6.1 Chromosomes and Meiosis

KEY CONCEPT Gametes have half the number of chromosomes that body cells have.

MAIN IDEAS

- You have body cells and gametes.
- Your cells have autosomes and sex chromosomes.
- Body cells are diploid; gametes are haploid.

VOCABULARY

somatic cell, p. 168
gamete, p. 168
homologous chromosome, p. 169
autosome, p. 169
sex chromosome, p. 169
sexual reproduction, p. 170
fertilization, p. 170
diploid, p. 170
haploid, p. 170
meiosis, p. 170

CALIFORNIA STANDARDS

2.b ***Students know*** **only certain cells in a multicellular organism undergo meiosis.**

2.f ***Students know*** **the role of chromosomes in determining an individual's sex.**

2.a *Students know* meiosis is an early step in sexual reproduction in which the pairs of chromosomes separate and segregate randomly during cell division to produce gametes containing one chromosome of each type.

Connect Perhaps you are familiar with the saying, "Everything old is new again." This phrase usually indicates that a past style is again current. However, it applies equally well to you. The fusion of a single egg and sperm cell resulted in the complex creature that is you. There's never been anyone quite like you. And yet the DNA that directs your cells came from your mother and father. And their DNA came from their mother and father, and so on and so on. In this chapter, you will examine the processes that went into making you who you are.

MAIN IDEA

You have body cells and gametes.

You have many types of specialized cells in your body, but they can be divided into two major groups: somatic cells and germ cells. **Somatic cells** (soh-MAT-ihk), also called body cells, make up most of your body tissues and organs. For example, your spleen, kidneys, and eyeballs are all made entirely of body cells. DNA in your body cells is not passed on to your children. Germ cells, in contrast, are cells in your reproductive organs, the ovaries or the testes, that develop into gametes. **Gametes** are sex cells—ova, or eggs, in the female, and spermatozoa, or sperm cells, in the male. DNA in your gametes can be passed on to your children.

Each species has a characteristic number of chromosomes per cell. This number is typically given for body cells, not for gametes. Chromosome number does not seem to be related to the complexity of an organism. For example, yeast have 32 chromosomes, which come in 16 pairs. The fruit flies commonly used in genetic experiments have 8 chromosomes, which come in 4 pairs. A fern holds the record for the most chromosomes—more than 1200. Each of your body cells contains a set of 46 chromosomes, which come in 23 pairs. These cells are genetically identical to each other unless mutations have occurred. As you learned in Chapter 5, cells within an organism differ from each other because different genes are expressed, not because they have different genes.

Identify **Which cell type makes up the brain?**

TAKING NOTES

Make a two-column table to keep track of the vocabulary in this chapter.

Term	Definition
somatic cell	
gamete	

MAIN IDEA

Your cells have autosomes and sex chromosomes.

Suppose you had 23 pairs of gloves. You would have a total of 46 gloves that you could divide into two sets, 23 right and 23 left. Similarly, your body cells have 23 pairs of chromosomes for a total of 46 that can be divided into two sets: 23 from your mother and 23 from your father. Just as you use both gloves when it's cold outside, your cells use both sets of chromosomes to function properly.

Together, each pair of chromosomes is referred to as a homologous pair. In this context, *homologous* means "having the same structure." **Homologous chromosomes** are two chromosomes—one inherited from the mother, one from the father—that have the same length and general appearance. More importantly, these chromosomes have copies of the same genes, although the two copies may differ. For example, if you have a gene that influences blood cholesterol levels on chromosome 8, you will have one copy from your mother and one copy from your father. It is possible that one of these copies is associated with high cholesterol levels, while the other is associated with low cholesterol levels. For convenience, scientists have assigned a number to each pair of homologous chromosomes, ordered from largest to smallest. As **FIGURE 6.1** shows, the largest pair of chromosomes is number 1, the next largest pair is number 2, and so forth.

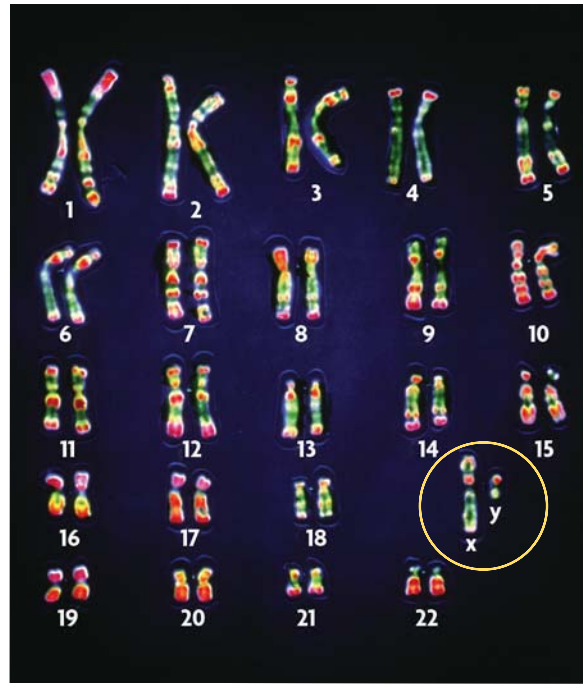


FIGURE 6.1 Human DNA is organized into two sets of 23 chromosomes. Each set contains 22 autosomes and 1 sex chromosome. Females have two X chromosomes. Males have an X and a Y chromosome (circled). (colored LM; magnification 4400×)

Collectively, chromosome pairs 1 through 22 make up your **autosomes,** chromosomes that contain genes for characteristics not directly related to the sex of an organism. But what about the 23rd chromosome pair?

Most sexually reproducing species also have **sex chromosomes** that directly control the development of sexual characteristics. Humans have two very different sex chromosomes, X and Y. How sex is determined varies by species. In all mammals, including humans, an organism's sex is determined by the XY system. An organism with two X chromosomes is female. An organism with one X and one Y chromosome is male. Sex chromosomes make up your 23rd pair of chromosomes. Although the X and Y chromosomes pair with each other, they are not homologous. The X chromosome is the larger sex chromosome and contains numerous genes, including many that are unrelated to sexual characteristics. The Y chromosome is the sex chromosome that contains genes that direct the development of the testes and other male traits. It is the smallest chromosome and carries the fewest genes.

Summarize **Are homologous chromosomes identical to each other? Explain.**

"The parents are both geneticists."

MAIN IDEA

Body cells are diploid; gametes are haploid.

Sexual reproduction involves the fusion of two gametes that results in offspring that are a genetic mixture of both parents. The actual fusion of an egg and a sperm cell is called **fertilization.** When fertilization occurs, the nuclei of the egg and sperm cell fuse to form one nucleus. This new nucleus must have the correct number of chromosomes for a healthy new organism to develop. Therefore, the egg and sperm cell need only half the usual number of chromosomes—one chromosome from each homologous pair.

Diploid and Haploid Cells

Body cells and gametes have different numbers of chromosomes. Your body cells are diploid. **Diploid** (DIHP-LOYD) means a cell has two copies of each chromosome: one copy from the mother, and one copy from the father. Diploid cells can be represented as 2*n*. In humans, the diploid chromosome number is 46.

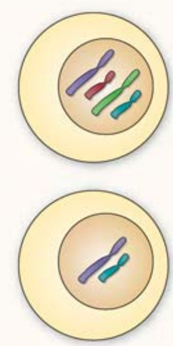
Gametes are not diploid cells; they are haploid cells, represented as *n*. **Haploid** (HAP-LOYD) means that a cell has only one copy of each chromosome. Each human egg or sperm cell has 22 autosomes and 1 sex chromosome. In the egg, the sex chromosome is always an X chromosome. In the sperm cell, the sex chromosome can be an X chromosome or a Y chromosome. The reason for this difference will be discussed in the following sections.

VOCABULARY

Diploid comes from the Greek word *diplous,* which means "double". *Haploid* comes from the Greek word *haplous,* which means "single."

VISUAL VOCAB

Diploid cells have two copies of each chromosome: one copy from the mother and one from the father.



Haploid cells have only one copy of each chromosome.

Maintaining the correct number of chromosomes is important to the survival of all organisms. Typically, a change in chromosome number is harmful. However, increasing the number of sets of chromosomes can, on occasion, give rise to a new species. The fertilization of nonhaploid gametes has played an important role in plant evolution by rapidly making new species with more than two sets of chromosomes. For example, some plants have four copies of each chromosome, a condition called tetraploidy (4*n*). This type of event has occurred in many groups of plants, but it is very rare in animals.

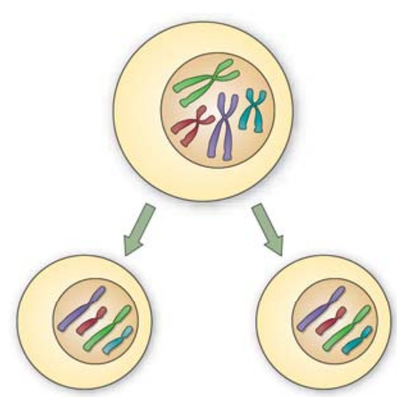
***Connecting* CONCEPTS**

Plant Life Cycles As you will learn in **Chapter 22**, all plants complete their life cycle by alternating between two phases: diploid and haploid. During the diploid phase, plants make spores. During the haploid phase, plants make gametes.

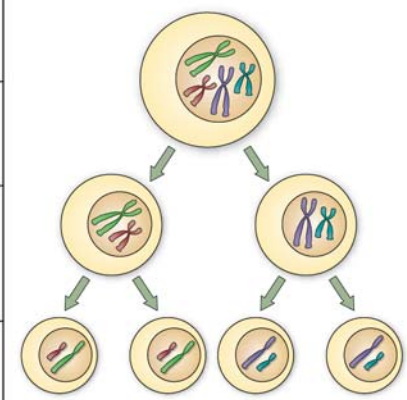
Meiosis

Germ cells in your reproductive organs undergo the process of meiosis to form gametes. **Meiosis** (my-OH-sihs) is a form of nuclear division that divides a diploid cell into haploid cells. This process is essential for sexual reproduction. The details of meiosis will be presented in the next section. But **FIGURE 6.2** highlights some differences between mitosis and meiosis in advance to help you keep these two processes clear in your mind.

FIGURE 6.2 Comparing Mitosis and Meiosis



MITOSIS	MEIOSIS
Produces genetically identical cells	Produces genetically unique cells
Results in diploid cells	Results in haploid cells
Takes place throughout an organism's lifetime	Takes place only at certain times in an organism's life cycle
Involved in asexual reproduction	Involved in sexual reproduction



Compare **Using the diagrams above, explain how you think the process of meiosis differs from mitosis.**

In Chapter 5 you learned about mitosis, another form of nuclear division. Recall that mitosis is a process that occurs in body cells. It helps produce daughter cells that are genetically identical to the parent cell. In cells undergoing mitosis, DNA is copied once and divided once. Both the parent cell and the daughter cells are diploid. Mitosis is used for development, growth, and repair in all types of organisms. It is also used for reproduction in asexually reproducing eukaryotes.

In contrast, meiosis occurs in germ cells to produce gametes. This process is sometimes called a "reduction division" because it reduces chromosome number by half. In cells undergoing meiosis, DNA is copied once but divided twice. Meiosis makes genetically unique haploid cells from a diploid cell. These haploid cells then undergo more processing in the ovaries or testes, finally forming mature gametes.

Apply **Why is it important that gametes are haploid cells?**

6.1 ASSESSMENT

ONLINE QUIZ ClassZone.com

REVIEWING MAIN IDEAS

1. Where are germ cells located in the human body? **2.b**
2. What is the difference between an **autosome** and a **sex chromosome**?
3. Is the cell that results from **fertilization** a **haploid** or **diploid** cell? Explain. **2.a**

CRITICAL THINKING

4. **Infer** Does mitosis or **meiosis** occur more frequently in your body? Explain your answer. **2.b**
5. **Analyze** Do you think the Y chromosome contains genes that are critical for an organism's survival? Explain your reasoning. **2.f**

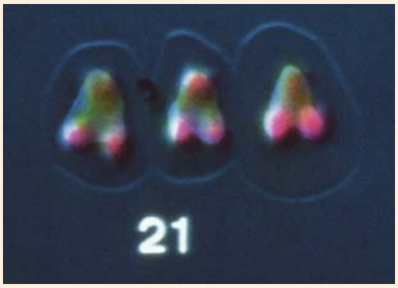
Connecting CONCEPTS

6. **Telomeres** The ends of DNA molecules form telomeres that help keep the ends of chromosomes from sticking to each other. Why might this be especially important in germ cells, which go through meiosis and make haploid **gametes**?

DATA ANALYSIS ClassZone.com

Genetic Data

Bar graphs use bars to show data. In a bar graph, the independent variable is usually graphed on the *x*-axis and the dependent variable is usually graphed on the *y*-axis. Both axes are labeled with the name and unit of the variable.



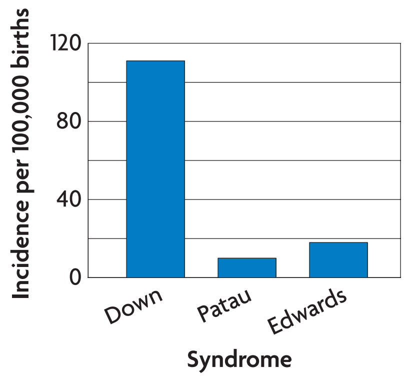
In most cases, Down syndrome results from having an extra chromosome 21. (colored LM; magnification 2000×)

EXAMPLE

The bar graph below contains data about the frequency of some genetic disorders in the human population. Each of the disorders listed is the result of nondisjunction, the failure of two chromosomes to separate properly during meiosis. This results in one extra chromosome or one less chromosome being passed on to the offspring.

For each syndrome on the *x*-axis, the bar extends vertically on the *y*-axis to represent the incidence per 100,000 births. For example, out of 100,000 births, 111 children are born with Down syndrome.

GRAPH 1. FREQUENCY OF GENETIC DISORDERS



Source: U.S. National Library of Medicine

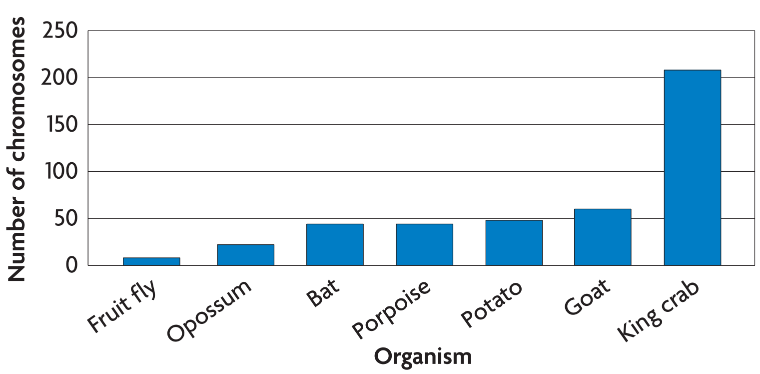
CALIFORNIA STANDARDS

IE.1.d Formulate explanations by using logic and evidence.

INTERPRET A BAR GRAPH

The bar graph below contains data about the diploid number of chromosomes in different organisms.

GRAPH 2. DIPLOID NUMBER OF CHROMOSOMES IN VARIOUS ORGANISMS



Source: Rutgers University

1. **Analyze** Which organism has the greatest number of chromosomes? The least?
2. **Evaluate** Does chromosome number appear to correlate to the type of organism? Explain.
3. **Hypothesize** Do you think there is an upper limit to chromosome number? Explain.

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

CALIFORNIA STANDARDS

2.a ***Students know*** **meiosis is an early step in sexual reproduction in which the pairs of chromosomes separate and segregate randomly during cell division to produce gametes containing one chromosome of each type.**

2.e ***Students know*** **why approximately half of an individual's DNA sequence comes from each parent.**

2.c *Students know* how random chromosome segregation explains the probability that a particular allele will be in a gamete.

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.

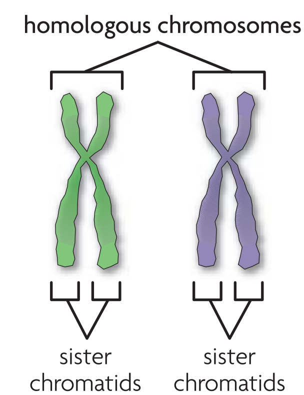


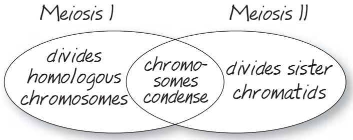
FIGURE 6.3 Homologous chromosomes (shown duplicated) are two separate chromosomes—one inherited from the mother, and one from the father.

***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.



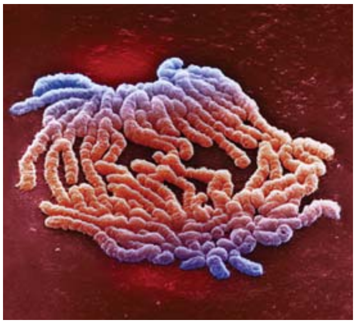


FIGURE 6.4 Homologous chromosomes separate during anaphase I. (colored SEM; magnification 2200×)

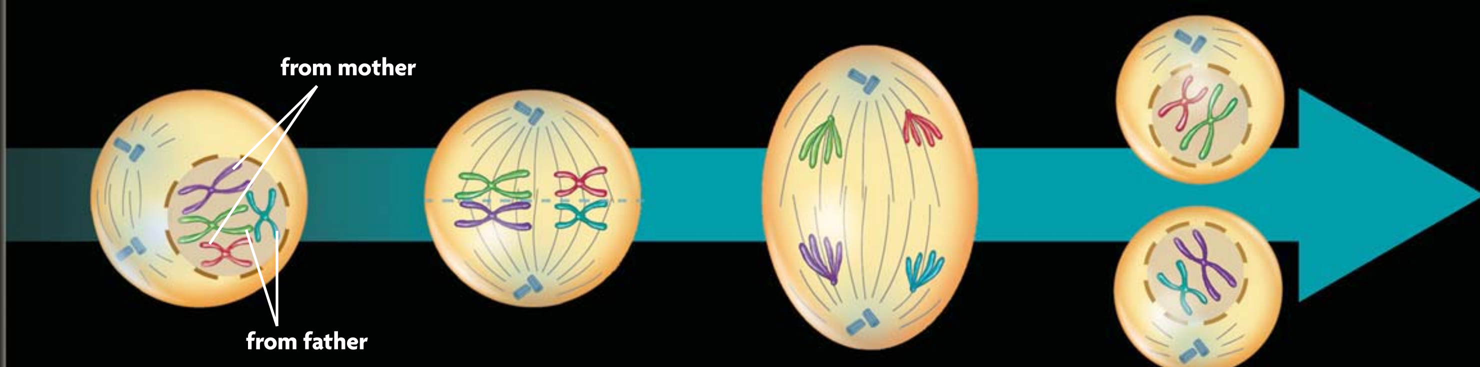
Meiosis I

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.

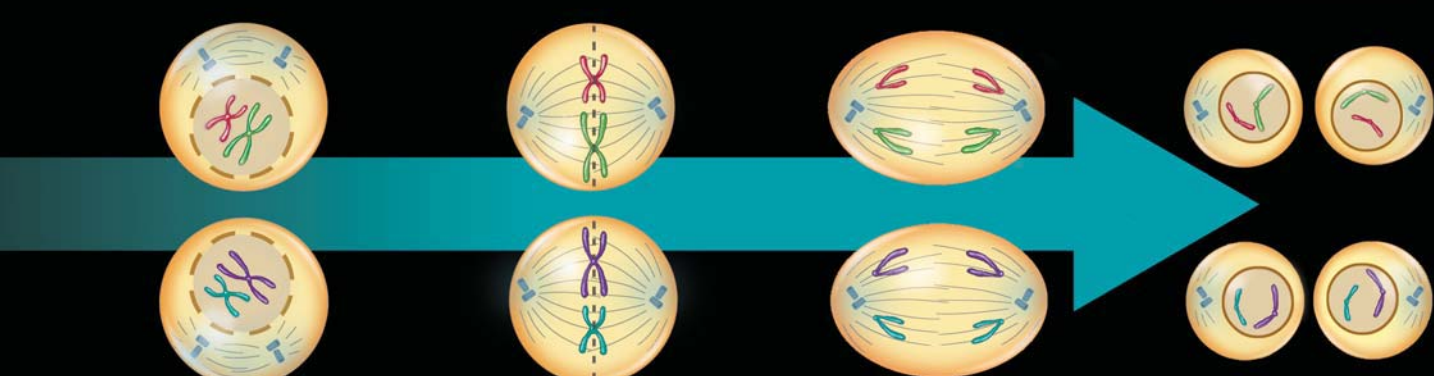
Contrast **What is the major difference between metaphase I and metaphase II?**

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.

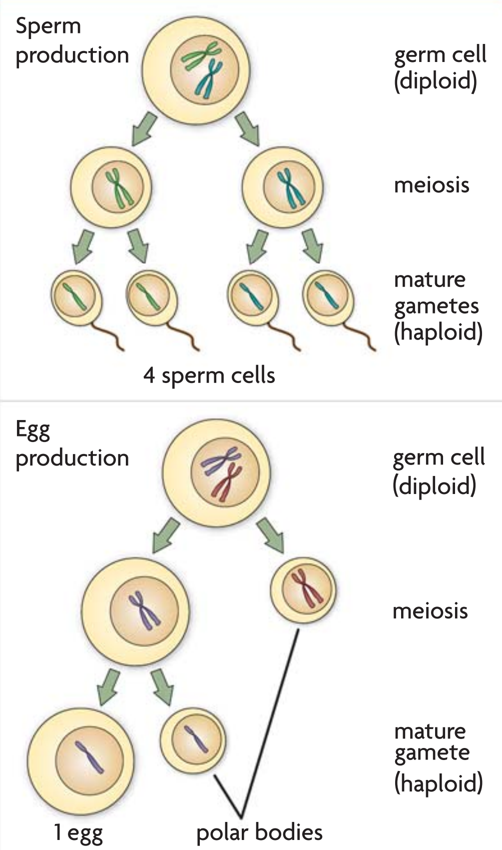
7 **Anaphase II** The sister chromatids are pulled apart from each other and move to opposite sides of the cell.

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 ClassZone.com

REVIEWING MAIN IDEAS

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

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. **2.c**
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.