6.2 Process of Meiosis

KEY CONCEPT During meiosis, diploid cells undergo two cell divisions that result in haploid cells.

MAIN IDEAS

- Cells go through two rounds of division in meiosis.
- Haploid cells develop into mature gametes.

VOCABULARY

gametogenesis, p. 176
sperm, p. 176
egg, p. 176
polar body, p. 176

REVIEW AT CLASSZONE.COM

Connect Sometimes division is difficult, such as splitting the bill at a restaurant or dividing people into teams for basketball. Luckily, understanding how meiosis divides chromosomes between cells is not that hard. Meiosis begins with a diploid cell that has already undergone DNA replication. The cell copies the chromosomes once and divides them twice, making four haploid cells.

MAIN IDEA

Cells go through two rounds of division in meiosis.

Meiosis is a form of nuclear division that creates four haploid cells from one diploid cell. This process involves two rounds of cell division—meiosis I and meiosis II. Each round of cell division has four phases, which are similar to those in mitosis. To keep the two processes distinct in your mind, focus on the big picture. Pay attention to how meiosis reduces chromosome number and creates genetic diversity.

Homologous Chromosomes and Sister Chromatids

To understand meiosis, you need to distinguish between homologous chromosomes and sister chromatids. As **FIGURE 6.3** shows, homologous chromosomes are two separate chromosomes: one from your mother, one from your father. Homologous chromosomes are very similar to each other, since they have the same length and carry the same genes. But they are not copies of each other. In contrast, each half of a duplicated chromosome is called a chromatid. Together, the two chromatids are called sister chromatids. Thus, *sister chromatids* refers to the duplicated chromosomes that remain attached (by the centromere). Homologous chromosomes are divided in meiosis I. Sister chromatids are not divided until meiosis II.

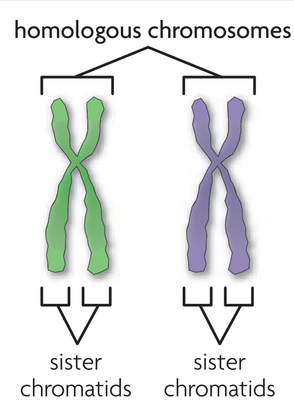


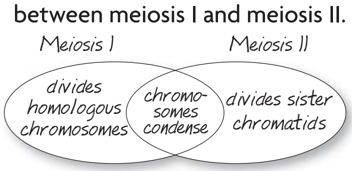
FIGURE 6.3 Homologous chromosomes (shown duplicated) are two separate chromosomes—one inherited from the mother, and one from the father.

***Connecting* CONCEPTS**

Mitosis As you learned in **Chapter 5**, a condensed, duplicated chromosome is made of two chromatids. Sister chromatids separate during anaphase in mitosis.

TAKING NOTES

Draw a Venn diagram like the one below to summarize the similarities and differences between meiosis I and meiosis II.



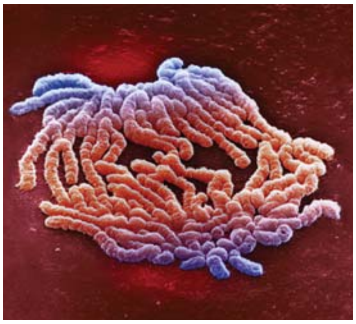


FIGURE 6.4 Homologous chromosomes separate during anaphase I. (colored SEM; magnification 2200×)

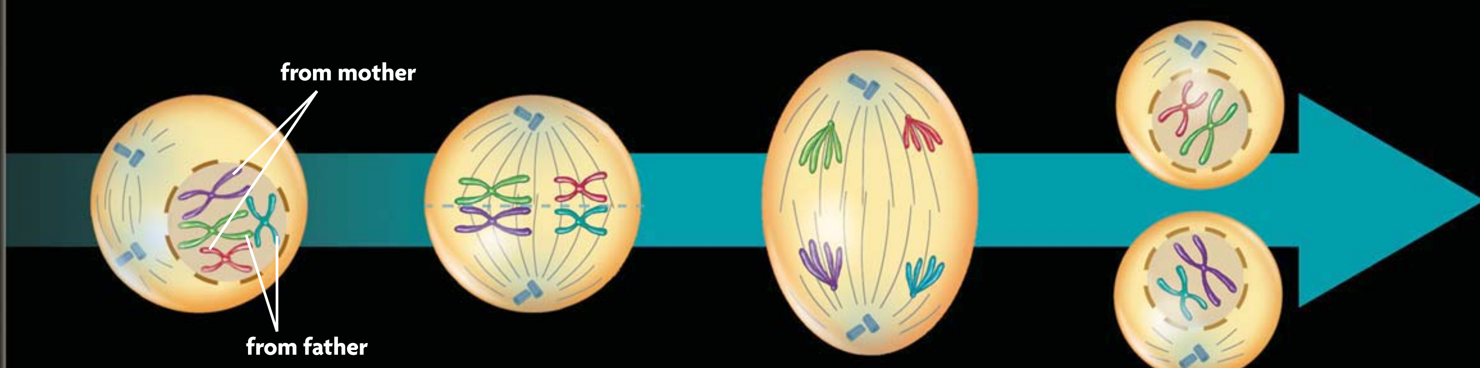
Meiosis I

Before meiosis begins, DNA has already been copied. Meiosis I divides homologous chromosomes, producing two haploid cells with duplicated chromosomes. Like mitosis, scientists describe meiosis in terms of phases, illustrated in **FIGURE 6.5** below. The figure is simplified, showing only four chromosomes.

1. **Prophase I** Early in meiosis, the nuclear membrane breaks down, the centrosomes and centrioles move to opposite sides of the cell, and spindle fibers start to assemble. The duplicated chromosomes condense, and homologous chromosomes pair up. They appear to pair up precisely, gene for gene, down their entire length. The sex chromosomes also pair with each other, and some regions of their DNA appear to line up as well.
2. **Metaphase I** The homologous chromosome pairs are randomly lined up along the middle of the cell by spindle fibers. The result is that 23 chromosomes—some from the father, some from the mother—are lined up along each side of the cell equator. This arrangement mixes up the chromosomal combinations and helps create and maintain genetic diversity. Since human cells have 23 pairs of chromosomes, meiosis may result in 2^{23}, or 8,388,608, possible combinations of chromosomes.
3. **Anaphase I** Next, the paired homologous chromosomes separate from each other and move toward opposite sides of the cell. The sister chromatids remain together during this step and throughout meiosis I.
4. **Telophase I** The nuclear membrane forms again in some species, the spindle fibers disassemble, and the cell undergoes cytokinesis. The end result is two cells that each have a unique combination of 23 duplicated chromosomes coming from both parents.

FIGURE 6.5 Meiosis

Meiosis I divides homologous chromosomes.



1. **Prophase I** The nuclear membrane breaks down. The centrosomes and centrioles begin to move, and spindle fibers start to assemble. The duplicated chromosomes condense, and homologous chromosomes begin to pair up.
2. **Metaphase I** Spindle fibers align the homologous chromosomes along the cell equator. Each side of the equator has chromosomes from both parents.
3. **Anaphase I** The paired homologous chromosomes separate from each other and move toward opposite sides of the cell. Sister chromatids remain attached.
4. **Telophase I** The spindle fibers disassemble, and the cell undergoes cytokinesis.

Meiosis II

Meiosis II divides sister chromatids, and results in undoubled chromosomes. The following description of this process applies to both of the cells produced in meiosis I. Note that DNA is not copied again between these two stages.

5. **Prophase II** The nuclear membrane breaks down, centrosomes and centrioles move to opposite sides of the cell, and spindle fibers assemble.
6. **Metaphase II** Spindle fibers align the 23 chromosomes at the cell equator. Each chromosome still has two sister chromatids at this stage.
7. **Anaphase II** Next, the sister chromatids are pulled apart from each other and move to opposite sides of the cell.
8. **Telophase II** Finally, nuclear membranes form around each set of chromosomes at opposite ends of the cell, the spindle fibers break apart, and the cell undergoes cytokinesis. The end result is four haploid cells with a combination of chromosomes from both the mother and father.

Now that you've seen how meiosis works, let's review some key differences between the processes of meiosis and mitosis.

- Meiosis has two cell divisions. Mitosis has only one cell division.
- During meiosis, homologous chromosomes pair up along the cell equator. During mitosis, homologous chromosomes never pair up.
- In anaphase I of meiosis, sister chromatids remain together. In anaphase of mitosis, sister chromatids separate.
- Meiosis results in haploid cells. Mitosis results in diploid cells.

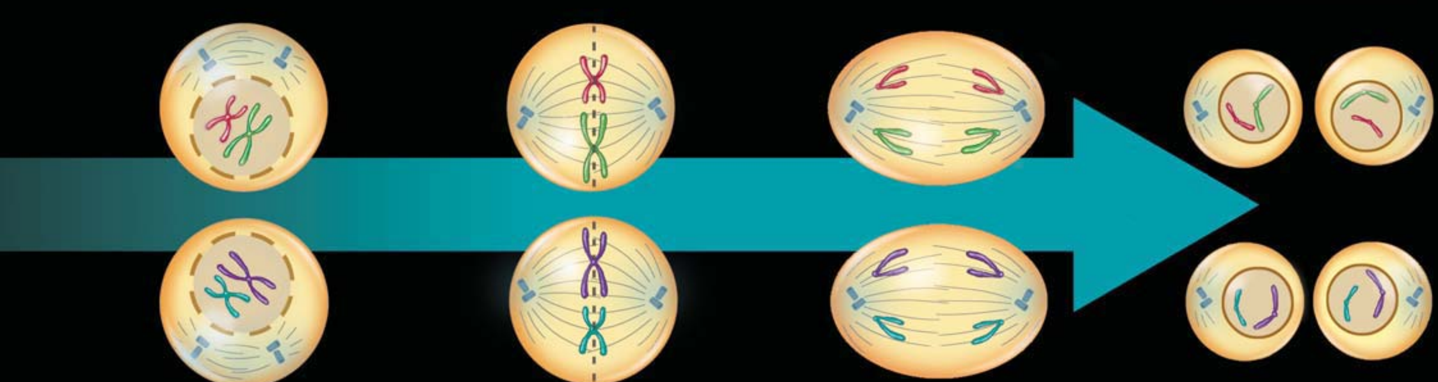
Contrast **What is the major difference between metaphase I and metaphase II?**

Connecting CONCEPTS

Cytokinesis As you learned in **Chapter 5**, cytokinesis is the division of the cell cytoplasm. This process is the same in cells undergoing either mitosis or meiosis.

Animated BIOLOGY
Watch meiosis in action at ClassZone.com.

Meiosis II divides sister chromatids. The overall process produces haploid cells.



5 **Prophase II** The centrosomes and centrioles move to opposite sides of the cell, and spindle fibers start to assemble.

6 **Metaphase II** Spindle fibers align the chromosomes along the cell equator.

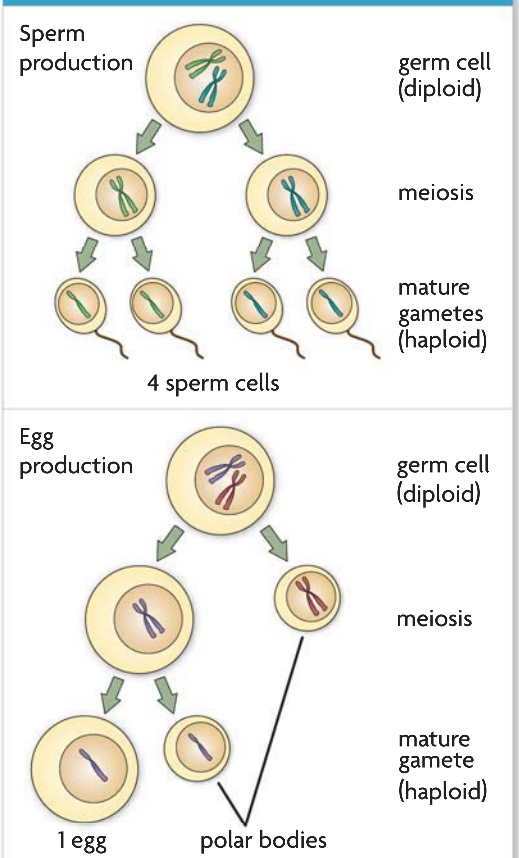
7 **Anaphase II** The sister chromatids are pulled apart from each other and move to opposite sides of the cell.

8 **Telophase II** The nuclear membranes form again around the chromosomes, the spindle fibers break apart, and the cell undergoes cytokinesis.

MAIN IDEA

Haploid cells develop into mature gametes.

FIGURE 6.6 GAMETOGENESIS



Haploid cells are the end result of meiosis. Yet these cells are incapable of fertilization until they go through more changes to form mature gametes. **Gametogenesis** (guh-MEE-tuh-JEHN-ih-sihs) is the production of gametes. As **FIGURE 6.6** shows, gametogenesis includes both meiosis and other changes that produce a mature cell. The final stages of gametogenesis differ between the sexes.

The **sperm** cell, the male gamete, is much smaller than the **egg,** the female gamete. The sperm cell's main contribution to an embryo is DNA. Yet it must swim to an egg to fertilize it, so the ability to move is critical. Sperm formation starts with a round cell and ends by making a streamlined cell that can move rapidly. During this process, significant changes occur. DNA is tightly packed and much of the cytoplasm is lost, forming a compact head. The sperm cell develops a whiplike flagellum and connecting neck region packed with mitochondria that drive the cell. Other changes also take place, such as the addition of new proteins to the cell membrane.

The formation of an egg is a complicated process, as you will read about in greater detail in Chapter 34. It begins before birth, inside the developing body of a female embryo, and is not finished until that egg is fertilized by a sperm many years later. The process includes periods of active development and long periods of inactivity.

An egg not only gives its share of DNA to an embryo but also contributes the organelles, molecular building blocks, and other materials an embryo needs to begin life. Only one of the four cells produced by each round of meiosis actually makes an egg. One cell—the egg—receives most of the organelles, cytoplasm, and nutrients. Many molecules are not evenly distributed throughout the egg's cytoplasm. This unequal distribution of molecules helps cells in the developing embryo to specialize. The other cells produced by meiosis become **polar bodies,** cells with little more than DNA that are eventually broken down. In many species, including humans, the polar body produced by meiosis I does not undergo meiosis II.

NSTA SCiLINKS
scilinks.org
For more about meiosis, go to scilinks.org.
Keycode: MLB006

Apply **Briefly explain how a sperm cell's structure is related to its function.**

6.2 ASSESSMENT

ONLINE QUIZ
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REVIEWING MAIN IDEAS

1. How do homologous chromosomes differ from sister chromatids?
2. Explain why an **egg** is so much larger than a **sperm** cell.

CRITICAL THINKING

3. **Predict** If, during metaphase I, all 23 maternal chromosomes lined up on one side of the cell, would genetic diversity increase? Explain.
4. **Contrast** List the key differences between meiosis I and II.

Connecting CONCEPTS

5. **Cell Biology** Both mitosis and meiosis are types of nuclear division, but they result in different cell types. Describe how the steps of meiosis I differ from those of mitosis.