What does this mean for cells? How does the surface area-to-volume ratio affect cell function? If cell size doubled, the cell would require eight times more nutrients and would have eight times more waste to excrete. The surface area, however, would increase by a factor of only four. Thus, the plasma membrane would not have enough surface area through which oxygen, nutrients, and wastes could diffuse. The cell would either starve to death or be poisoned from the buildup of waste products. You can investigate surface area-to-volume ratios yourself in the Problem-Solving Lab shown here.

Because cell size can have dramatic and negative effects on a cell, cells must have some method of maintaining optimum size. In fact, cells divide before they become too large to function properly. Cell division accomplishes other purposes, too, as you will read next.

Cell Reproduction

Recall that the cell theory states that all cells come from preexisting cells. Cell division is the process by which new cells are produced from one cell. Cell division results in two cells that are identical to the original, parent cell. Right now, as you are reading this page, many of the cells in your body are growing, dividing, and dying. Old cells on the soles of your feet and on the palms of your hands are being shed and replaced, cuts and bruises are healing, and your intestines are producing millions of new cells each second. New cells are produced as tadpoles become frogs, and as an ivy vine grows and wraps around a garden trellis. All organisms grow and change; worn-out tissues are repaired or are replaced by newly produced cells.

The discovery of chromosomes

Most interesting to the early biologists was their observation that just before cell division, several short, stringy structures suddenly appeared in the nucleus. Scientists also noticed that these structures seemed to vanish as mysteriously as they appeared soon after division of a cell. These structures, which contain DNA and become darkly colored when stained, are called chromosomes (KROH muh sohmz).

Eventually, scientists learned that chromosomes are the carriers of the genetic material that is copied and passed from generation to generation of cells. This genetic material is crucial to the identity of the cell.
How does the length of the cell cycle vary? The cell cycle varies greatly in length from one kind of cell to another. Some kinds of cells divide rapidly, while others divide more slowly.

**Analysis**
Examine the cell cycle diagrams of two different types of cells. Observe the total length of each cell cycle and the length of time each cell spends in each phase of the cell cycle.

**Thinking Critically**
1. Which part of the cell cycle is most variable in length?
2. What can you infer about the functions of these two types of cells?
3. Why do you think the cycle of some types of cells is faster than in others? Explain your answer.

Accurate transmission of chromosomes during cell division is critical.

**The structure of eukaryotic chromosomes**
For most of a cell’s lifetime, chromosomes exist as chromatin, long strands of DNA wrapped around proteins. Under an electron microscope, chromatin looks somewhat chaotic, resembling a plate of tangled-up spaghetti. This loose, seemingly unorganized arrangement is necessary for the protein blueprints to be copied. However, before a cell can divide, the long strands of chromatin must be reorganized, just as you would coil a long strand of rope before storing it. As the nucleus begins to divide, chromosomes take on a different structure in which the chromatin becomes tightly packed.

**The Cell Cycle**
Fall follows summer, night follows day, and low tide follows high tide. Many events in nature follow a recurring, cyclical pattern. Living organisms are no exception. One cycle common to most living things is the cycle of the cell. The cell cycle is the sequence of growth and division of a cell.

As a cell proceeds through its cycle, it goes through two general periods: a period of growth and a period of division. The majority of a cell’s life is spent in the growth period known as interphase. During interphase, a cell grows in size and carries on metabolism. Also during this period, chromosomes are duplicated in preparation for the period of division.

Following interphase, a cell enters its period of nuclear division called mitosis (mi TOH sus). Mitosis is the process by which two daughter cells are formed, each containing a complete set of chromosomes. Interphase and mitosis make up the bulk of the cell cycle. One final process, division of the cytoplasm, takes place after mitosis. Look at the Inside Story to find out how many stages of growth are involved in interphase. You can use the Problem-Solving Lab on this page and the BioLab at the end of this chapter to investigate the rate of mitosis.
The Cell Cycle

The cell cycle is divided into interphase, when most of the cell's metabolic functions are carried out and the chromosomes are replicated, and mitosis, when nuclear division occurs, leading to the formation of two daughter cells. The division of cytoplasm, called cytokinesis, follows mitosis.

Critical Thinking During which stage of the interphase does a cell spend most of its time? Why?

1. G1 Interphase begins with the G1 stage. At this point the chromosomes are not visible under the light microscope because they are uncoiled. Protein synthesis is rapidly occurring as the cell grows and develops.

2. S Stage During this stage of interphase, the chromosomes are replicated in the nucleus. Chromosomes divide to form identical sister chromatids connected by a centromere.

3. G2 The chromosomes begin to shorten and coil, and protein synthesis is in high gear. In this stage of interphase, most of the proteins being synthesized are needed for mitosis and the cell organizes and prepares for mitosis. In animals, the centriole pair replicates and prepares to form the mitotic spindle.

4. Mitosis When interphase is complete, the cell undergoes mitosis. Mitosis consists of four stages (Figure 8.12) that result in the formation of two daughter cells with identical copies of the DNA. Following mitosis, the cytoplasm divides, separating the two daughter cells.
the chromosomes have been duplicated, the cell enters another shorter growth period in which mitochondria and other organelles are manufactured and cell parts needed for cell division are assembled. Following this activity, interphase ends and mitosis begins.

The Phases of Mitosis

Cells undergo mitosis as they approach the maximum cell size at which the nucleus can provide blueprints for proteins and the plasma membrane can efficiently transport nutrients and wastes into and out of the cell.

Although cell division is a continuous process, biologists recognize four distinct phases of mitosis—each phase merging into the next. The four phases of mitosis are prophase, metaphase, anaphase, and telophase. Refer to Figure 8.12 to help you understand the process as you read about mitosis.

Prophase: the first phase of mitosis

During prophase, the first and longest phase of mitosis, the long, stringy chromatin coils up into visible chromosomes. At this point the chromosomes look hairy. As you can see in Figure 8.11, each duplicated chromosome is made up of two halves. The two halves of the doubled structure are called sister chromatids. Sister chromatids and the DNA they contain are exact copies of each other and are formed when DNA is copied during interphase. Sister chromatids are held together by a structure called a centromere, which plays a role in chromosome movement during mitosis. By their characteristic location, centromeres also help scientists identify and study chromosomes.
Figure 8.12
Mitosis begins after interphase. Follow the stages of mitosis as you read the text. The diagrams describe mitosis in animal cells and the photos show mitosis in plant cells.

A **Interphase** precedes mitosis. Refer to the *Inside Story.*

B **Prophase** The chromatin coils to form visible chromosomes.

C **Metaphase** The chromosomes move to the equator of the spindle.

D **Anaphase** The centromeres split and the sister chromatids are pulled apart to opposite poles of the cell.

E **Telophase** Two distinct daughter cells are formed. The cells separate as the cell cycle proceeds into the next interphase.
As prophase continues, the nucleus begins to disappear as the nuclear envelope and the nucleolus disintegrate. By late prophase, these structures are completely absent. In animal cells, two important pairs of structures, the centrioles, begin to migrate to opposite ends of the cell. Centrioles are small, dark, cylindrical structures that are made of microtubules and are located just outside the nucleus, Figure 8.13. Centrioles play a role in chromatid separation.

As the pairs of centrioles move to opposite ends of the cell, another important structure, called the spindle, begins to form between them. The spindle is a football-shaped, cagelike structure consisting of thin fibers made of microtubules. In plant cells, the spindle forms without centrioles. The spindle fibers play a vital role in the separation of sister chromatids during mitosis.

**Metaphase: the second stage of mitosis**

During metaphase, the short second phase of mitosis, the doubled chromosomes become attached to the spindle fibers by their centromeres. The chromosomes are pulled by the spindle fibers and begin to line up on the midline, or equator, of the spindle. Each sister chromatid is attached to its own spindle fiber. One sister chromatid’s spindle fiber extends to one pole, and the other extends to the opposite pole. This arrangement is important because it ensures that each new cell receives an identical and complete set of chromosomes.

**Anaphase: the third phase of mitosis**

The separation of sister chromatids marks the beginning of anaphase, the third phase of mitosis.
During anaphase, the centromeres split apart and chromatid pairs from each chromosome separate from each other. The chromatids are pulled apart by the shortening of the microtubules in the spindle fibers.

**Telophase: the fourth phase of mitosis**

The final phase of mitosis is **telophase**. Telophase begins as the chromatids reach the opposite poles of the cell. During telophase, many of the changes that occurred during prophase are reversed as the new cells prepare for their own independent existence. The chromosomes, which had been tightly coiled since the end of prophase, now unwind so they can begin to direct the metabolic activities of the new cells. The spindle begins to break down, the nucleolus reappears, and a new nuclear envelope forms around each set of chromosomes. Finally, a new double membrane begins to form between the two new nuclei.

**Division of the cytoplasm**

Following telophase, the cell’s cytoplasm divides in a process called **cytokinesis** (site uh kih NEE sus). Cytokinesis differs between plants and animals. Toward the end of telophase in animal cells, the plasma membrane pinches in along the equator as shown in Figure 8.14. As the cell cycle proceeds, the two new cells are separated. Find out more about mitosis in animal cells in the MiniLab.

Plant cells have a rigid cell wall, so the plasma membrane does not pinch in. Rather, a structure known as the cell plate is laid down across the cell’s equator. A cell membrane forms around each cell, and new cell walls form on each side of the cell plate until separation is complete.

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**MiniLab 8-2 Comparing and Contrasting**

**Seeing Asters** The result of the process of mitosis is similar in plant and animal cells. However, animal cells have asters whereas plant cells do not. Animal cells undergoing mitosis clearly show these structures.

**Procedure**

1. Examine a slide marked “fish mitosis” under low- and high-power magnification. **CAUTION: Use care when handling prepared slides.**
2. Find cells that are undergoing mitosis. You will be able to see dark-stained rodlike structures within certain cells. These structures are chromosomes.
3. Note the appearance and location of asters. They will appear as ray or starlike structures at opposite ends of cells that are in metaphase.
4. Asters may also be observed in cells that are in other phases of mitosis.

**Analysis**

1. Describe the appearance and location of asters in cells that are in prophase.
2. Explain how you know that asters are not critical to mitosis.
3. Design an experiment that tests the hypothesis that asters are not essential for mitosis in animal cells.

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**Figure 8.14**

At the end of telophase in animal cells, such as this frog egg, proteins positioned just under the plasma membrane at the equator of the cell contract and slide past each other to cause a deep furrow. The furrow deepens until the cell is pinched in two.
Cells of complex multicellular organisms are organized into tissues, organs, and organ systems.

**Results of mitosis**

Mitosis is a process that guarantees genetic continuity, resulting in the production of two new cells with chromosome sets that are identical to those of the parent cell. These new daughter cells will carry out the same cellular processes and functions as those of the parent cell and will grow and divide just as the parent cell did.

When mitosis is complete, unicellular organisms remain as single cells—the organism simply multiplied. In multicellular organisms, cell growth and reproduction result in groups of cells that work together as tissue to perform a specific function. Tissues organize in various combinations to form organs that perform more complex roles within the organism. For example, cells make up muscle tissue, then muscle tissue works with other tissues in the organ called the stomach to mix up food. Multiple organs that work together form an organ system. The stomach is one organ in the digestive system, which functions to break up and digest food.

All organ systems work together for the survival of the organism, whether the organism is a fly or a human. Figure 8.15 shows an example of cell specialization and organization for a complex organism. In addition to its digestive system, the panther has a number of other organ systems that have developed through cell specialization. It is important to remember that no matter how complex the organ system or organism becomes, the cell is still the most basic unit of that organization.

### Understanding Main Ideas

1. Describe how a cell’s surface area-to-volume ratio limits its size.
2. Why is it necessary for a cell’s chromosomes to be distributed to daughter cells in such a precise manner?
3. How is the division of the cytoplasm different in plants and in animals?
4. In multicellular organisms, describe two cellular specializations that result from mitosis.

### Thinking Critically

5. At one time, interphase was referred to as the resting phase of the cell cycle. Why do you think this description is no longer used?

### Skill Review

6. Making and Using Tables Make a table showing the phases of the cell cycle. Mention one important event that occurs at each phase. For more help, refer to Organizing Information in the Skill Handbook.