This human lymphocyte is dividing into two new cells. (17,687×)
**CHROMOSOMES**

Recall that DNA is a long, thin molecule that stores genetic information. The DNA in a human cell is estimated to consist of three billion nucleotides. To visualize the enormity of three billion nucleotides, imagine increasing a cell nucleus to the size of a basketball. Then, imagine taking the DNA out of the basketball-sized nucleus and stretching it into a straight line. That line of DNA would stretch for more than 20 miles. How can a nucleus hold so much DNA? Inside the nucleus, the DNA is coiled and packed in a complicated yet organized manner. As a cell prepares to divide, the DNA coils even further into tightly compacted structures.

**CHROMOSOME STRUCTURE**

During cell division, the DNA in a eukaryotic cell’s nucleus is coiled into very compact structures called chromosomes. **Chromosomes** are rod-shaped structures made of DNA and proteins. In Figure 8-1, you can see the many levels of DNA coiling required to form a chromosome.

The chromosomes of stained eukaryotic cells undergoing cell division are visible as darkened structures inside the nuclear membrane. Each chromosome is a single DNA molecule associated with proteins. The DNA in eukaryotic cells wraps tightly around proteins called **histones**. Histones help maintain the shape of the chromosome and aid in the tight packing of DNA. Nonhistone proteins are generally involved in controlling the activity of specific regions of the DNA.

---

**OBJECTIVES**

- Describe the structure of a chromosome.
- Identify the differences in structure between prokaryotic chromosomes and eukaryotic chromosomes.
- Compare the numbers of chromosomes in different species.
- Explain the differences between sex chromosomes and autosomes.
- Distinguish between diploid and haploid cells.

**VOCABULARY**

- chromosome
- histone
- chromatid
- centromere
- chromatin
- sex chromosome
- autosome
- homologous chromosome
- karyotype
- diploid
- haploid

**FIGURE 8-1**

As a cell prepares to divide, its DNA coils around histones and twists into rod-shaped chromosomes.
Figure 8-2 shows a chromosome that was isolated from a dividing cell. Notice that the chromosome consists of two identical halves. Each half of the chromosome is called a chromatid. Chromatids form as the DNA makes a copy of itself before cell division. When the cell divides, each of the two new cells will receive one chromatid from each chromosome. The two chromatids of a chromosome are attached at a point called a centromere. The centromere holds the two chromatids together until they separate during cell division. As you will learn in the next section, centromeres are especially important for the movement of chromosomes during cell division.

Between cell divisions, DNA is not so tightly coiled into chromosomes. Regions of DNA uncoil between cell divisions so they can be read and so the information can be used to direct the activities of the cell. The less tightly coiled DNA-protein complex is called chromatin.

As you might expect, chromosomes are simpler in prokaryotes than in eukaryotes. The DNA of most prokaryotes consists of only one chromosome, which is attached to the inside of the cell membrane. Prokaryotic chromosomes consist of a circular DNA molecule. As with eukaryotic chromosomes, prokaryotic chromosomes must be very compact to fit into the cell.

**TABLE 8-1  Chromosome Numbers of Various Species**

<table>
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<tr>
<th>Organism</th>
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<td>Carrot</td>
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<tr>
<td>Orangutan</td>
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</tr>
<tr>
<td>Sand dollar</td>
<td>52</td>
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</tbody>
</table>

Each species has a characteristic number of chromosomes in each cell. Table 8-1 lists the number of chromosomes found in some organisms. Some species of organisms have the same number of chromosomes. For example, potatoes, plums, and chimpanzees all have 48 chromosomes in each cell.

**Sex Chromosomes and Autosomes**

Human and animal chromosomes are categorized as either sex chromosomes or autosomes. Sex chromosomes are chromosomes that determine the sex of an organism, and they may also carry genes for other characteristics. In humans, sex chromosomes are either X or Y. Females normally have two X chromosomes, and males normally have an X and a Y chromosome. All of the other chromosomes in an organism are called autosomes. Two of the 46 human chromosomes are sex chromosomes, and the remaining 44 chromosomes are autosomes.

Every cell of an organism produced by sexual reproduction has two copies of each autosome. The organism receives one copy of each autosome from each parent. The two copies of each autosome are called homologous chromosomes, or homologues. Homologous chromosomes are the same size and shape and carry genes for the same traits. For example, if one chromosome in a pair of homologues contains a gene for eye color, so will the other chromosome in the homologous pair.
Figure 8-3 shows a **karyotype**, which is a photomicrograph of the chromosomes in a normal dividing cell found in a human. Notice that the 46 human chromosomes exist as 22 homologous pairs of autosomes and 2 sex chromosomes (XY in males and XX in females).

**Diploid and Haploid Cells**

Cells having two sets of chromosomes are **diploid**. Diploid cells have two autosomes for each homologous pair. Diploid cells also have two sex chromosomes in animals, including humans, and in many other organisms that have sex chromosomes. All human cells, except reproductive cells (sperm cells and egg cells), are normally diploid cells. Diploid is commonly abbreviated as 2n. In humans, the diploid, or 2n, number of chromosomes is 46—22 pairs of homologous autosomes and 2 sex chromosomes.

Sperm cells and egg cells are **haploid** cells, which contain only one set of chromosomes. Haploid cells have half the number of chromosomes that are present in diploid cells. Thus, haploid cells have only one autosome of each homologous pair and only one sex chromosome (23 total). Haploid is abbreviated as 1n. When a sperm cell (1n) and an egg cell (1n) combine to create the first cell of a new organism, the new cell will be diploid (2n). If the reproductive cells were diploid, the new cell would have too many chromosomes and would not be functional.

---

**SECTION 1 REVIEW**

1. Name the proteins that DNA wraps around to form a chromosome in eukaryotic cells.
2. How do the structure and location of a prokaryotic chromosome differ from that of a eukaryotic chromosome?
3. Does chromosome number indicate whether an organism is a plant or an animal? Explain.
4. Contrast sex chromosomes with autosomes.
5. Using Table 8-1, list the haploid and diploid number of chromosomes for each organism.

**CRITICAL THINKING**

6. **Forming Reasoned Opinions** Is there a correlation between the number of chromosomes and the complexity of an organism? Give support for your answer.
7. **Predicting Results** What would be the consequence for future generations of cells if sperm and egg cells were normally diploid?
8. **Interpreting Graphics** What is the sex of the person whose chromosomes are shown in Figure 8-3 above? Explain your answer.
CHAPTER 8

CELL DIVISION

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.

**SECTION 2**

**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

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

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.
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.
**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 8-9 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.

**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 (G₁) 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 G₁ 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 G₀ phase at this checkpoint. Many cells that have passed into the G₀ phase will never divide again.
2. **DNA synthesis (G\textsubscript{2}) checkpoint.** At this point in the G\textsubscript{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\textsubscript{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?
STEM CELLS: Promise and Difficulty

Stem cells are unspecialized cells that give rise to the different types of cells that make up the human body. Scientists researching stem cells hope someday to be able to use them to replace damaged or diseased cells in the body. There are two general types of stem cells: embryonic stem cells and adult stem cells.

Embryonic Stem Cells
Embryonic stem cells seem to show more promise in medical treatment than do adult stem cells. Embryonic stem cells are easier to find than are adult stem cells. Embryonic stem cells can reproduce indefinitely in culture and have the potential to grow into any cell type. However, embryonic stem cells would be genetically different from the cells of a transplant recipient. The recipient’s immune system could reject the cells, causing transplant failure.

Adult Stem Cells
Some stem cells remain in the body into adulthood. These adult stem cells naturally produce just one or a few types of cells. For example, bone marrow stem cells give rise only to new blood cells. Studies have shown some success in coaxing adult stem cells into becoming other cell types. Using a person’s own stem cells for cell transplant would avoid a possible immune response. However, because there are so few adult stem cells, they can be difficult to find. Adult stem cells also have a limited life span in the lab, which gives rise to questions about the life span of any transplant done with adult stem cells.

Stem Cell Controversy
Despite the possibilities of stem cell use, research on them has been controversial. Embryonic stem cells are harvested from human embryos that are unused for fertility treatment. When embryonic stem cells are harvested, the embryo is destroyed. Many people believe it is unethical to destroy embryos that have the potential to develop into babies. The harvesting of adult stem cells causes no lasting harm to the donor, but the potential for the cells may be limited.

Stem cell transplants might one day be used routinely to treat diseases and disorders such as Alzheimer’s disease, diabetes, cancer, and spinal cord injuries. We may even be able to grow complete new organs from stem cells. Funding will be one factor that affects the direction of research. Federal, state, and private funding set the landscape for the future of stem cell research. While the promise of stem cells seems unlimited, major advances will only be achieved through years of intensive research.

REVIEW
1. How do adult stem cells differ from embryonic stem cells?
2. Why is stem cell research controversial?
3. Critical Thinking What do you think are the strongest reasons for and against further research? Based on these two points, would you propose stem cell research be regulated? If so, how?
Meiosis

Meiosis is a process of nuclear division that reduces the number of chromosomes in new cells to half the number in the original cell. The halving of the chromosome number counteracts a joining of cells later in the life cycle of the organism.

Formation of Haploid Cells

In animals, meiosis produces gametes, which are haploid reproductive cells. Human gametes are sperm cells and egg cells. Sperm and egg cells each contain 23 \((1n)\) chromosomes. The fusion of a sperm and an egg results in a zygote that contains 46 \((2n)\) chromosomes.

Cells preparing to divide by meiosis undergo the \(G_1\), \(S\), and \(G_2\) phases of interphase. During interphase, the cell grows to a mature size and copies its DNA. Thus, cells begin meiosis with a duplicate set of chromosomes, just as cells beginning mitosis do. Because cells undergoing meiosis divide twice, diploid \((2n)\) cells that divide meiotically result in four haploid \((1n)\) cells rather than two diploid \((2n)\) cells. The stages of the first cell division are called meiosis I, and the stages of the second cell division are called meiosis II.

Meiosis I

While reading about each phase of meiosis I, shown in Figure 8-11 on the next page, notice how these phases compare with the corresponding phases that occur in mitosis.

Prophase I

In prophase I (step 1), DNA coils tightly into chromosomes. As in the prophase of mitosis, spindle fibers appear. Then, the nucleolus and nuclear membrane disassemble. Notice that every chromosome lines up next to its homologue. The pairing of homologous chromosomes, which does not occur in mitosis, is called synapsis. Each pair of homologous chromosomes is called a tetrad. In each tetrad, chromatids of the homologous chromosomes are aligned lengthwise so that the genes on one chromosome are adjacent to the corresponding genes on the other chromosome.
During synapsis, the chromatids within a homologous pair twist around one another, as shown in Figure 8-12. Portions of chromatids may break off and attach to adjacent chromatids on the homologous chromosome—a process called **crossing-over**. This process permits the exchange of genetic material between maternal and paternal chromosomes. Thus, **genetic recombination** results, because a new mixture of genetic material is created.

**Metaphase I**
During metaphase I (step 2), the tetrads line up randomly along the midline of the dividing cell, as shown in Figure 8-11. The orientation of the pair of chromosomes is random with respect to the poles of the cell. Spindle fibers from one pole attach to the centromere of one homologous chromosome. Spindle fibers from the opposite pole attach to the other homologous chromosome of the pair.

**Anaphase I**
During anaphase I (step 3), each homologous chromosome (consisting of two chromatids attached by a centromere) moves to an opposite pole of the dividing cell. The random separation of the homologous chromosomes is called **independent assortment**. Independent assortment results in genetic variation.

**Telophase I and Cytokinesis I**
During telophase I (step 4), the chromosomes reach the opposite ends of the cell, and cytokinesis begins. Notice that the new cells contain a haploid number of chromosomes.

During meiosis I, the original cell produces two new cells, each containing one chromosome from each homologous pair. The new cells contain half the number of chromosomes of the original cell. However, each new cell contains two copies (as chromatids), because the original cell copied its DNA before meiosis I.

---

**FIGURE 8-11**
Meiosis occurs in diploid reproductive cells. Before meiosis begins, the DNA of the diploid reproductive cells is copied. Meiosis I results in two haploid cells. Meiosis II results in four haploid offspring cells.

**FIGURE 8-12**
Crossing-over occurs when chromosomes that make up a tetrad exchange portions of their chromatids during synapsis. Crossing-over results in an exchange of genes and in new combinations of genes.
MEIOSIS II

Meiosis II occurs in each cell formed during meiosis I and is not preceded by the copying of DNA. The events of meiosis II are shown above. In some species, meiosis II begins after the nuclear membrane re-forms in the new cells. In other species, meiosis II begins immediately following meiosis I.

Prophase II, Metaphase II, and Anaphase II

During prophase II (step 5), spindle fibers form and begin to move the chromosomes toward the midline of the dividing cell. In metaphase II (step 6), the chromosomes move to the midline of the dividing cell, with each chromatid facing opposite poles of the dividing cell. In anaphase II (step 7), the chromatids separate and move toward opposite poles of the cell.

Telophase II and Cytokinesis II

In telophase II (step 8), a nuclear membrane forms around the chromosomes in each of the four new cells. Cytokinesis II then occurs, resulting in four new cells, each of which contains half of the original cell’s number of chromosomes.

DEVELOPMENT OF GAMETES

In animals, the only cells that divide by meiosis are those that produce gametes within the reproductive organs. However, organisms vary in timing and structures associated with gamete formation. In humans, meiosis occurs in the testes (males) and the ovaries (females). Figure 8-13 shows a male human gamete joining with a female human gamete.
CHAPTER 8

1. How do the end products of meiosis differ from the end products of mitosis?

2. How does anaphase I in meiosis differ from anaphase in mitosis?

3. Explain the role of crossing-over in ensuring genetic variation.

4. During which stage of meiosis is the diploid number of chromosomes reduced to the haploid number of chromosomes?

5. Describe the differences between spermatogenesis and oogenesis.

6. Why is meiosis essential to sexual reproduction?

CRITICAL THINKING

7. Applying Information  Explain why the chromosomes in the haploid cells that are produced by meiosis I look different from those produced by meiosis II.

8. Relating Concepts  Explain how it might happen that a human offspring with 47 chromosomes could be produced.

9. Distinguishing Relevant Information  In humans, the egg is larger than the sperm. Explain how it is possible that a child inherits equally from its mother and father.

In the testes, meiosis is involved in the production of male gametes known as sperm cells or spermatozoa. In the development of sperm cells, a diploid reproductive cell divides meiotically to form four haploid cells called spermatids. Each spermatid develops into a mature sperm cell. The production of sperm cells is called spermatogenesis, shown in Figure 8-14a.

Oogenesis (oh-oh-JEN-uh-sis) is the production of mature egg cells, or ova. During oogenesis, a diploid reproductive cell divides meiotically to produce one mature egg cell (ovum). During cytokinesis and cytokinesis II of oogenesis, the cytoplasm of the original cell is divided unequally between new cells. As Figure 8-14b shows, one cell, which develops into a mature egg cell, receives most of the cytoplasm of the original cell. As a result, one egg cell is produced by meiosis. The other three products of meiosis, called polar bodies, eventually will degenerate.
**SECTION 1**

**Chromosomes**

- Chromosomes are tightly coiled DNA molecules. In eukaryotes, proteins called histones help maintain the compact structure of chromosomes.
- Chromosomes in prokaryotes are simpler than chromosomes in eukaryotes.
- Each species has a characteristic number of chromosomes in each cell.

**Vocabulary**

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**SECTION 2**

**Cell Division**

- Cell division is the process by which cells reproduce themselves. Binary fission is the process of cell division in prokaryotes.
- The cell cycle is the repeating set of events in the life of a cell. The cell cycle consists of cell division and interphase.
- Cell division in eukaryotes includes nuclear division (mitosis) and the division of cytoplasm (cytokinesis).
- Interphase consists of growth (G₁), DNA replication (S), and preparation for cell division (G₂).

**Vocabulary**

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**SECTION 3**

**Meiosis**

- Meiosis is a process of nuclear division that reduces the number of chromosomes in new cells to half the number in the original cell. Meiosis produces gametes.
- Cells undergoing meiosis divide twice. Diploid cells that divide meiotically result in four haploid cells rather than two diploid cells as in mitosis.
- Meiosis I includes prophase I, metaphase I, anaphase I, and telophase I. Crossing-over during prophase I results in genetic recombination.

**Vocabulary**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>synapsis</td>
<td>161</td>
</tr>
<tr>
<td>tetrad</td>
<td>161</td>
</tr>
<tr>
<td>crossing-over</td>
<td>162</td>
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<tr>
<td>genetic recombination</td>
<td>162</td>
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<tr>
<td>independent assortment</td>
<td>162</td>
</tr>
<tr>
<td>spermatogenesis</td>
<td>164</td>
</tr>
<tr>
<td>oogenesis</td>
<td>164</td>
</tr>
<tr>
<td>polar body</td>
<td>164</td>
</tr>
<tr>
<td>sexual reproduction</td>
<td>164</td>
</tr>
</tbody>
</table>
CHAPTER REVIEW

USING VOCABULARY

1. For each pair of terms, explain how the meanings of the terms differ.
   a. autosome and sex chromosome
   b. synapsis and crossing-over
   c. haploid and diploid

2. Explain the relationship between the terms chromosome and homologous chromosomes.

3. Use the following terms in the same sentence: mitosis, meiosis, and cytokinesis.

4. Word Roots and Origins The word oogenesis is derived from the Greek oion, which means “egg,” and geneia, which means “birth.” Using this information, explain why the term oogenesis is a good name for the biological process it describes.

UNDERSTANDING KEY CONCEPTS

5. Describe the structure of a chromosome.

6. Compare prokaryotic chromosomes with eukaryotic chromosomes.

7. State the number of chromosomes in normal human cells.

8. Identify the type of chromosome that determines the sex of an organism.

9. Distinguish between haploid cells and diploid cells.

10. Define the term binary fission. In what type of organism does this type of cell division occur?

11. Differentiate mitosis from cytokinesis.

12. Describe the events that occur in the G₀, G₁, and G₂ phases.

13. Summarize the phases of mitosis.

14. Describe the process of cytokinesis in plant cells.

15. List the three main checkpoints at which the cell cycle is controlled.

16. Identify the type of nuclear division that results in haploid cells.

17. Compare the phases of meiosis I with those of meiosis II.

18. Name the meiotic process that results in genetic recombination.

19. Summarize the major characteristics of spermatogenesis and oogenesis.

20. Identify the relationship between sexual reproduction and genetic variation.

21. Unit 4—Cell Reproduction
   Write a report summarizing how different cancer-fighting drugs kill cancer cells by interrupting the events of the cell cycle.

22. CONCEPT MAPPING Use the following terms to create a concept map that shows the connection between cellular division in prokaryotes and eukaryotes: binary fission, cell cycle, cytokinesis, eukaryote, mitosis, and prokaryote.

CRITICAL THINKING

23. Predicting Results Can mitosis occur in the absence of cytokinesis? Support your answer. If your answer is yes, describe how the new cell would appear in the G₁ phase.

24. Making Calculations If you consider the mass of DNA in a sperm (a haploid cell) to be 1, what would the relative value be for the DNA mass of a cell in the G₂ phase of the cell cycle?

25. Applying Information Does a cell in metaphase II have the same mass of DNA as a diploid cell in the G₁ phase? Assume that both cells are from the same animal. Explain your answer.

26. Analyzing Information The events of mitosis in plants and animals are very similar, with the exception of the absence of centrioles in plants. How has the absence of centrioles in plant cells influenced scientists’ thinking about the function of centrioles in mitosis?

27. Interpreting Graphics The photograph below shows cell division in a grasshopper testis. The offspring cells are gametes. Do you think the photograph shows mitosis or meiosis? Explain your answer.

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DIRECTIONS: Choose the letter of the answer choice that best answers the question.

1. Which of the following statements about prokaryotic chromosomes is true?
   A. Prokaryotes have at least two chromosomes.
   B. Prokaryotic chromosomes consist of a circular DNA molecule.
   C. Prokaryotic chromosomes include histone and nonhistone proteins.
   D. Prokaryotic chromosomes are made of DNA wrapped tightly around histone proteins.

2. Crossing-over occurs during which process?
   F. mitosis
   G. meiosis I
   H. meiosis II
   J. interphase

INTERPRETING GRAPHICS: The graph below shows the relative mass of DNA and chromosome number for a cell undergoing mitosis. Use the graph to answer the questions that follow.

3. In which phase of mitosis do chromatids separate and become individual chromosomes?
   A. prophase
   B. metaphase
   C. anaphase
   D. telophase/cytokinesis

4. What process occurs that leads to the decrease in the cell’s DNA mass?
   F. prophase
   G. metaphase
   H. anaphase
   J. telophase/cytokinesis

DIRECTIONS: Complete the following analogy.

5. prokaryote : binary fission :: eukaryote :
   A. mitosis
   B. cytokinesis
   C. crossing-over
   D. genetic recombination

INTERPRETING GRAPHICS: The diagram below shows a model of cell division. Use the diagram to answer the question that follows.

6. Which type of cell division is shown in the diagram?
   F. mitosis
   G. meiosis
   H. binary fission
   J. sexual reproduction

SHORT RESPONSE

Human cells are either diploid or haploid. All human cells with 46 chromosomes are diploid. Would a human cell with any 23 chromosomes be haploid? Explain your answer.

EXTENDED RESPONSE

For a cell to function efficiently, its surface area must exceed that of its volume.

Part A Explain how cell division maintains the relationship between surface area and volume.

Part B How does a stable ratio between surface area and volume help maintain proper cell functioning?

Test Tip: To help you learn the stages of mitosis and meiosis, make a note card describing each stage, mix the cards up, and practice reordering the stages.
Observing Mitosis in Plant Cells

**OBJECTIVES**
- Examine the dividing root-tip cells of an onion.
- Identify the phase of mitosis that different cells in an onion root tip are undergoing.
- Determine the relative length of time each phase of mitosis takes in onion root-tip cells.

**PROCESS SKILLS**
- observing
- classifying
- collecting
- organizing
- analyzing data
- calculating

**MATERIALS**
- compound light microscope
- prepared microscope slide of a longitudinal section of *Allium* (onion) root tip

**Background**
1. Mitosis is divided into four phases: prophase, metaphase, anaphase, and telophase.
2. Interphase is not considered a part of mitosis.
3. List the visible characteristics of each phase of mitosis.
4. In many plants, there are growth regions called **meristems** where mitosis is ongoing. Meristems are found in the tips of plant roots and shoots.

**PART A Identifying the Phases of Mitosis**

1. Look at the photograph below of a longitudinal section of an onion root tip. Find the meristem on the photograph. As you can see, the meristem is located just behind the root cap.

![ONION ROOT TIP]

---

**TABLE A RELATIVE DURATION OF EACH PHASE OF MITOSIS**

<table>
<thead>
<tr>
<th>Phase of mitosis</th>
<th>Tally marks</th>
<th>Count</th>
<th>Percentage</th>
<th>Time (in minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prophase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metaphase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaphase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telophase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. In your lab report, prepare a data table like Table A.
4. Examine the meristem carefully. Choose a sample of about 50 cells. Look for a group of cells that appear to have been actively dividing at the time that the slide was made. The cells will appear in rows, so it should be easy to keep track of them. The dark-staining bodies are the chromosomes.
5. For each of the cells in your sample, identify the stage of mitosis and place a mark in the “Tally marks” column beside the appropriate phase.

### PART B Calculating the Relative Length of Each Phase

6. When you have classified each cell in your sample, count the tally marks for each phase and fill in the “Count” column. In which phase of mitosis were the greatest number of cells? In which phase were the fewest number of cells?
7. Calculate the percentage of cells found in each phase. Divide the number of cells in a phase by the total number of cells in your sample, and multiply by 100 percent. Enter the figures under “Percentage.”
8. The percentage of cells found in each phase can be used as a measure of how long each phase lasts. For example, if 25 percent of the cells are in prophase, then prophase takes 25 percent of the total time it takes for a cell to undergo mitosis. Mitosis in onion cells takes about 80 minutes. Calculate the actual time for each phase using this information and the percentage you have just determined.

\[
\text{Duration of phase (in minutes)} = \frac{\text{percentage}}{100} \times 80 \text{ minutes}
\]

9. Record the actual time for each phase in your data table.
10. Make another data table, similar to Table B, shown above. Collect and record the count for each phase of mitosis for the entire class. Fill in the percentage and time information using the data collected by the entire class.
11. Clean up your materials before leaving the lab.

### Analysis and Conclusions

1. What color are the chromosomes stained?
2. How can you distinguish between early and late anaphase?
3. According to your data table, which phase of mitosis lasts the longest? Why might this phase require more time than other phases of mitosis?
4. According to your data table, which phase takes the least amount of time?
5. How do your results compare with those of the entire class?
6. In this investigation, you assumed that the percentage of the total time that any given phase takes is equal to the percentage of cells in that phase at any moment. Why might this not be true for very small samples of cells?

### Further Inquiry

1. Given the rate of mitosis in a type of animal cells, how could you determine how long each phase of mitosis takes in those cells?
2. Cancerous tissue is composed of cells undergoing uncontrolled, rapid cell division. How could you develop a procedure to identify cancerous tissue by counting the number of cells undergoing mitosis?