Quick Review

Answer the following without referring to earlier sections of your book.

1. **Define** the terms *evolution* and *natural selection*. (Chapter 1, Section 1)

2. **Define** the term *homologous chromosomes*, and identify chromatids. (Chapter 6, Section 1)

3. **Differentiate** between haploid cells and diploid cells. (Chapter 6, Section 1)

4. **Describe** the structure and function of the spindle. (Chapter 6, Section 3)

5. **Summarize** the steps of mitosis. (Chapter 6, Section 3)

*Did you have difficulty?* For help, review the sections indicated.

Looking Ahead

**Section 1**

**Meiosis**
- Formation of Haploid Cells
- Meiosis and Genetic Variation
- Meiosis and Gamete Formation

**Section 2**

**Sexual Reproduction**
- Sexual and Asexual Reproduction
- Sexual Life Cycles in Eukaryotes

Reading Activity

Take a few moments to study the first two pages in Section 1, including Figure 1. Then on a sheet of paper or in your notebook, answer the following questions:

- What is the topic of Section 1?
- How are meiosis I and meiosis II similar?
- How are meiosis I and meiosis II different?

A special form of cell reproduction produces the egg and sperm cells shown here. When an egg joins with a single sperm cell, genetic instructions from a male and female are combined, and a new individual is formed.
Meiosis

Formation of Haploid Cells

Some organisms reproduce by joining gametes to form the first cell of a new individual. The gametes are haploid—they contain one set of chromosomes. Imagine how the chromosome number would increase with each generation if chromosome reduction did not occur!

Meiosis is a form of cell division that halves the number of chromosomes when forming specialized reproductive cells, such as gametes or spores. Meiosis involves two divisions of the nucleus—meiosis I and meiosis II.

Before meiosis begins, the DNA in the original cell is replicated. Thus, meiosis starts with homologous chromosomes. Recall that homologous chromosomes are similar in size, shape, and genetic content. The stages of meiosis are summarized in Figure 1.

**Step 1** Prophase I
The chromosomes condense, and the nuclear envelope breaks down. Homologous chromosomes pair along their length. Crossing-over occurs when portions of a chromatid on one homologous chromosome are broken and exchanged with the corresponding chromatid portions of the other homologous chromosome.

**Figure 1**

Stages of Meiosis

Four cells are produced, each with half as much genetic material as the original cell.

1. **Prophase I**
   - Chromosomes become visible. The nuclear envelope breaks down.
   - Crossing-over occurs.

2. **Metaphase I**
   - Pairs of homologous chromosomes move to the equator of the cell.

3. **Anaphase I**
   - Homologous chromosomes move to opposite poles of the cell.

4. **Telophase I and cytokinesis**
   - Chromosomes gather at the poles of the cell.
   - The cytoplasm divides.
Step 2 **Metaphase I** The pairs of homologous chromosomes are moved by the spindle to the equator of the cell. The homologous chromosomes remain together.

Step 3 **Anaphase I** The homologous chromosomes separate. As in mitosis, the chromosomes of each pair are pulled to opposite poles of the cell by the spindle fibers. *But the chromatids do not separate at their centromeres—each chromosome is still composed of two chromatids. The genetic material, however, has recombined.*

Step 4 **Telophase I** Individual chromosomes gather at each of the poles. In most organisms, the cytoplasm divides (cytokinesis), forming two new cells. Both cells or poles contain one chromosome from each pair of homologous chromosomes. *Chromosomes do not replicate between meiosis I and meiosis II.*

Step 5 **Prophase II** A new spindle forms around the chromosomes.

Step 6 **Metaphase II** The chromosomes line up along the equator and are attached at their centromeres to spindle fibers.

Step 7 **Anaphase II** The centromeres divide, and the chromatids (now called chromosomes) move to opposite poles of the cell.

Step 8 **Telophase II** A nuclear envelope forms around each set of chromosomes. The spindle breaks down, and the cell undergoes cytokinesis. The result of meiosis is four haploid cells.
Meiosis and Genetic Variation

Meiosis is an important process that allows for the rapid generation of new genetic combinations. Three mechanisms make key contributions to this genetic variation: independent assortment, crossing-over, and random fertilization.

**Independent Assortment**

Most organisms have more than one chromosome. In humans, for example, each gamete receives one chromosome from each of 23 pairs of homologous chromosomes. But, which of the two chromosomes that an offspring receives from each of the 23 pairs is a matter of chance. This random distribution of homologous chromosomes during meiosis is called **independent assortment**. Independent assortment is summarized in Figure 2. Each of the 23 pairs of chromosomes segregates (separates) independently. Thus, \(2^{23}\) (about 8 million) gametes with different gene combinations can be produced from one original cell by this mechanism.

**Crossing-Over and Random Fertilization**

The DNA exchange that occurs during crossing-over adds even more recombination to the independent assortment of chromosomes that occurs later in meiosis. Thus, the number of genetic combinations that can occur among gametes is practically unlimited.

---

**Figure 2 Independent assortment**

The same cell is shown twice. Because each pair of homologous chromosomes separates independently, four different gametes can result in each case.

- **Possibility 1**
  - Metaphase of meiosis I
    - The arrangement of chromosomes in each of these cells is equally probable.
  - Gametocytes with different possible combinations

- **Possibility 2**
  - Metaphase of meiosis II
  - The same cell is shown twice. Because each pair of homologous chromosomes separates independently, four different gametes can result in each case.
Furthermore, the zygote that forms a new individual is created by the random joining of two gametes (each gamete produced independently). Because fertilization of an egg by a sperm is random, the number of possible outcomes is squared \(2^{23} \times 2^{23} = 64\) trillion.

**Importance of Genetic Variation**

Meiosis and the joining of gametes are essential to evolution. No genetic process generates variation more quickly. In many cases, the pace of evolution appears to increase as the level of genetic variation increases. For example, when domesticated animals such as cattle and sheep are bred for large size, many large animals are produced at first. But as the existing genetic combinations become used up, the ability to obtain larger and larger animals slows down. Further progress must then wait for the formation of new gene combinations.

Racehorse breeding provides another example. Thoroughbred racehorses are all descendants of a small number of individuals, and selection for speed has accomplished all it can with this limited amount of genetic variation. The winning times in major races stopped dramatically improving decades ago.

The pace of evolution is sped up by genetic recombination. The combination of genes from two organisms results in a third type, not identical to either parent. But bear in mind that natural selection does not always favor genetic change. Indeed, many modern organisms are little changed from their ancestors of the distant past. Natural selection may favor existing combinations of genes, slowing the pace of evolution.

---

**Modeling Crossing-Over**

You can use paper strips and pencils to model the process of crossing-over.

**Materials**

4 paper strips, pens or pencils (two colors), scissors, tape

**Procedure**

1. Using one color, write the letters \(A\) and \(B\) on two paper strips. These two strips will represent one of the two homologous chromosomes shown above.

2. Using a second color, write the letters \(a\) and \(b\) on two paper strips. These two strips will represent the second homologous chromosome shown above.

3. Use your chromosome models, scissors, and tape to demonstrate crossing-over between the chromatids of two homologous chromosomes.

**Analysis**

1. Determine what the letters \(A\), \(B\), \(a\), and \(b\) represent.

2. Infer why the chromosomes you made are homologous.

3. Compare the number of different types of chromatids (combinations of \(A\), \(B\), \(a\), and \(b\)) before crossing-over with the number after crossing-over.

4. Critical Thinking

Applying Information

How does crossing-over relate to genetic recombination?

---

**WORD Origins**

The word *meiosis* is from the Greek word *meioun*, meaning “to make smaller.” Knowing this makes it easier to remember that during meiosis, the chromosome number is reduced by half to form haploid gametes.
Meiosis and Gamete Formation

The fundamental events of meiosis occur in all sexually reproducing organisms. However, organisms vary in timing and structures associated with gamete formation. Meiosis is the primary event in the formation of gametes—gametogenesis.

Meiosis in Males

The process by which sperm are produced in male animals is called spermatogenesis ( spur mat uh JEHN uh sihs ). Spermatogenesis occurs in the testes (male reproductive organs). As illustrated in Figure 3, a diploid cell first increases in size and becomes a large immature cell (germ cell). The large cell then undergoes meiosis I. Two cells are produced, each of which undergoes meiosis II to form a total of four haploid cells. The four cells change in form and develop a tail to become male gametes called sperm.

Meiosis in Females

The process by which gametes are produced in female animals is called oogenesis ( oh oh JEHN uh sihs ). Oogenesis, summarized in Figure 3, occurs in the ovaries (female reproductive organs). Notice that during cytokinesis following meiosis I, the cytoplasm divides unequally. One of the resulting cells gets nearly all of the cytoplasm. It is this cell that will ultimately give rise to an egg cell. The other cell is very small and is called a polar body. The polar body may divide again, but its offspring cells will not survive.

Figure 3  Meiosis in male and female animals

Meiosis of a male diploid cell results in four haploid sperm, while meiosis of a female diploid cell results in only one functional haploid egg cell.
The larger cell undergoes meiosis II, and the division of the egg cell during cytokinesis is again unequal. The larger cell develops into a gamete called an **ovum** (plural, ova) or, more commonly, egg. The smaller cell, the second polar body, dies. Because of its larger share of cytoplasm, the mature ovum has a rich storehouse of nutrients. These nutrients nourish the young organism that develops if the ovum is fertilized.

### Section 1 Review

1. **Explain** the significance of meiosis in sexual reproduction.  
2. **Name** the stage of meiosis during which chromatids are separated to opposite poles of the cell.  
3. **Compare** the processes of crossing-over and independent assortment.  
4. **Differentiate** gamete formation in male animals from gamete formation in female animals.  

### Critical Thinking Evaluating Information

If one cell in a dog (2n = 78) undergoes meiosis and another cell undergoes mitosis, how many chromosomes will each resulting cell contain?

If a cell begins meiosis with two pairs of homologous chromosomes, how many chromatids will be in each cell that is produced at the end of meiosis I?  

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>C</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>D</td>
<td>8</td>
</tr>
</tbody>
</table>

### Oogenesis in Drosophila

Researchers have examined oogenesis in great detail in the fruit fly, *Drosophila melanogaster*. As in other animals, eggs in *Drosophila* are produced when germ cells divide. Four rapid cell divisions produce 16 cells, which form a cluster known as a germ cell cyst. Bridges called **ring canals** interconnect all cells in the cyst. However, only one of the cells develops into an egg. The other 15 cells become nurse cells, which donate organelles—including mitochondria and parts of the endoplasmic reticulum—to the growing egg. The organelles move through the ring canals by traveling along a network of microtubules. Some scientists believe that this movement reflects an organized sorting process, in which functional organelles collect in the egg and damaged organelles collect in the nurse cells. The nurse cells die as the egg completes its development.

### Oogenesis in Other Organisms

A comparable process of cyst formation takes place during oogenesis in the mouse. As in the fruit fly, many cellular components are redistributed among the cells in the cyst. These findings suggest that the early steps in egg formation may be very similar in a wide range of organisms.
Sexual and Asexual Reproduction

Some organisms look exactly like their parents and siblings. Others share traits with family members but are not identical to them. Some organisms have two parents, while others have one. The type of reproduction that produces an organism determines how similar the organism is to its parents and siblings. Reproduction, the process of producing offspring, can be asexual or sexual.

In asexual reproduction, a single parent passes copies of all of its genes to each of its offspring; there is no fusion of haploid cells such as gametes. An individual produced by asexual reproduction is a clone, an organism that is genetically identical to its parent. As you have read, prokaryotes reproduce by a type of asexual reproduction called binary fission. Many eukaryotes, as shown in Figure 4, also reproduce asexually.

In contrast, in sexual reproduction, two parents each form reproductive cells that have one-half the number of chromosomes. A diploid mother and father would give rise to haploid gametes, which join to form diploid offspring. Because both parents contribute genetic material, the offspring have traits of both parents but are not exactly like either parent. As shown in Figure 5, sexual reproduction, with the formation of haploid cells, occurs in eukaryotic organisms, including humans.

Types of Asexual Reproduction

There are many different types of asexual reproduction. For example, amoebas reproduce by fission, the separation of a parent into two or more individuals of about equal size. Some multicellular eukaryotes undergo fragmentation, a type of reproduction in which the body breaks into several pieces. Some or all of these fragments later develop into complete adults when missing parts are regrown. Other organisms, like the hydra shown in Figure 4, undergo budding, in which new individuals split off from existing ones. The bud may break from the parent and become an independent organism, or it may remain attached to the parent. An attached bud can eventually give rise to a group of many individuals.
Genetic Diversity
Asexual reproduction is the simplest and most primitive method of reproduction. In a stable environment, asexual reproduction allows organisms to produce many offspring in a short period of time, without using energy to produce gametes or to find a mate. However, the DNA of these organisms varies little between individuals. This may be a disadvantage in a changing environment because a population of organisms may not be able to adapt to a new environment.

On the other hand, sexual reproduction provides a powerful means of quickly making different combinations of genes among individuals. Such genetic diversity is the raw material for evolution.

Evolution of Sexual Reproduction
The evolution of sexual reproduction may have allowed early protists to repair their own DNA. Only diploid cells can repair certain kinds of chromosome damage, such as breaks in both strands of DNA. Many modern protists are haploid most of the time, and they reproduce asexually. (They form a diploid cell only in response to stress in the environment.) Thus the process of meiosis and the pairing of homologous chromosomes may have allowed early protistan cells to repair damaged DNA. This hypothesis is further supported by the fact that many enzymes that repair DNA damage are involved in meiosis.

Observing Reproduction in Yeast

Yeast are unicellular organisms that live in liquid or moist environments. You can examine a culture of yeast to observe one of the types of reproduction that yeast can undergo.

Materials
- microscope, microscope slides, dropper, culture of yeast

Procedure
1. Make a wet mount of a drop of yeast culture.
2. Observe the yeast with a compound microscope under low power.
3. Look for yeast that appear to be in “pairs.”
4. Observe the pairs under high power, and then make drawings of your observations.

Analysis
1. Infer the type of reproduction you observed when the yeast appeared to be in pairs.
2. Identify the reason for your answer.
3. Determine, by referring to your textbook, the name of the type of reproduction you observed.
Sexual Life Cycles in Eukaryotes

The entire span in the life of an organism from one generation to the next is called a life cycle. The life cycles of all sexually reproducing organisms follows a basic pattern of alternation between the diploid and haploid chromosome numbers. The type of sexual life cycle that a eukaryotic organism has depends on the type of cell that undergoes meiosis and on when meiosis occurs. Eukaryotes that undergo sexual reproduction can have one of three types of sexual life cycles: haploid, diploid, or alternation of generations.

Haploid Life Cycle

The haploid life cycle is the simplest of sexual life cycles. In this life cycle, shown in Figure 6, haploid cells occupy the major portion of the life cycle. The zygote is the only diploid cell, and it undergoes meiosis immediately after it is formed, creating new haploid cells. The haploid cells give rise to haploid multicellular individuals that produce gametes by mitosis (not meiosis). In a process called fusion, the gametes fuse to produce a diploid zygote, and the cycle continues.

When the diploid zygote undergoes meiosis it provides an opportunity for the cell to correct any genetic damage, as discussed earlier. The damage is repaired during meiosis, when the two homologous chromosomes are lined up side-by-side in preparation for crossing over. Special repair enzymes remove any damaged sections of double stranded DNA, and fill in any gaps. This type of life cycle is found in many protists, as well as in some fungi and algae, such as the unicellular Chlamydomonas (KLUH mih duh moh nuhs), shown in Figure 6.

**Figure 6** Haploid life cycle. Some organisms, such as Chlamydomonas, have haploid cells as a major portion of their life cycle.
Diploid Life Cycle

The outstanding characteristic of the diploid life cycle is that adult individuals are diploid, each individual inheriting chromosomes from two parents. In most animals, including humans, a diploid reproductive cell undergoes meiosis to produce gametes.

As shown in Figure 7, the gametes (sperm and egg cells) join in a process called fertilization, which results in a diploid zygote. After fertilization, the resulting zygote begins to divide by mitosis. This single diploid cell eventually gives rise to all of the cells of the adult. The cells of the adult are also diploid since they are produced by mitosis.

The diploid individual that develops from the zygote occupies the major portion of the diploid life cycle. The gametes are the only haploid cells in the diploid life cycle; all of the other cells are diploid.

Cloning by Parthenogenesis

A snake is born to a mother that did not have a mate. Although this may sound impossible, or like some headline in a tabloid magazine, this can actually occur in nature. Parthenogenesis (pahr thuh noh JEHN uh sihs) is a type of reproduction in which a new individual develops from an unfertilized egg. Since there is no male that contributes genetic material, the offspring is a clone (genetically identical) of the mother. Clones are usually produced in nature by asexual reproduction. Parthenogenesis, however, is a special form of cloning.

How Does Parthenogenesis Occur?

Parthenogenesis in snakes has usually occurred in older females that have lived many years without male companionship, such as those in a zoo. It is hypothesized that in the mother snake, her own chromosomes are copied in place of the missing father’s chromosomes, thereby self-fertilizing her egg. Other scientists think that after a long absence of males, some unknown signal (such as a hormone) triggers the egg to start dividing.

Organisms That Undergo Parthenogenesis

Organisms capable of reproducing by parthenogenesis include dandelions, hawkweeds, and some fishes, lizards, and frogs. Whiptail lizards are all females that lay eggs that hatch without any male contributions. Honeybees also produce male drones by parthenogenesis.

Parthenogenesis is not thought to be possible in mammals. Embryos of mammals that do not have genes from both a female and a male parent do not develop normally. The only natural mammalian clones known are identical twins, which develop when a fertilized egg splits and two individuals develop.
Alternation of Generations

Plants, algae, and some protists have a life cycle that regularly alternates between a haploid phase and a diploid phase. As shown in Figure 8, in plants, the diploid phase in the life cycle that produces spores is called a **sporophyte** (SPOH ruh fiet). Spore-forming cells in the sporophyte undergo meiosis to produce spores. A **spore** is a haploid reproductive cell produced by meiosis that is capable of developing into an adult without fusing with another cell. Thus, unlike a gamete, a spore gives rise to a multicellular individual called a gametophyte (guh MEET uh fiet) without joining with another cell.

In the life cycle of a plant, the **gametophyte** is the haploid phase that produces gametes by mitosis. The gametophyte produces gametes that fuse and give rise to the diploid phase. Thus, the sporophyte and gametophyte generations take turns, or alternate, in the life cycle.

In moss, for example, haploid spores develop in a capsule at the tip of the sporophyte “stalk.” When the lid of the capsule pops off, the spores scatter. The spores germinate by mitosis and eventually form sexually mature gametophytes. The male gametophytes release sperm which swim through a film of moisture to the eggs in the female gametophyte. The diploid zygote develops as a sporophyte within the gametophyte and the life cycle continues.

It is important not to lose sight of the basic similarity of all three types of sexual life cycles. All three involve an alternation of haploid and diploid phases. The three types of sexual life cycles differ from each other only in which phases become multicellular.

---

**Figure 8 Alternation of generations**

Some organisms, such as roses, have a life cycle that alternates between diploid and haploid phases.

---

**Section 2 Review**

1. **Identify** the type of reproduction that results in offspring that are genetically identical to their parent. 🌹 6E
2. **Describe** two different types of eukaryotic asexual reproduction. 🌹 6E
3. **Compare** the haploid life cycle found in *Chlamydomonas* with a diploid life cycle.
4. **Summarize** the process of alternation of generations. 🌹 4B
5. **Critical Thinking Evaluating Information**
   Evaluate the significance of mutations and repair of mutations to the evolution of sexual reproduction. 🌹 6C
6. **TAKS Test Prep**
   The amount of genetic variation in offspring is greatest in organisms that reproduce:
   - A sexually through meiosis.
   - B sexually through fission.
   - C asexually through mitosis.
   - D asexually through budding.
Key Concepts

1. **Meiosis**
   - Meiosis reduces the number of chromosomes by half to form reproductive cells. When the reproductive cells unite in fertilization, the normal diploid number is restored.
   - During meiosis I, homologous chromosomes separate. Crossing-over during prophase I results in the exchange of genetic material between homologous chromosomes.
   - During meiosis II, the two chromatids of each chromosome separate. As a result of meiosis, four haploid cells are produced from one diploid cell.
   - Independent assortment, crossing-over, and random fertilization contribute to produce genetic variation in sexually reproducing organisms.
   - In sexually reproducing eukaryotic organisms, gametes form through the process of spermatogenesis in males and oogenesis in females.

2. **Sexual Reproduction**
   - Asexual reproduction is the formation of offspring from one parent. The offspring are genetically identical to the parent.
   - Sexual reproduction is the formation of offspring through the union of gametes. The offspring are genetically different from their parents.
   - A disadvantage to asexual reproduction in a changing environment is the lack of genetic diversity among the offspring.
   - Sexual reproduction increases variation in the population by making possible genetic recombination.
   - Sexual reproduction may have begun as a mechanism to repair damaged DNA.
   - Eukaryotic organisms can have one of three kinds of sexual life cycles, depending on the type of cell that undergoes meiosis and on when meiosis occurs.

Unit 4—Cell Reproduction
Use Topics 5–6 in this unit to review the key concepts and terms in this chapter.