells—about 25 million cells per second—are produced by an adult human body every day. All cells come from the division of preexisting cells. Cell division (also called cell reproduction*) is the process by which cells produce offspring cells. Cell division differs in prokaryotes and eukaryotes. But cell reproduction in both prokaryotes and eukaryotes produces the same result—two cells from one.*

CELL DIVISION IN PROKARYOTES

Prokaryotes have cell walls but lack nuclei and membrane-bound organelles. A prokaryote's single DNA molecule is not coiled around proteins to form chromosomes. Instead, a prokaryote's DNA is a circular chromosome attached to the inner surface of the plasma membrane like a rope attached to the inner wall of a tent. For most prokaryotes, cell division takes place through a process called binary fission.

Binary fission is the division of a prokaryotic cell into two offspring cells, as shown in Figure 8-4. The DNA is copied, resulting in two identical chromosomes attached to the inside of the prokaryote's inner cell membrane. A new cell membrane then begins to develop between the two DNA copies. The cell grows until it reaches approximately twice the cell's original size. As new material is added, the growing cell membrane pushes inward and the cell is constricted in the center, like a balloon being squeezed in the middle. A new cell wall forms around the new membrane. Eventually, the dividing prokaryote is split into two independent cells. Each cell contains one of the identical chromosomes that resulted from the copying of the original cell's chromosome.

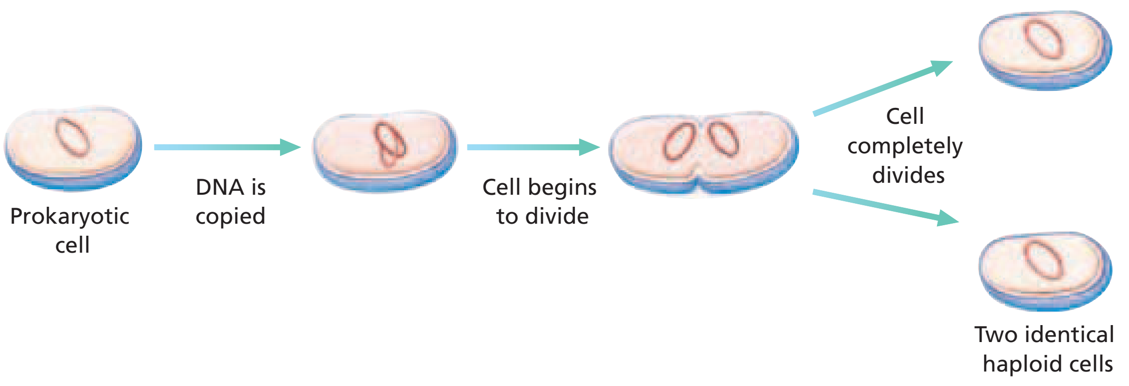


FIGURE 8-4
Most prokaryotes reproduce by binary fission, in which two identical cells are produced from one cell.

CELL DIVISION IN EUKARYOTES

In eukaryotic cell division, both the cytoplasm and the nucleus divide. There are two kinds of cell division in eukaryotes. The first type of cell division that you will learn about is called mitosis. **Mitosis** results in new cells with genetic material that is identical to the genetic material of the original cell. Mitosis occurs in organisms undergoing growth, development, repair, or asexual reproduction. **Asexual reproduction** is the production of offspring from one parent.

The second type of cell division that you will learn about (in the next section) is called meiosis. **Meiosis** occurs during the formation of **gametes,** which are haploid reproductive cells. Meiosis reduces the chromosome number by half in new cells. Each new cell has the potential to join with another haploid cell to produce a diploid cell with a complete set of chromosomes.

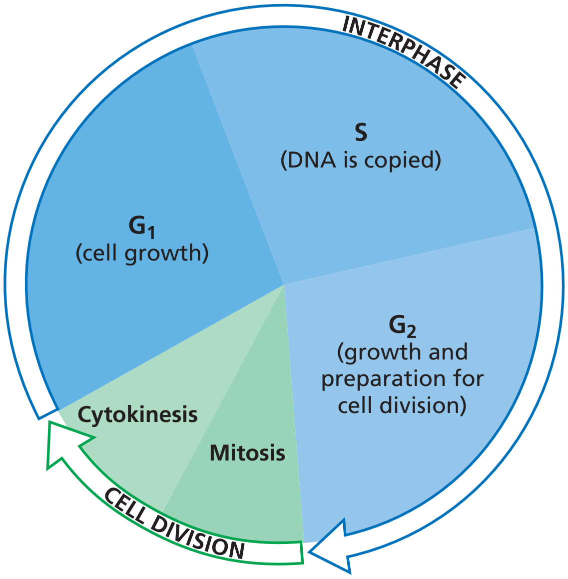


FIGURE 8-5

The cell cycle consists of interphase and cell division. Phases of growth, DNA synthesis, and preparation for cell division make up interphase. Cell division is divided into mitosis (division of the nucleus) and cytokinesis (division of the cytoplasm).

The Cell Cycle

The *cell cycle* is the repeating set of events in the life of a cell. Cell division is one phase of the cycle. The time between cell divisions is called **interphase.** Interphase is divided into three phases, and cell division is divided into two phases, as shown in Figure 8-5.

During cell division, the chromosomes and cytoplasm are equally divided between two offspring cells. Cell division consists of mitosis and cytokinesis. During mitosis, the nucleus of a cell divides. **Cytokinesis** is the division of the cell's cytoplasm.

Interphase

Notice in Figure 8-5 that cells spend most of the cell cycle in interphase. Following cell division, offspring cells are approximately half the size of the original cell. During the first stage of interphase—called the *G_1 phase*—offspring cells grow to mature size. G_1 stands for the time gap following cell division and preceding DNA replication. After cells have reached a mature size, many proceed into the next phase of interphase, called the *S phase*. During the S phase, the cell's DNA is copied (synthesized). The *G_2 phase* represents the time gap following DNA synthesis (S phase) and preceding cell division. The G_2 phase is a time during which the cell prepares for cell division.

Cells can also exit the cell cycle (usually from the G_1 phase) and enter into a state called the *G_0 phase*. During the G_0 phase, cells do not copy their DNA and do not prepare for cell division. Many cells in the human body are in the G_0 phase. For example, fully developed cells in the central nervous system stop dividing at maturity and normally never divide again.

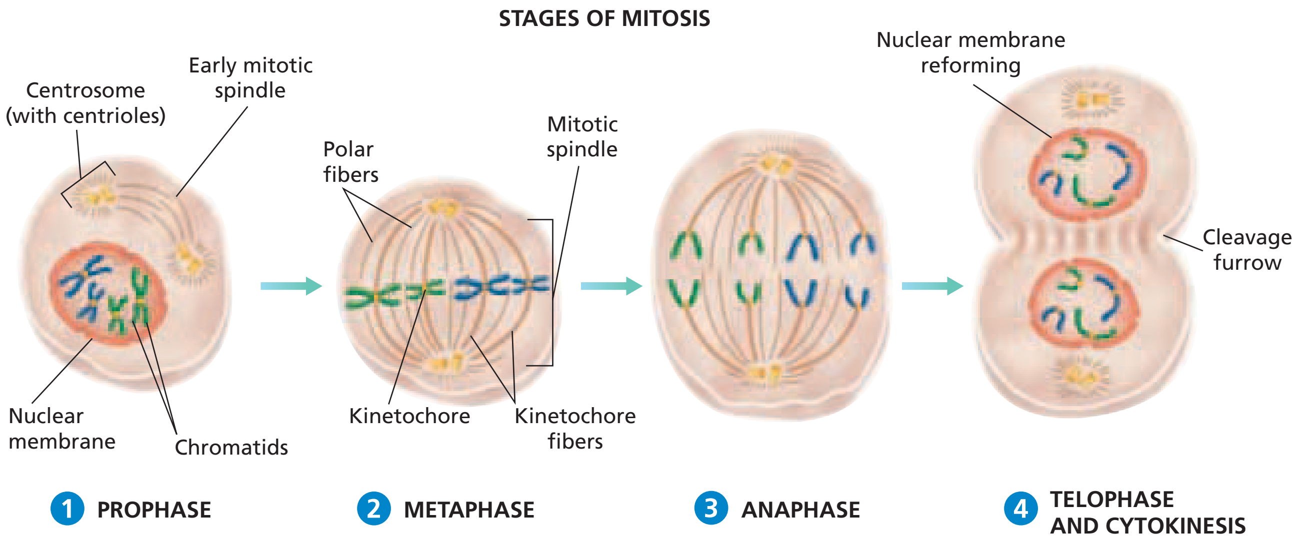


FIGURE 8-6

1 During prophase, the copied DNA coils into chromosomes. 2 During metaphase, the chromosomes line up along the midline of the dividing cell. 3 During anaphase, the chromatids of each chromosome begin moving toward opposite poles of the cell. 4 During telophase, the chromosomes reach opposite poles of the cell, and a cleavage furrow is formed. Cytokinesis follows.

STAGES OF MITOSIS

Mitosis is the division of the nucleus, which occurs during cell division. Mitosis is a continuous process that allows for the organized distribution of a cell's copied DNA to offspring cells. The process of mitosis is usually divided into four phases for ease of understanding: prophase, metaphase, anaphase, and telophase.

Prophase

Prophase is the first phase of mitosis. Prophase, shown in step 1 of Figure 8-6, begins with the shortening and tight coiling of DNA into rod-shaped chromosomes that can be seen with a light microscope. Recall that during the S phase, each chromosome is copied. The two copies of each chromosome—the chromatids—stay connected to one another by the centromere. At this time, the nucleolus and the nuclear membrane break down and disappear.

Two pairs of dark spots called *centrosomes* appear next to the disappearing nucleus. In animal cells, each centrosome contains a pair of small, cylindrical bodies called *centrioles*. The centrosomes of plant cells lack centrioles. In both animal and plant cells, the centrosomes move toward opposite poles of the cell during prophase.

As the centrosomes separate, **spindle fibers** made of microtubules radiate from the centrosomes in preparation for metaphase. This array of spindle fibers is called the *mitotic spindle,* which serves to equally divide the chromatids between the two offspring cells during cell division. Two types of spindle fibers make up the mitotic spindle: kinetochore fibers and polar fibers. *Kinetochore fibers* attach to a disk-shaped protein—called a *kinetochore*—that is found in the centromere region of each chromosome. Kinetochore fibers extend from the kinetochore of each chromatid to one of the centrosomes. *Polar fibers* extend across the dividing cell from centrosome to centrosome but do not attach to the chromosomes.

Word Roots and Origins

kinetochore

from the Greek *kinetos,* meaning "moving," and *choros,* meaning "place"

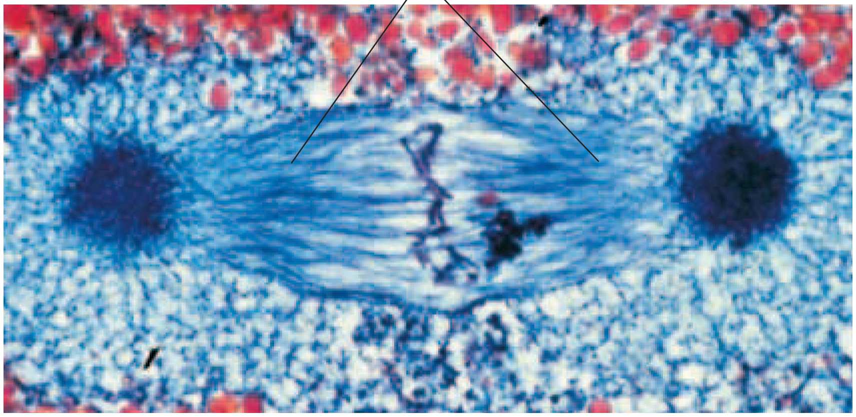


FIGURE 8-7

This micrograph of the spindle apparatus during metaphase shows the kinetochore fibers moving the chromosomes to the center of the dividing cell. The wormlike structures in the center are the chromosomes. (LM 1,080×)

Metaphase

Metaphase, as shown in step 2 of Figure 8-6, is the second phase of mitosis. During metaphase, chromosomes are easier to identify by using a microscope than during other phases; thus, karyotypes are typically made from photomicrographs of chromosomes in metaphase. As shown in Figure 8-7 above, the kinetochore fibers move the chromosomes to the center of the dividing cell during metaphase. Once in the center of the cell, each chromosome is held in place by the kinetochore fibers.

Anaphase

During **anaphase,** shown in step 3 of Figure 8-6 on the previous page, the chromatids of each chromosome separate at the centromere and slowly move, centromere first, toward opposite poles of the dividing cell. After the chromatids separate, they are considered to be individual chromosomes.

Telophase

Telophase is shown in step 4 in Figure 8-6 on the previous page. After the chromosomes reach opposite ends of the cell, the spindle fibers disassemble, and the chromosomes return to a less tightly coiled chromatin state. A nuclear envelope forms around each set of chromosomes, and a nucleolus forms in each of the newly forming cells.

CYTOKINESIS

During telophase, the cytoplasm begins dividing by the process of cytokinesis. In animal cells, cytokinesis begins with a pinching inward of the cell membrane midway between the dividing cell's two poles, as shown in Figure 8-8. The area of the cell membrane that pinches in and eventually separates the dividing cell into two cells is called the *cleavage furrow*. The cleavage furrow pinches the cell into two cells through the action of microfilaments.

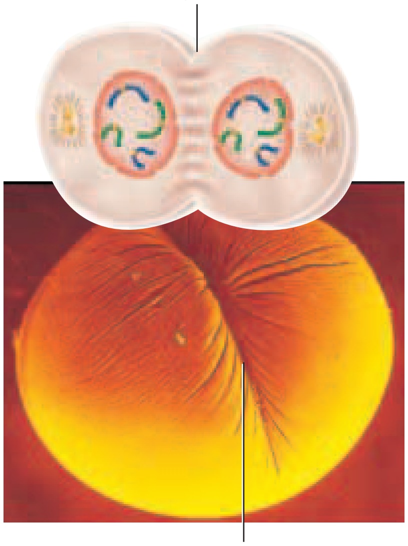
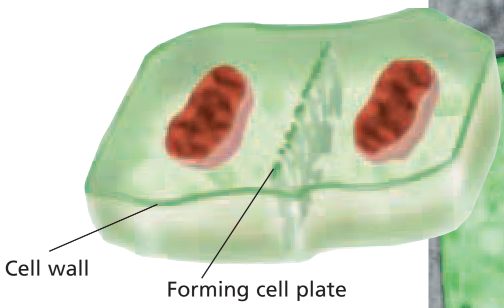


FIGURE 8-8

In animal cells, such as this frog cell, the cell membrane pinches in at the center of the dividing cell, eventually dividing the cell into two offspring cells. (SEM 78×)



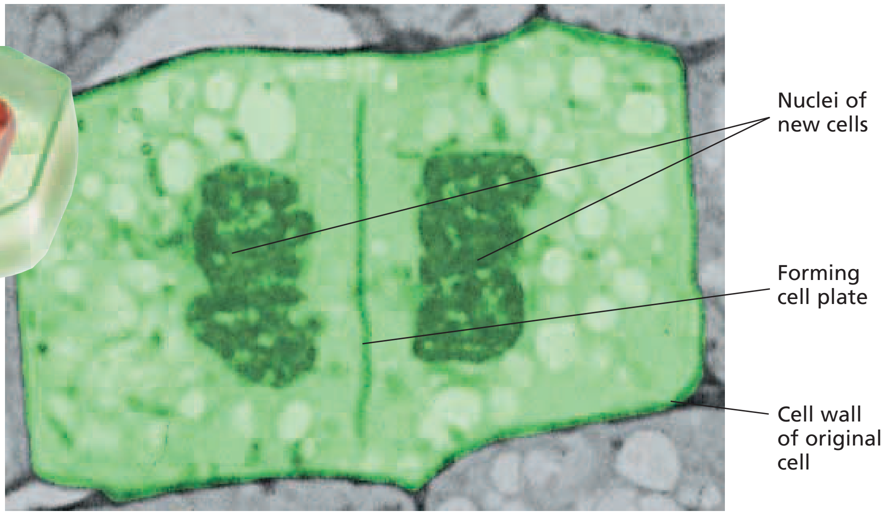


FIGURE 8-9

In plant cells, such as this onion cell, a cell plate forms along the midline of the dividing cell, eventually dividing the cell into two offspring cells. (LM 4,104×)

Figure 8-9 shows cytokinesis in plant cells. In plant cells, vesicles from the Golgi apparatus join together at the midline of the dividing cell to form a **cell plate.** A cell wall eventually forms from the cell plate at the midline, dividing the cell into two cells.

In both animal cells and plant cells, offspring cells are approximately equal in size. Each offspring cell receives an identical copy of the original cell's chromosomes and approximately one-half of the original cell's cytoplasm and organelles.

Quick Lab

Identifying Prefixes and Suffixes

Materials dictionary, 3 × 5 in. index cards (18), pencil

Procedure

1. Write each of the following prefixes and suffixes on separate cards: *pro-, meta-, ana-, telo-, cyto-, oo-, inter-, -kinesis,* and *-genesis.*
2. Use a dictionary to find the definition of each prefix and suffix. Write the definitions on cards.
3. Play "Memory" with a partner. Mix the cards, and place each one face down on the table. Turn over two cards. If the two cards consist of a prefix or suffix and its definition, pick up the cards, and take another turn. If the two cards do not match, turn them face down again, and leave them in the same place.
4. Repeat step 3 until no cards remain on the table. The player with the most pairs wins.

Analysis How does knowing the meaning of a prefix or suffix help you understand a word's meaning?

CONTROL OF CELL DIVISION

Recall that a cell spends most of its time in interphase, the time between cell divisions. What triggers a cell to leave interphase and begin dividing? In eukaryotes, proteins regulate the progress of cell division at certain checkpoints. This system of checkpoints can be thought of as a kind of "traffic signal" for the cell. Certain feedback signals from the cell can trigger the proteins to initiate the next phase of the cell cycle, much as a green light signals traffic to move forward. Other feedback signals from the cell can trigger the proteins to halt the cycle, just as a red light signals traffic to stop.

Control occurs at three main checkpoints. These checkpoints are illustrated in Figure 8-10 on the next page.

1. **Cell growth (G_1) checkpoint.** Proteins at this checkpoint control whether the cell will divide. If the cell is healthy and has grown to a suitable size during the G_1 phase, proteins will initiate DNA synthesis (the S phase). The cell copies its DNA during this phase. If conditions are not favorable for DNA synthesis, the cell cycle will stop at this point. The cell cycle may also stop at this checkpoint if the cell needs a rest period. Certain cells pass into the G_0 phase at this checkpoint. Many cells that have passed into the G_0 phase will never divide again.

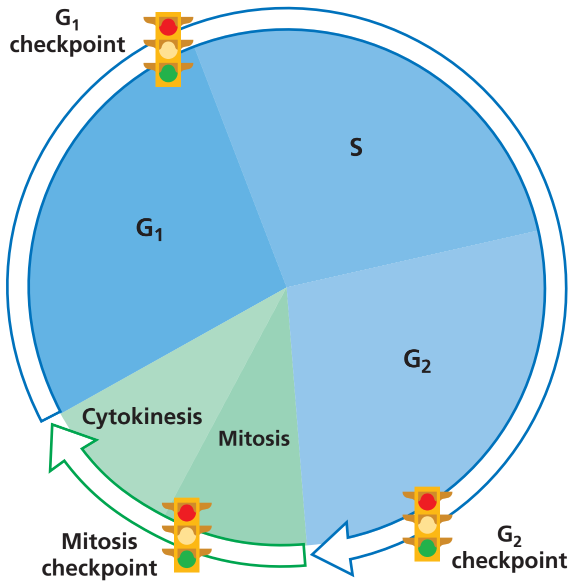


FIGURE 8-10

The cell cycle in eukaryotes is controlled at three inspection points, or checkpoints. Many proteins are involved in the control of the cell cycle.

2. **DNA synthesis (G_2) checkpoint.** At this point in the G_2 phase, DNA repair enzymes check the results of DNA replication. If this checkpoint is passed, proteins will signal the cell to begin the molecular processes that will allow the cell to divide mitotically.
3. **Mitosis checkpoint.** If a cell passes this checkpoint, proteins signal the cell to exit mitosis. The cell then enters into the G_1 phase, the major growth phase of the cell cycle, once again.

When Control Is Lost: Cancer

The proteins that regulate cell growth and division are coded for by genes. If a mutation occurs in one of these genes, the proteins may not function properly. Cell growth and division may be disrupted as a result. Such a disruption could lead to *cancer,* the uncontrolled growth of cells. Cancer cells do not respond normally to the body's control mechanisms. Some mutations cause cancer by overproducing growth-promoting molecules, which can lead to increased cell division. Other mutations may interfere with the ability of control proteins to slow or stop the cell cycle.

SECTION 2 REVIEW

1. Name the process by which prokaryotic cells divide.
2. What is the name of the process by which the cell's cytoplasm divides?
3. During which of the phases of interphase does an offspring cell grow to mature size?
4. During which phase of mitosis do chromatids separate to become chromosomes?
5. Explain the main difference between cytokinesis in animal cells and cytokinesis in plant cells.
6. Which type of molecule controls the cell cycle?

CRITICAL THINKING

7. **Predicting Results** What would happen if cytokinesis took place before mitosis?
8. **Applying Information** What would result if chromosomes did not replicate during interphase?
9. **Evaluating Information** Why are individual chromosomes more difficult to see during interphase than during mitosis?