GLOBAL EDITION

Campbell Essential Biology

SEVENTH EDITION

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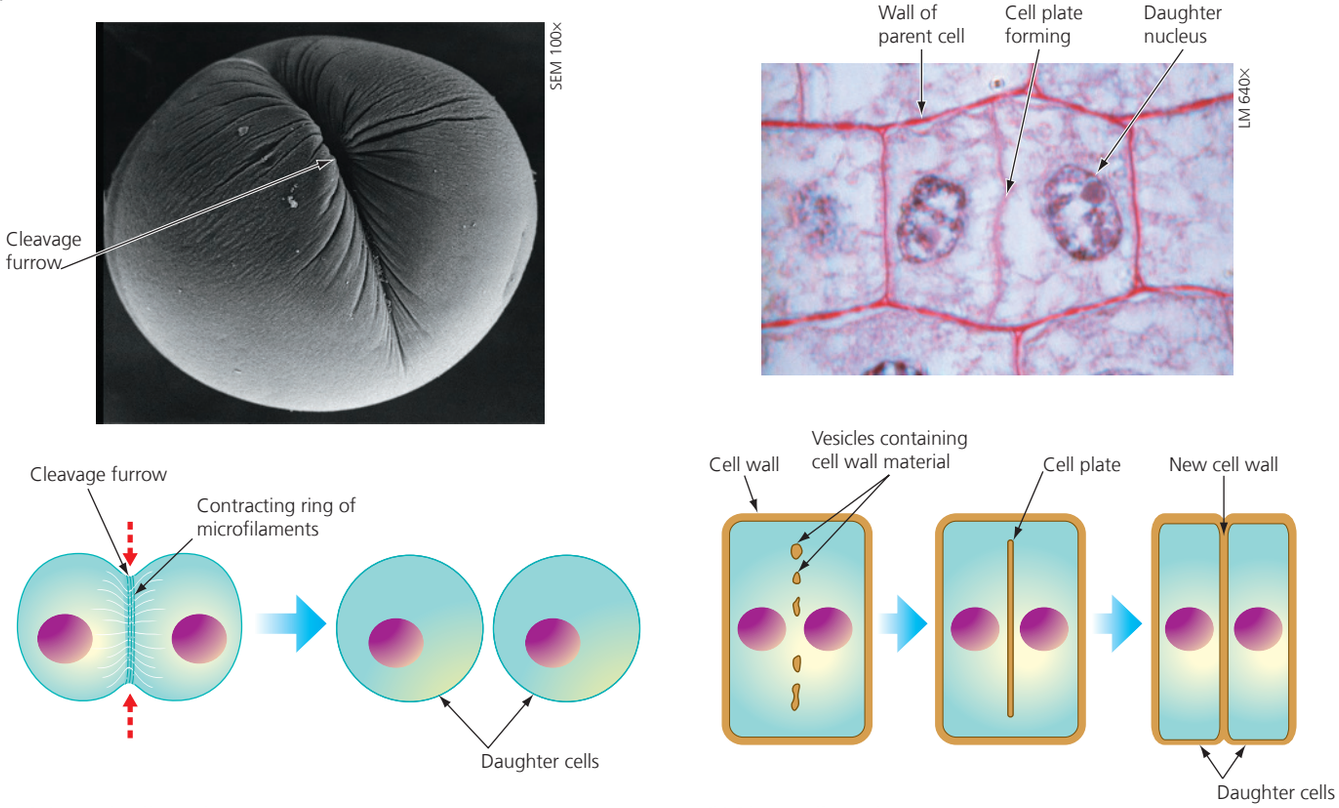
▼ Figure 8.8 Cytokinesis in animal and plant cells.



(a) Animal cell cytokinesis

(b) Plant cell cytokinesis

✓ CHECKPOINT

An organism called a plasmodial slime mold is one huge cytoplasmic mass with many nuclei. Explain how a variation in the cell cycle could cause this "monster cell" to arise.

■ *Answer: Mitosis occurs repeatedly without cytokinesis.*

Cytokinesis, the division of the cytoplasm into two cells, usually begins during telophase, overlapping the end of mitosis. In animal cells, the cytokinesis process is known as **cleavage**. The first sign of cleavage is the appearance of an indentation called a cleavage furrow. A ring of microfilaments in the cytoplasm just under the plasma membrane contracts, like the pulling of a drawstring on a hooded sweatshirt, deepening the furrow and pinching the parent cell in two **(Figure 8.8a)**.

Cytokinesis in a plant cell occurs differently. Vesicles containing cell wall material collect at the middle of the cell. The vesicles fuse, forming a membranous disk called the **cell plate**. The cell plate grows outward, accumulating more cell wall material as more vesicles join it. Eventually, the membrane of the cell plate fuses with the plasma membrane, and the cell plate's contents join the parental cell wall. The result is two daughter cells **(Figure 8.8b)**. ✓

Cancer Cells: Dividing Out of Control

For a plant or animal to grow and maintain its tissues normally, it must control the timing of cell division—speeding up, slowing down, or turning the process off or on as needed. The sequential events of the cell cycle are directed by a **cell cycle control system** that consists of specialized proteins within the cell. These proteins integrate information from the environment and from other body cells and send "stop" and "go-ahead" signals at certain key points during the cell cycle. For example, the cell cycle normally halts within the G_1 phase of interphase unless the cell receives a go-ahead signal through certain control proteins. If that signal never arrives, the cell will switch into a permanently nondividing state. The cell cycles of your nerve and muscle cells, for example, are arrested this way. If the go-ahead signal is received and the G_1 checkpoint is passed, the cell will usually complete the rest of the cycle. **Therefore, the reproductive behavior of cells—whether they will divide or not—results from interactions of many different molecules.**

What Is Cancer?

Cancer, which currently claims the lives of one out of every five people in the United States and other industrialized nations, is a disease of the cell cycle. Cancer cells do not respond normally to the cell cycle control system; they divide excessively and may invade other tissues of the body. If unchecked, cancer cells may continue to divide until they kill the host. Cancer cells are thus referred to as

"immortal" because, unlike other human cells, they will never cease dividing. In fact, thousands of laboratories around the world today use a laboratory strain of human cells that were originally obtained from a woman named Henrietta Lacks, who died of cervical cancer in 1951.

The abnormal behavior of cancer cells begins when a single cell undergoes genetic changes (mutations) in one or more genes that encode for proteins in the cell cycle control system. These changes cause the cell to grow abnormally. The immune system generally recognizes and destroys such cells. However, if the cell evades destruction, it may proliferate to form a **tumor**, an abnormally growing mass of body cells. If the abnormal cells remain at the original site, the lump is called a **benign tumor**. Benign tumors can cause problems if they grow large and disrupt certain organs, such as the brain, but often they can be completely removed by surgery and are rarely deadly.

A TUMOR RESULTS FROM AN ERROR IN THE DIVISION OF ONE OF THE BODY'S OWN CELLS.

In contrast, a **malignant tumor** is one that has the potential to spread into neighboring tissues and other parts of the body, forming new tumors **(Figure 8.9)**. A malignant tumor may or may not have actually begun to spread, but if it does, it will soon displace normal tissue and interrupt organ function. A person with a malignant tumor is said to have **cancer**. The spread of cancer cells beyond their original site is called **metastasis**, and such cells are said to metastasize. Cancers are named according to where they originate. Liver cancer, for example, always begins in liver tissue and may metastasize from there.

Cancer Treatment

Once a tumor starts growing in the body, how can it be treated? There are three main types of cancer treatment. Surgery to remove a tumor is usually the first step. For many benign tumors, surgery alone may be sufficient. If not, the next step is usually **radiation therapy**. Cancerous tumors are exposed to high-energy radiation, which harms cancer cells more than normal cells. Radiation therapy is often effective against malignant tumors that have not yet spread. However, radiation can damage normal body cells enough to produce side effects, such as nausea and hair loss. **Chemotherapy**, the use of drugs to disrupt cell division, is used to treat tumors that have spread throughout the body. Some chemotherapy drugs prevent cell division by interfering with the mitotic spindle. Other drugs prevent the mitotic spindle from forming in the first place. Chemotherapy often has significant side effects because it contacts and may damage many different body tissues.

Frontiers of Cancer Treatment

Medical researchers are constantly searching for new ways to combat cancerous cells. One particularly promising area is immunotherapy, treatments that use the body's immune system to attack tumors. Immunotherapy can be accomplished by boosting the body's natural immunity in general or by boosting specific immune components that attack cancer cells. Alternatively, immune components (such as proteins specifically designed to recognize and help destroy cancer cells) may be created in the lab and injected into a patient. This type of therapy has been effective against cancers of the breast, stomach, and some forms of leukemia and lymphoma. Many cancer researchers believe that immunotherapy represents the next major breakthrough in cancer treatment that could save many lives in the coming decades.

Cancer Prevention and Survival

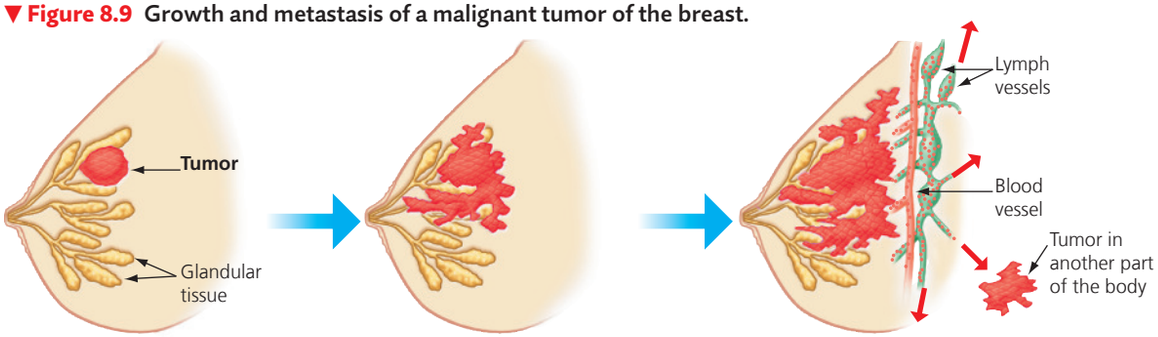
Although cancer can strike anyone, there are certain lifestyle changes you can make to reduce your chances of developing cancer or increase your chances of surviving it. Not smoking, exercising adequately (usually defined as at least 150 minutes of moderate exercise each week), avoiding overexposure to the sun, and eating a high-fiber, low-fat diet can all help reduce the likelihood of getting cancer. Seven types of cancer can be easily detected: skin and oral (by physical exam), breast (by self-exams or mammograms for higher-risk women and women 50 and older), prostate (by rectal exam), cervical (by Pap smear), testicular (by self-exam), and colon (by colonoscopy). Regular visits to the doctor can help identify tumors early, which is the best way to increase the chance of successful treatment. ✅

✅ CHECKPOINT

What differentiates a benign tumor from a malignant tumor?

■ *Answer: A benign tumor remains at its point of origin, whereas a malignant tumor can spread.*

▼ Figure 8.9 Growth and metastasis of a malignant tumor of the breast.



A tumor grows from a single cancer cell.

Cancer cells invade neighboring tissue.

Metastasis: Cancer cells spread through lymph and blood vessels to other parts of the body.

Meiosis, the Basis of Sexual Reproduction

Only maple trees produce more maple trees; only goldfish make more goldfish; and only people make more people. These simple facts of life have been recognized for thousands of years and are reflected in the age-old saying, "Like begets like." But in a strict sense, "Like begets like" applies only to asexual reproduction, where offspring inherit all their DNA from a single parent. Asexual offspring are exact genetic replicas of that one parent and of each other, and their appearances are very similar.

The family photo in **Figure 8.10** makes the point that in a sexually reproducing species like does not exactly beget like. You probably resemble your biological parents more closely than you resemble strangers, but you do not look exactly like your parents or a sibling—unless you are an identical twin. Each offspring of sexual reproduction inherits a unique combination of genes from its two parents, and this combined set of genes programs a unique combination of traits. As a result, sexual reproduction can produce tremendous variety among offspring.

▲ **Figure 8.10 The varied products of sexual reproduction.** Every child inherits a unique combination of genes from his or her parents and displays a unique combination of traits.

Sexual reproduction depends on the cellular processes of meiosis and fertilization. But before exploring these processes, we need to return to chromosomes and the role they play in the life cycle of sexually reproducing organisms.

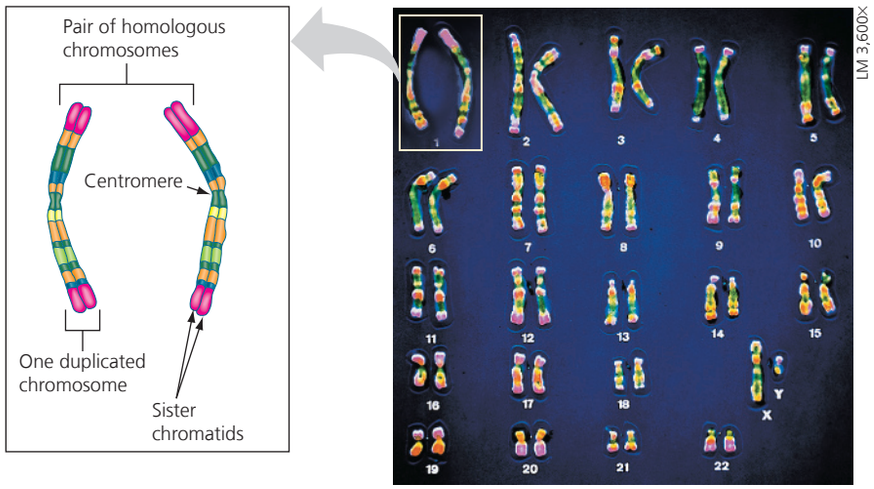
Homologous Chromosomes

If we examine cells from different individuals of a single species—sticking to one sex, for now—we find that they have the same number and types of chromosomes. Viewed with a microscope, your chromosomes would look exactly like those of Beyoncé (if you're a woman) or Jay Z (if you're a man).

A typical body cell, called a **somatic cell**, has 46 chromosomes in humans. A technician can break open a human cell in metaphase of mitosis, stain the chromosomes with dyes, take a picture with the aid of a microscope, and arrange the chromosomes in matching pairs by size. The resulting display is called a **karyotype (Figure 8.11)**. Notice in the figure that each chromosome is duplicated, with two sister chromatids joined along their length. Within the white box, for example, each "stick" is actually a pair of sister chromatids stuck together (as shown in the drawing to the left). Notice also that almost every chromosome has a twin that resembles it in length and centromere position; in the figure, the white box surrounds one set of twin chromosomes. The two chromosomes of such a matching pair, called **homologous chromosomes**, carry genes controlling the same inherited characteristics. For example, if a gene influencing freckles is located at a particular place on one chromosome—within the yellow band in the drawing in Figure 8.11, for instance—then the homologous chromosome has that same gene in the same location. However, the two homologous chromosomes may have different versions of the same gene. Let's restate this concept because it often confuses students: A pair of homologous chromosomes has two nearly identical chromosomes, each of which consists of two identical sister chromatids after chromosome duplication.

In human females, the 46 chromosomes fall neatly into 23 homologous pairs. For a male, however, the chromosomes in one pair do not look alike. This nonmatching pair, only partly homologous, is the male's sex chromosomes. **Sex chromosomes** determine a person's sex (male versus female). In mammals, males have one X chromosome and one Y chromosome. Females have two X chromosomes. (Other organisms have different

▼ **Figure 8.11 Pairs of homologous chromosomes in a human male karyotype.** This karyotype shows 22 completely homologous pairs (autosomes) and a 23rd pair that consists of an X chromosome and a Y chromosome (sex chromosomes). With the exception of X and Y, the homologous chromosomes of each pair match in size, centromere position, and staining pattern.



systems; in this chapter, we focus on humans.) The remaining chromosomes (44 in humans), found in both males and females, are called **autosomes**. For both autosomes and sex chromosomes, you inherited one chromosome of each pair from your mother and the other from your father.

Gametes and the Life Cycle of a Sexual Organism

The **life cycle** of a multicellular organism is the sequence of generation-to-generation stages from fertilization to the production of its own offspring. Having two sets of chromosomes, one inherited from each parent, is a key factor in the life cycle of humans and all other species that reproduce sexually. **Figure 8.12** shows the human life cycle, emphasizing the number of chromosomes.

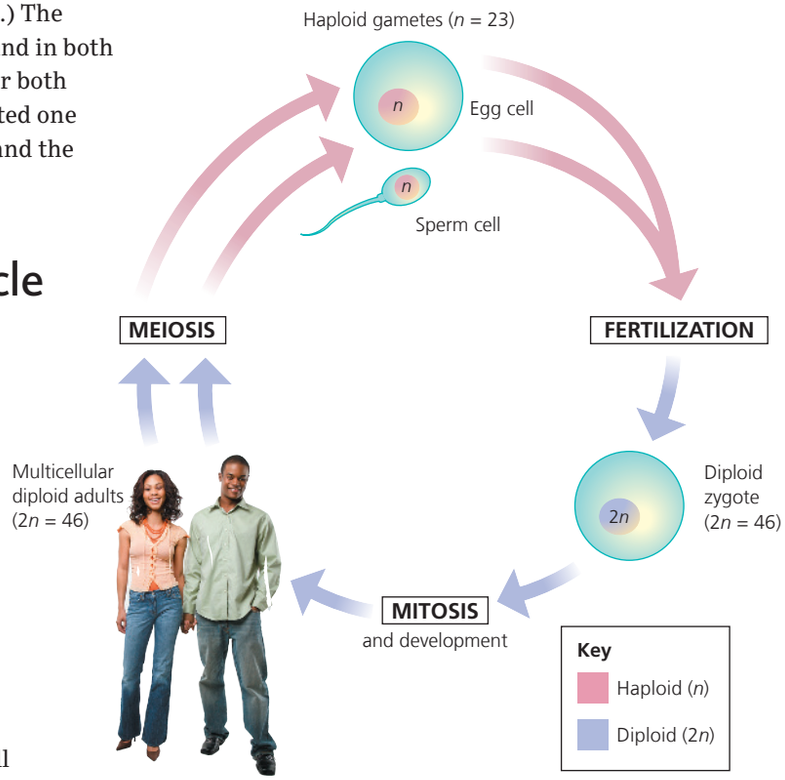


Figure Walkthrough
Mastering Biology
goo.gl/AJGKBd

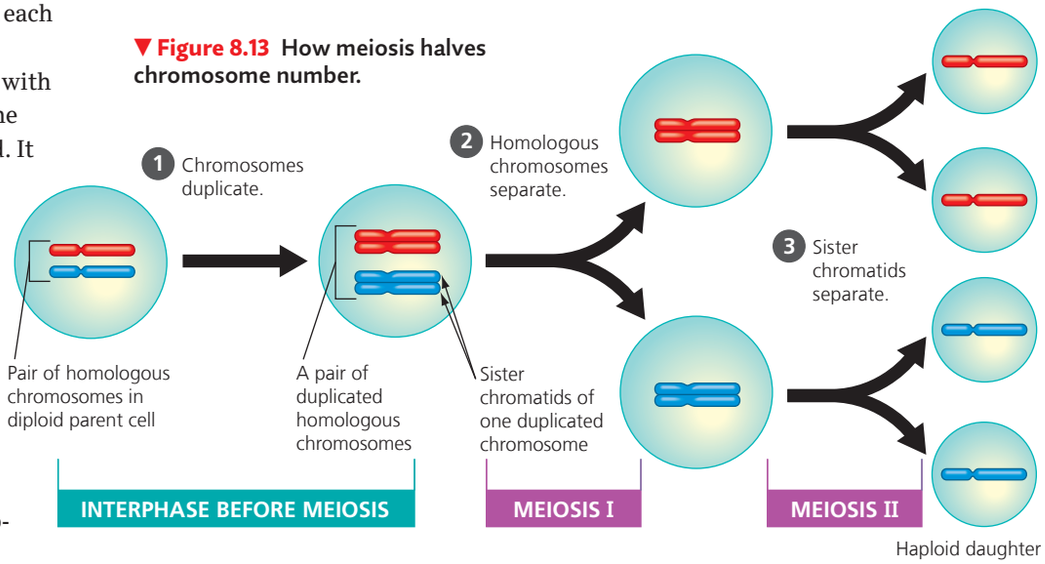
◀ Figure 8.12 The human life cycle. In each generation, the doubling of chromosome number that results from fertilization is offset by the halving of chromosome number during meiosis.

Humans (as well as most other animals and many plants) are **diploid** organisms because all typical body cells (somatic cells) contain pairs of homologous chromosomes. In other words, all your chromosomes come in matching sets. This is similar to shoes in your closet: You may have 46 shoes, but they are organized as 23 pairs, with the members of each pair being nearly identical to each other. The total number of chromosomes, 46 in humans, is the diploid number (abbreviated 2*n*). The gametes, egg and sperm cells, are not diploid. Made by meiosis in an ovary or testis, each gamete has a single set of chromosomes: 22 autosomes plus a sex chromosome, either X or Y. A cell with a single chromosome set is called a **haploid** cell; it has only one member of each pair of homologous chromosomes. To visualize the haploid state, imagine your closet containing only one shoe from each pair. For humans, the haploid number, *n*, is 23.

In the human life cycle, a haploid sperm fuses with a haploid egg in a process called **fertilization**. The resulting fertilized egg, called a **zygote**, is diploid. It has two sets of chromosomes, one set from each parent. The life cycle is completed as a sexually mature adult develops from the zygote. Mitotic cell division ensures that all somatic cells of the human body receive a copy of all of the zygote's 46 chromosomes. Thus, every one of the trillions of cells in your body can trace its ancestry back through mitotic divisions to the single zygote produced when your father's sperm and your mother's egg fused about nine months before you were born (although you probably don't want to dwell on those details!).

Producing haploid gametes by meiosis keeps the chromosome number from doubling in every generation. To illustrate, **Figure 8.13** tracks one pair of homologous chromosomes. ❶ Each of the chromosomes is duplicated during interphase (before mitosis). ❷ The first division, meiosis I, segregates the two chromosomes of the homologous pair, packaging them in separate (haploid) daughter cells. But each chromosome is still doubled. ❸ Meiosis II separates the sister chromatids. Each of the four daughter cells is haploid and contains only a single chromosome from the pair of homologous chromosomes.

▼ Figure 8.13 How meiosis halves chromosome number.



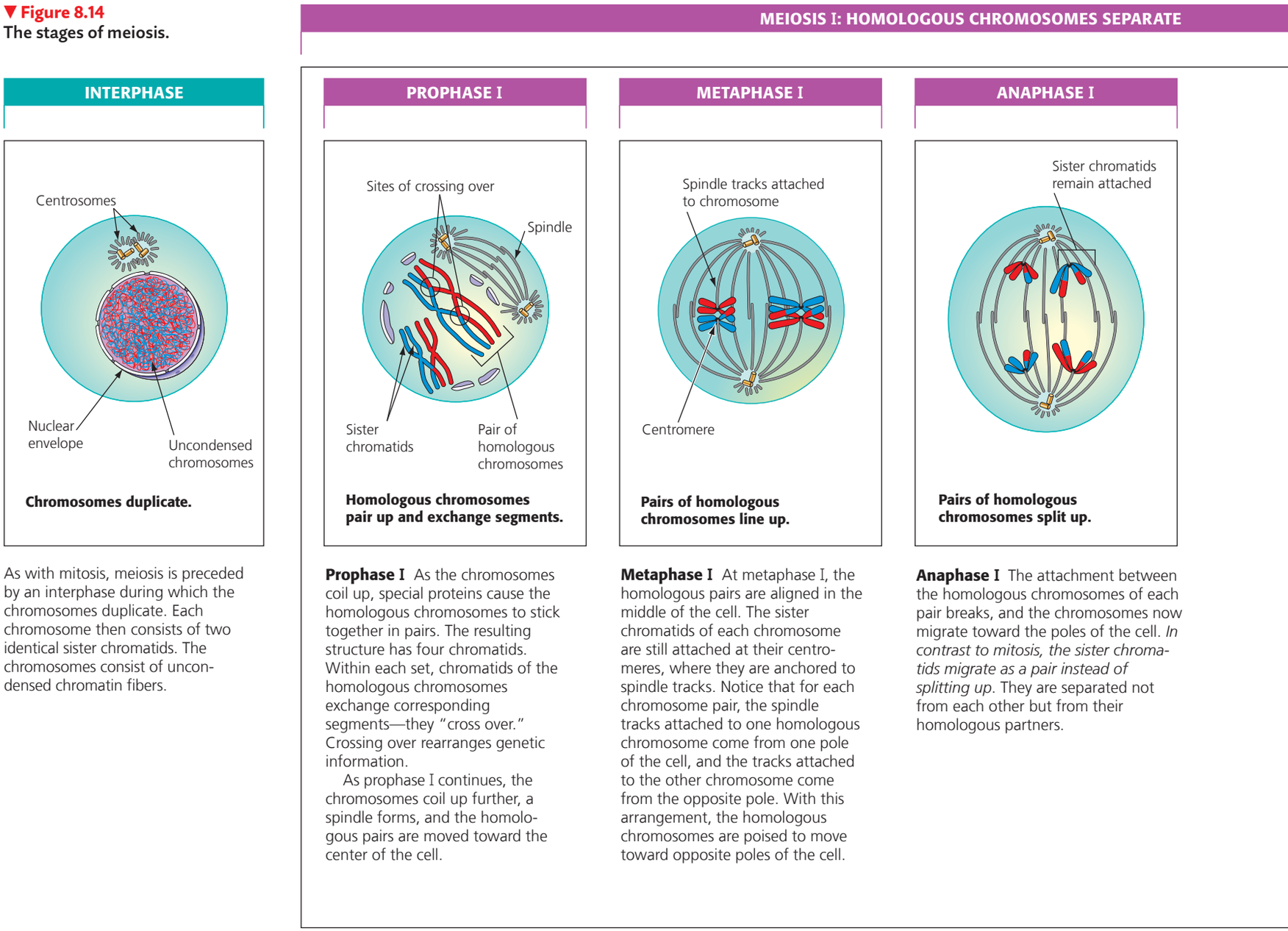
The Process of Meiosis

Meiosis, the process of cell division that produces haploid gametes in diploid organisms, resembles mitosis, but with two important differences. The first difference is that during meiosis the number of chromosomes is cut in half. In meiosis, a cell that has duplicated its chromosomes undergoes two consecutive divisions, called meiosis I and meiosis II. Because one duplication of the chromosomes is followed by two divisions, each of the four daughter cells resulting from meiosis has a haploid set of chromosomes—half as many chromosomes as the starting cell.

The second difference between meiosis and mitosis is an exchange of genetic material—pieces of chromosomes—between homologous chromosomes. This exchange, called crossing over, occurs during the first prophase of meiosis. We'll look more closely at crossing over later. For now, study **Figure 8.14**, including the text below it, which describes the stages of meiosis in detail for a hypothetical animal cell containing four chromosomes.

As you go through Figure 8.14, keep in mind the difference between homologous chromosomes and sister chromatids: The two chromosomes of a homologous pair are individual chromosomes that were inherited from

▼ Figure 8.14
The stages of meiosis.



As with mitosis, meiosis is preceded by an interphase during which the chromosomes duplicate. Each chromosome then consists of two identical sister chromatids. The chromosomes consist of uncondensed chromatin fibers.

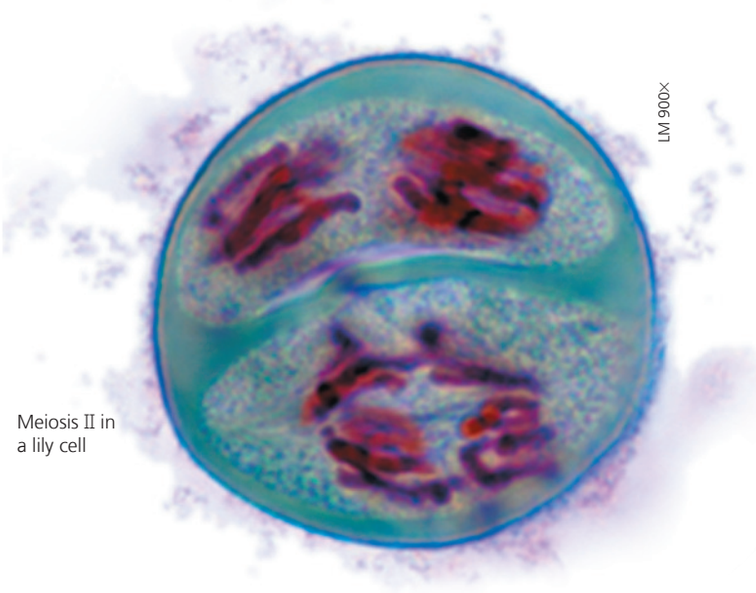
Prophase I As the chromosomes coil up, special proteins cause the homologous chromosomes to stick together in pairs. The resulting structure has four chromatids. Within each set, chromatids of the homologous chromosomes exchange corresponding segments—they "cross over." Crossing over rearranges genetic information.

As prophase I continues, the chromosomes coil up further, a spindle forms, and the homologous pairs are moved toward the center of the cell.

Metaphase I At metaphase I, the homologous pairs are aligned in the middle of the cell. The sister chromatids of each chromosome are still attached at their centromeres, where they are anchored to spindle tracks. Notice that for each chromosome pair, the spindle tracks attached to one homologous chromosome come from one pole of the cell, and the tracks attached to the other chromosome come from the opposite pole. With this arrangement, the homologous chromosomes are poised to move toward opposite poles of the cell.

Anaphase I The attachment between the homologous chromosomes of each pair breaks, and the chromosomes now migrate toward the poles of the cell. *In contrast to mitosis, the sister chromatids migrate as a pair instead of splitting up.* They are separated not from each other but from their homologous partners.

different parents, one from the mother and one from the father. The members of a pair of homologous chromosomes in Figure 8.14 (and later figures) are identical in size and shape but colored in the illustrations differently (red versus blue) to remind you that they differ in this way. In the interphase just before meiosis, each chromosome duplicates to form sister chromatids that remain together until anaphase of meiosis II. Before crossing over occurs, sister chromatids are identical and carry the same versions of all their genes. ✓



Meiosis II in a lily cell

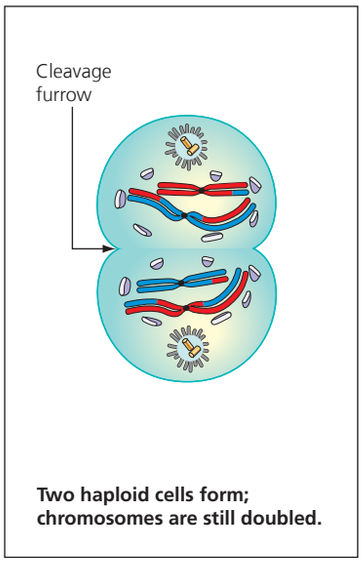
✓ CHECKPOINT

If a single diploid somatic cell with 18 chromosomes undergoes meiosis and produces sperm, the result will be _____ sperm, each with _____ chromosomes. (Provide two numbers.)

■ Answer: four; nine

MEIOSIS II: SISTER CHROMATIDS SEPARATE

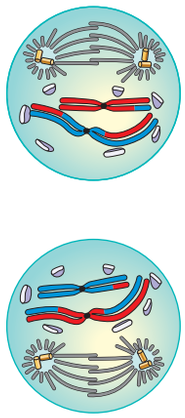
TELOPHASE I AND CYTOKINESIS



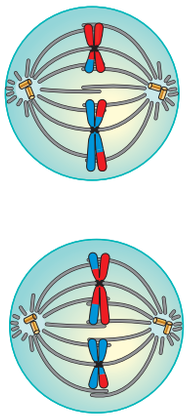
Two haploid cells form; chromosomes are still doubled.

Telophase I and Cytokinesis In telophase I, the chromosomes arrive at the poles of the cell. When they finish their journey, each pole has a haploid chromosome set, although each chromosome is still in duplicate form. Usually, cytokinesis occurs along with telophase I, and two haploid daughter cells are formed.

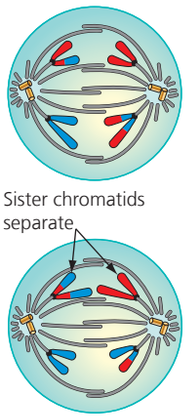
PROPHASE II



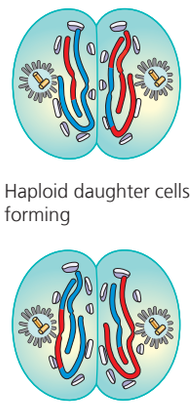
METAPHASE II



ANAPHASE II



TELOPHASE II AND CYTOKINESIS



During another round of cell division, the sister chromatids finally separate; four haploid daughter cells result, containing single chromosomes.

The Process of Meiosis II Meiosis II is essentially the same as mitosis. The important difference is that meiosis II starts with a haploid cell that has **not** undergone chromosome duplication during the preceding interphase.

During prophase II, a spindle forms and moves the chromosomes toward the middle of the cell. During metaphase II, the chromosomes are aligned as they are in mitosis, with the tracks attached to the sister chromatids of each chromosome coming from opposite poles.

In anaphase II, the centromeres of sister chromatids separate, and the sister chromatids of each pair move toward opposite poles of the cell. In telophase II, nuclei form at the cell poles, and cytokinesis occurs at the same time. There are now four haploid daughter cells, each with single chromosomes.