Focus

Overview

Before beginning this section review with your students the objectives listed in the Student Edition. This section introduces students to the processes of meiosis, spermatogenesis, and oogenesis. Students will also learn how these processes relate to genetic variation.

Bellringer

Pose this question to your students: "If a *human* sperm and egg each had 46 chromosomes, like other human body cells, how many chromosomes would a fertilized egg have?" (92) Then ask students to explain why increasing the number of chromosomes a human cell has might cause problems. (Answers will vary, but students should note that it would change the genetic makeup of *Homo sapiens*.) **LS Logical**

Motivate

Demonstration

On the board, draw a sperm cell near an egg cell. Draw three homologous chromosome pairs in each cell. Tell students that when the sperm fertilizes the egg, the number of chromosomes in the resulting cell, the new individual, will double. Lead students to the conclusion that the number of chromosomes in sperm and egg cells must be halved, or the number of chromosomes in each subsequent generation will continue to double. Tell students that the process by which the chromosome number is halved when reproductive cells are formed is called meiosis. **LS Visual**

Section 1 Meiosis

Objectives

- **Summarize** the events that occur during meiosis.
- **Relate** crossing-over, independent assortment, and random fertilization to genetic variation.
- **Compare** spermatogenesis and oogenesis.

Key Terms

meiosis
crossing-over
independent assortment
spermatogenesis
sperm
oogenesis
ovum

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 *(meye OH sihs)* 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.

BIO graphic

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.

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did you know?

Meiosis Timeframe In human males, meiosis and sperm production take about 9 weeks. It's a continuous process that begins at puberty. In females, meiosis and egg production begin before birth. The process stops abruptly, however, and does not begin again until a girl enters puberty. Until a woman reaches menopause, one egg each month resumes meiosis and finishes its development. Therefore, the meiosis of a single egg may take up to 50 years to complete!

MISCONCEPTION ALERT

Identifying Misconceptions Students may think that animals are the only organisms that reproduce sexually. Remind students that many plants, fungi, and algae also reproduce sexually. Point out that a flower, for example, contains both sperm nuclei and egg cells.

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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.*

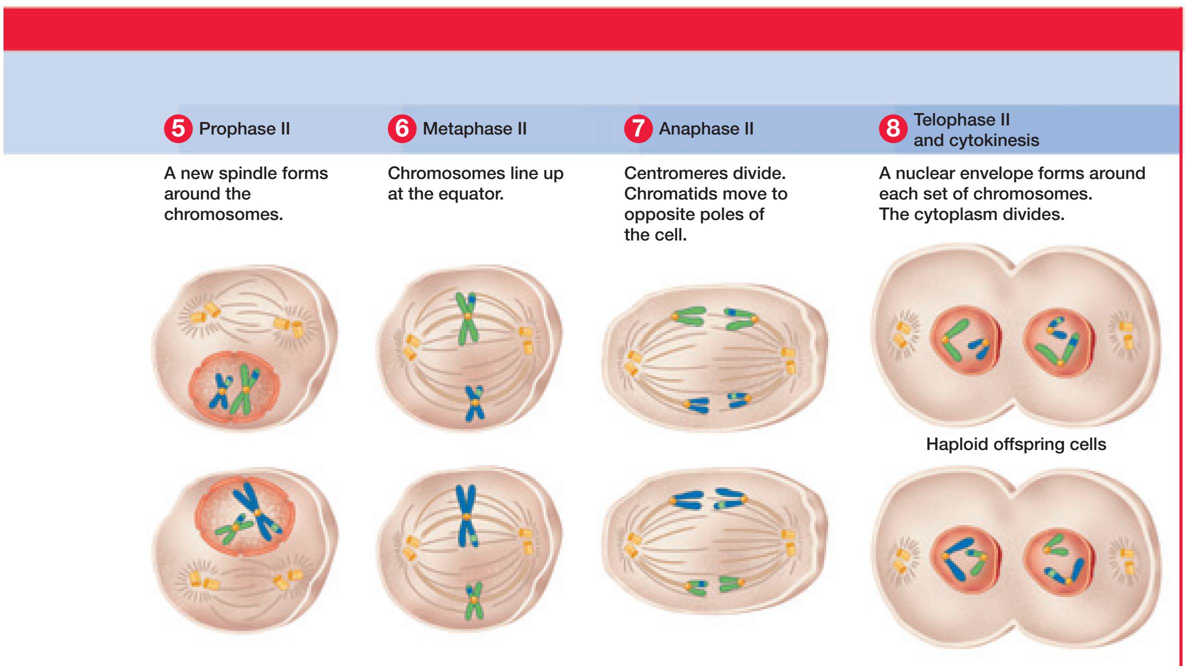
Step 4 Telophase I Individual chromosomes gather at each of the poles. In most organisms, the cytoplasm divides (cytokinesis), forming two new cells. Both cells or poles contain one chromosome from each pair of homologous chromosomes. *Chromosomes do not replicate between meiosis I and meiosis II.*

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.



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Teach

Group Activity — General

Modeling Meiosis Have students work in groups of four at a table. Give each group 32 beads of one color (yellow, for example) and 32 of a contrasting color (blue, for example). Give each group four 4-inch sections of pipe cleaner to act as centromeres. Have students make two 6-bead yellow strands. Attach with a pipe cleaner. This represents a chromosome with 2 chromatids. Make two 6-bead blue strands and attach together. This represents the homologous chromosome. Make two 10-bead blue strands and attach together, and two 10-bead yellow strands. Have students set the four chromosomes on the table and ask what the diploid number is for this cell. (4) Using these bead strands, lead students through the process of meiosis. Check student progress at each step. Crossing-over can be demonstrated by removing two beads at the ends of non-sister chromatids (having opposite colors) and switching them. When finished, the four resulting gametes should each have one long and one short chromosome, with varying crossover patterns. **LS Kinesthetic**

Transparencies

- **TR** Bellringer
- **TR B49** Stages of Meiosis
- **TR B51** Meiosis in Male and Female Animals

Interactive Biology Tutor

- **Unit 4—Cell Reproduction**

This engaging tutorial helps students to understand how cells divide during the processes of mitosis, meiosis, and gamete formation.

Chapter Resource File

- Directed Reading **Basic**
- Active Reading **General**
- Data Sheet for Quick Lab **General**

One-Stop Planner CD-ROM

- Reading Organizers **Basic**
- Reading Strategies **Basic**

Trends in Reproductive Biology

Development in Eggs Stanford University researchers recently discovered how sperm-egg contact initiates development in sea urchins. Sea urchin sperm contain an enzyme called nitric oxide synthase that becomes active a few seconds before fertilization. The enzyme quickly causes the production of a large amount of nitric oxide gas, which is injected into the egg once the sperm and egg make contact. The injection of this gas triggers the release of calcium inside the egg. As the calcium levels rise, metabolic changes occur that causes the egg to divide and form into an embryo.

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Teach, *continued*

READING SKILL BUILDER — BASIC

Interactive Reading Assign Chapter 7 of the *Holt Biology* Guided Audio CD Program to help students achieve greater success in reading the chapter. LS Visual

Using the Figure — GENERAL

Have students look at the first cell at the top left of **Figure 2.** Ask them how many chromosomes are in the cell. Some will answer "four" while others may say "eight." Tell students that as long as chromatids are connected together (by a centromere), they are considered a single chromosome. As soon as the chromatid pairs separate, they are considered two separate chromosomes. The top cell in **Figure 2** has four chromosomes, the two middle cells each have two chromosomes, and the bottom four cells each have two chromosomes. LS Visual

Teaching Tip — GENERAL

Crossing Over Draw two large chromosomes on the board with colored chalk. Each chromosome should have two chromatids and a centromere. Use different colors along the length of each chromatid to represent genes. Ask volunteers to show crossing-over in two different places by erasing and redrawing the chromosomes with the corresponding gene color. Point out that because of the random orientation of chromosomes at metaphase I and because of crossing-over, children resemble their parents but never look exactly like them. LS Interpersonal

internet connect
www.scilinks.org
Topic: Genetic Variation
Keyword: HX4093
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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

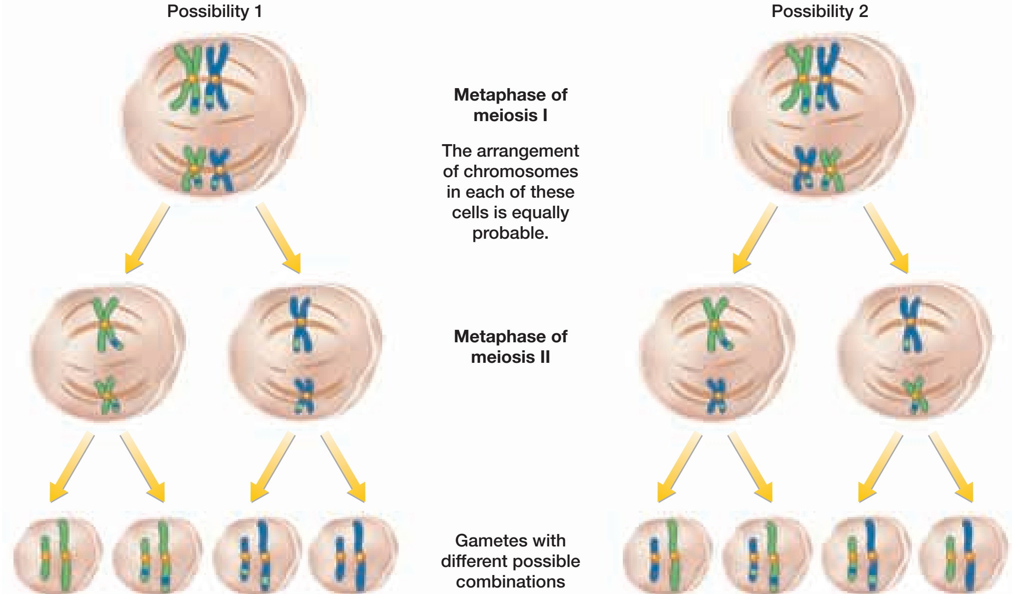
Most organisms have more than one chromosome. In humans, for example, each gamete receives one chromosome from each of 23 pairs of homologous chromosomes. But, which of the two chromosomes that an offspring receives from each of the 23 pairs is a matter of chance. This random distribution of homologous 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.



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MATH CONNECTION

At metaphase I, the orientation of homologous pairs is random: the paternal or maternal homologue can be on either side of the equator. Because of this random orientation, the number of possible chromosome combinations in the gametes is 2^n, where n represents the haploid chromosome number. Therefore, the number of possible chromosome combinations for humans (haploid number = 23) is 2^{23}. Have students use their calculators to determine how many combinations are possible. Have students calculate the possible number of combinations for a mosquito having 6 chromosomes and a dog having 78 chromosomes.

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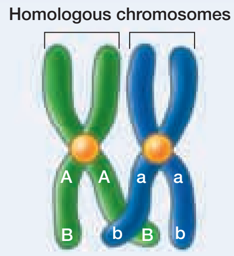
QUICK LAB

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?

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.

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.

QUICK LAB

Modeling Crossing-Over

Skills Acquired
Inferring, interpreting, comparing, applying information

Teacher's Notes
Before assigning the Quick Lab, prepare the paper strips for students to use.

Answers to Analysis

1. individual genes
2. The chromosomes are of similar size, shape, and genetic content.
3. Before crossing-over: AB, AB, ab, and ab. After crossing-over: answers will vary (for example, AB, Ab, aB, and ab).
4. Crossing-over causes genetic recombination.

Using the Figure — BASIC

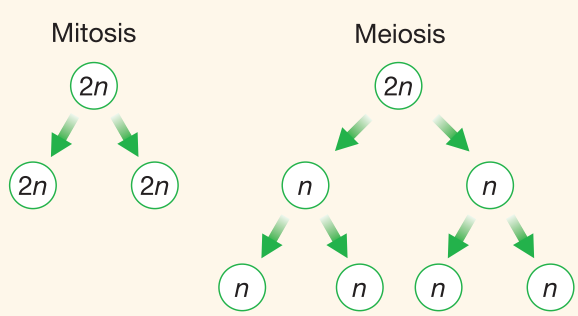
Have students look at the diagram of the two homologous chromosomes in the Quick Lab. Point out that the two green strands attached together by a centromere are called *sister* chromatids. Ask students how sister chromatids compare genetically. (They are identical.) The green and blue chromatids are known as *non-sister* chromatids. Ask students what would happen to the genetic makeup of a chromosome if crossing-over occurred between *sister* chromatids. (Since sister chromatids are copies of each other, the genetic makeup would not change.) **LS Visual**

Teaching Tip — GENERAL

Distinguishing Between Mitosis and Meiosis Have students make a Graphic Organizer similar to one at the bottom of this page to summarize the difference in chromosomal number between mitosis and meiosis. Ask students to include a brief paragraph that compares the two processes. **LS Logical**

Graphic Organizer

Use this graphic organizer with **Teaching Tip** on this page.



Back Print

Teach, *continued*

Real Life
Answer
Answers will vary. Some hermaphroditic genera includes *Lates*, which lives throughout the Indo-Pacific region and *Rivulus*, which is found throughout the West Indies and South America.

Teaching Tip — GENERAL
Gamete Development Have students make a Graphic Organizer similar to the one at the bottom of this page that explains the formation of gametes in humans. Be sure they include the terms spermatogenesis, oogenesis, diploid germ cell, sperm, polar bodies, and egg cell.
LS Logical

Using the Figure — GENERAL
Have students examine the immature sperm cells formed after Meiosis I of spermatogenesis in **Figure 3.** Ask students how they compare in size and shape. (They are identical.) Now ask students to compare the two cells formed after Meiosis I of oogenesis. (One cell is larger than the other is.) Ask students why this has happened, and how this helps the egg cell to survive. (The cytoplasm has been divided unequally; this ensures a rich supply of nutrients for the developing egg cell.) Point out to students that while spermatogenesis is continually occurring in human males, oogenesis is suspended after Meiosis I in females. In oogenesis, Meiosis II is not completed until a sperm cell enters the egg. LS Visual

Real Life
Some animals are both male and female.
Hermaphrodites *(huhr MAF roh DIETZ)* have both male and female reproductive organs. Most hermaphrodites mate with another individual, while some fertilize themselves. Other hermaphrodites can reverse their sex each breeding season.

Finding Information
What are some examples of hermaphroditic fish species, and where do they live?

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

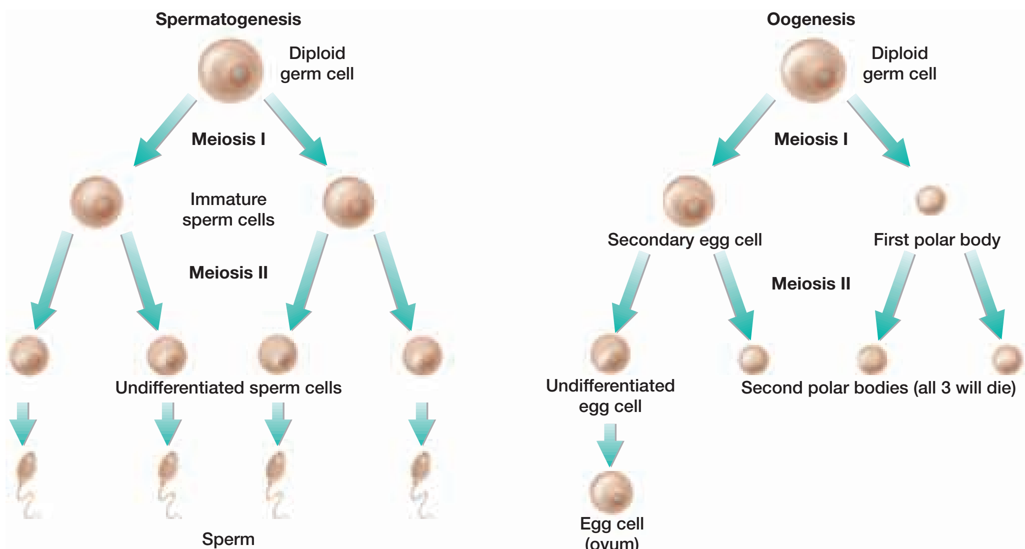
The process by which sperm are produced in male animals is called **spermatogenesis** *(spur mat uh JEHN uh sihs)*. Spermatogenesis occurs in the testes (male reproductive organs). As illustrated in **Figure 3,** a diploid cell first increases in size and becomes a large immature cell (germ cell). The 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.



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Graphic Organizer

Use this graphic organizer with **Teaching Tip** on this page.

Diploid germ cell → Spermatogenesis → Sperm cell

Diploid germ cell → Oogenesis → Egg cell, Polar bodies dergoes 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.

BIOWatch

The Making of an Egg

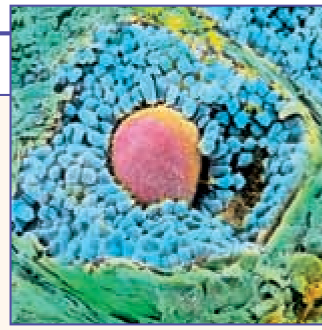
An intricate series of steps controls the formation of an egg. As oogenesis proceeds, eggs become very different from other cells in the organism. One obvious difference is the size of the egg cells. In many animals, eggs swell to gigantic proportions as they accumulate cellular components. How is this transformation accomplished?

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.


Human ovarian follicle

internet connect
www.scilinks.org
Topic: Oogenesis
Keyword: HX4194
SciLinks. Maintained by the National Science Teachers Association

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.
5. **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?
6. **Standardized Test Prep** 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?
   A 1 **C** 4
   B 2 **D** 8

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Answers to Section Review

1. Meiosis halves the number of chromosomes in gametes so that when two haploid gametes unite to form a zygote, the zygote contains the diploid number of chromosomes.
2. Anaphase II
3. Crossing-over occurs when part of a chromatid is broken and exchanged with the corresponding part on one of the chromatids of its homologous chromosome. Independent assortment is the random distribution of homologous chromosomes during meiosis.
4. In males, a diploid cell forms four haploid cells, which develop tails and become sperm. In females, a diploid cell forms one egg cell and three polar bodies. The polar bodies die.
5. The cells resulting from meiosis will contain 39 chromosomes each. The cells resulting from mitosis will contain 78 chromosomes each.
6. **A.** Incorrect. See answer C. **B.** Incorrect. See answer C. **C.** Correct. There will be 2 chromosomes, with 2 chromatids each. **D.** Incorrect. See answer C.

READING SKILL BUILDER — ADVANCED

Discussion Direct students' attention to the BioWatch feature. Have students brainstorm hypotheses as to how the egg cell might benefit from receiving nurse cell organelles. (Possible hypotheses might be: The egg cell is growing so fast that it cannot make its own organelles fast enough, or only the best organelles are transferred, in a type of mini-selection, etc.) Then ask students how receiving nurse cell mitochondria would help the egg. (The egg cell grows at a tremendous rate, and energy is needed for the numerous cellular activities involved in this rapid growth. Mitochondria are the organelles that release the energy needed for these activities.) Ask students why it is significant to humans that this nurse cell phenomenon was also found to occur in mice. (Mice are physiologically more similar to us than the fruit fly.)

Close

Reteaching — BASIC

Prior to class, make four homologous chromosome pairs of different lengths using different colors of paper. Divide the chromosomes into "genes" with a marker pen. Have students use the chromosomes to model meiosis. Ask students why sexual reproduction provides diversity in organisms. (New organisms have genetic information from two parents.)

Quiz — GENERAL

True or False:

1. Mitosis and meiosis both result in diploid cells. (False; meiosis produces haploid cells.)
2. What type of body cell does the process of meiosis form? (reproductive cells)

Alternative Assessment — GENERAL

Write a humorous story from the viewpoint of a single chromosome going through the stages of meiosis.

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Section 2

Section 2 Sexual Reproduction

Focus

Overview

Before beginning this section review with your students the objectives listed in the Student Edition. This section explains the differences between sexual and asexual reproduction, the advantages and disadvantages of each to a species, and how the three major sexual life cycles in eukaryotes function.

Bellringer

Display several numbered pictures of plants and animals (include a picture of a mule, which is sterile). On a piece of scratch paper, have students list whether they think the plant or animal reproduces asexually, sexually, both asexually and sexually, or neither. Discuss answers and reasons for them.
LS Interpersonal

Motivate

Identifying Preconceptions — GENERAL

Ask students to explain the difference between asexual and sexual reproduction. Many students will know that asexual reproduction involves just one parent while sexual reproduction involves two parents. Then ask which type of reproduction is "best" for a species. During discussion, lead students to realize that both types of reproduction have advantages and disadvantages depending on the species involved and the environment they live in.

Objectives

- **Differentiate** between asexual and sexual reproduction.
- **Identify** three types of asexual reproduction.
- **Evaluate** the relative genetic and evolutionary advantages and disadvantages of asexual and sexual reproduction.
- **Differentiate** between the three major sexual life cycles found in eukaryotes.

Key Terms

asexual reproduction
clone
sexual reproduction
life cycle
fertilization
sporophyte
spore
gametophyte

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.

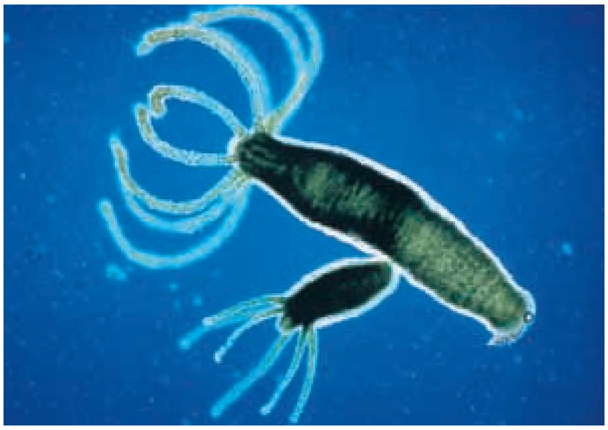

Figure 4 Asexual reproduction. Asexual reproduction creates clones. This hydra is in the process of reproducing asexually. The smaller hydra budding from the parent is genetically identical to the parent.

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Attention Grabber

Hermaphroditism Students may be surprised to learn that in certain species, a single animal can sexually reproduce alone. For example, in some species of nematodes, sperm are produced and then stored until eggs are produced. This is followed by self-fertilization.

One-Stop Planner CD-ROM
- **Reading Organizers** BASIC
- **Reading Strategies** BASIC
- **Occupational Application Worksheet** Medical Sonographer GENERAL
- **Supplemental Reading Guide** *The Lives of a Cell* ADVANCED

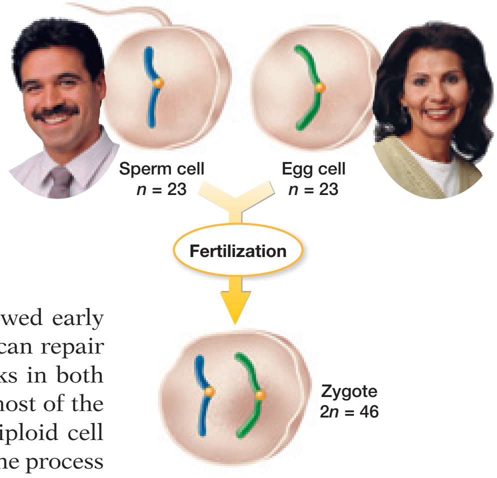
Genetic Diversity

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.

Figure 5 Sexual reproduction

Sexual reproduction creates genetic diversity. Human gametes contain 23 chromosomes. (Only one chromosome is shown in each gamete below.) After fertilization the resulting zygote has 23 pairs of chromosomes.



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.

QUICK LAB: *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.

Teach

Using the Figure — Basic

Have students examine **Figure 5.** Ask students what the letter "n" represents. (one chromosome set, in this case, 23 chromosomes) Ask students what "2n" represents. (two chromosome sets, in this case, 46 chromosomes)

Activity — General

Asexual Reproduction in Bacteria Bacteria can reproduce asexually, as fast as once every fifteen minutes. Using this rate, have students calculate the number of bacteria produced from a single bacterium after each hour for 6 hours. (After hour 1, 16 bacteria; hour 2, 256 bacteria; hour 3, 4,096 bacteria; hour 4, 65,536 bacteria; hour 5, 1,048,576 bacteria; hour 6, 16,777,216 bacteria) Tell students that at this rate the earth would quickly be covered with bacteria. Ask students why this doesn't happen. (Ideal growth conditions for bacteria seldom occur in nature for very long.) **LS Logical**

QUICK LAB: *Observing Reproduction in Yeast*

Skills Acquired
Observing, inferring, locating information

Teacher's Notes
Caution students to use care when working with a microscope, glass slides, and living organisms. Review the steps for making a wet-mount slide.

Answers to Analysis

1. asexual reproduction
2. Only one parent was observed. The new organism split off from the parent.
3. budding

Chapter Resource File

- Directed Reading **Basic**
- Active Reading **General**
- Data Sheet for Quick Lab **General**

Transparencies

TR Bellringer
TR F13 Haploid Life Cycle
TR B48 Diploid Life Cycle
TR G5 Alternation of Generations

MISCONCEPTION ALERT — General

Reproduction and sex are not the same process. Students often think that reproduction and sex are the same thing. Reproduction is the formation of new individuals, whether of unicellular or multicellular organisms. Sex, on the other hand, is the combining of genetic material from two cells.

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 follow 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.

Study TIP

Interpreting Graphics
After reading this chapter, trace or make a sketch of Figures 6, 7, and 8 without the labels. On separate pieces of paper, write down the labels. Without referring to your book, match the labels with the correct part of your sketch.

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.

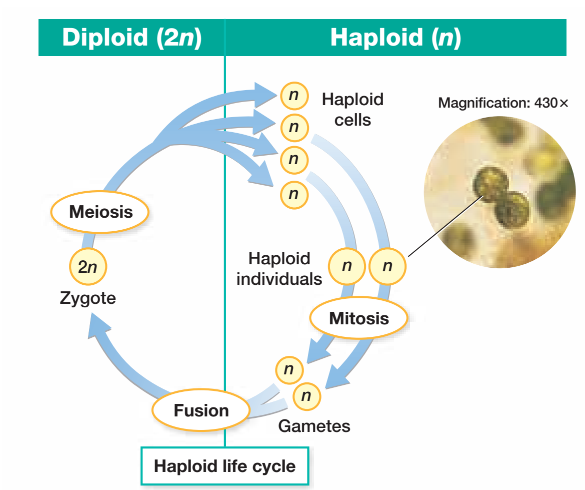


Figure 6 **Haploid life cycle.** Some organisms, such as *Chlamydomonas*, have haploid cells as a major portion of their life cycle.

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Teach, *continued*

READING SKILL BUILDER — BASIC

Reading Organizer Point out to students that they will encounter three reading organizers in this section. Ask students if they can spot the reading organizers provided. (They depict the haploid life cycle, the diploid life cycle, and alternation of generations.) Have them explain why these organizers are appropriate graphic representations of the text. **LS Visual**

Using the Figure — GENERAL

Draw students' attention to **Figure 6.** Use this figure to discuss the steps involved in a haploid life cycle. Be sure students know the difference between a diploid cell and a haploid cell. Have students answer the following questions. What is the diploid stage in the life cycle? (the zygote) What is the result of meiosis? (haploid cells) Why is this type of life cycle called a haploid life cycle? (The haploid cells occupy the major portion of the life cycle.) What event determines when the organism enters into the haploid stage of its life cycle? (meiosis) What event determines when the organism enters into the diploid stage of its life cycle? (fusion of gametes) What process occurs to produce haploid gametes from haploid cells? (mitosis) What event produces haploid cells from the diploid organism? (meiosis) **LS Visual** English Language Learners

HISTORY CONNECTION

Although Charles Darwin (1809–1882) recognized the importance of genetic variation in natural selection (the mechanism for evolution), he could not explain why offspring resembled but were not identical to their parents. Gregor Mendel (1822–1884) later published his theory of inheritance, which helped explain genetic variation. But Mendel's work was not recognized by biologists until more than 15 years after his death.

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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.

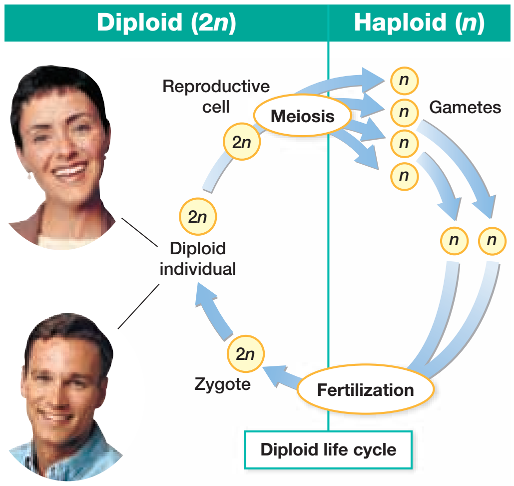

Figure 7 **Diploid life cycle.** Humans and other organisms have a life cycle dominated by a diploid individual.

Exploring Further

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.

Whiptail lizard

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.

Using the Figure — GENERAL

Use **Figure 7** to discuss the steps involved in a diploid life cycle. Ask students to point out the diploid stage in the life cycle. (the zygote, which grows into an individual) Ask students what the result of meiosis is. (haploid cells) Ask students why this type of life cycle is called a diploid life cycle. (The diploid individual occupies the major portion of the life cycle.)
LS Visual English Language Learners

Demonstration — GENERAL

Invite a technician from a fertility clinic to discuss the process of in vitro fertilization. Encourage the speaker to bring equipment or pictures to help students understand the process.

Exploring Further — ADVANCED

Cloning by Parthenogenesis

Teaching Strategies

Before students read the article, tell them that parthenogenesis is a type of reproduction in which a new individual develops from an unfertilized egg. Ask students what organisms might exhibit this type of reproduction. (Answers will vary.)

Discussion

Discuss the following questions with students.

- Why do scientists think parthenogenesis is not possible in mammals? (Mammalian embryos that do not have genes from both a female and a male do not develop normally.)
- What do scientists think initiates parthenogenesis? (Some unknown signal, such as a hormone, may trigger the egg to start dividing.)
- What organisms undergo parthenogenesis? (dandelions, hawkweeds, and some fishes, frogs, and lizards)
- What are the only natural mammalian clones? (identical twins)

did you know?

Sexual Variations Parthenogenesis is not the only variation on sexual reproduction that occurs among vertebrates. Among many species of fish, individuals can change their sex. Some begin life as females and then change into males, a phenomenon called protogyny. Others change from males into females, which is known as protandry. Even more unusual, some deep-sea fish are hermaphrodites—both male and female at the same time.

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Close

Reteaching — BASIC

Ask students to list an advantage of asexual reproduction (many offspring produced in a short time period) and sexual reproduction (genetic diversity). Have students name the three sexual life cycles and give an example of an organism of each kind. (Haploid life cycle—*Chlamydomonas;* Diploid life cycle—human; Alternation of Generations—moss)

Quiz — GENERAL

1. What does sexual reproduction involve? (the union of gametes from two parents)
2. Does sexual or asexual reproduction allow for the greatest genetic variation in offspring? (sexual reproduction)
3. True or false: humans spend most of their life cycle in the diploid state. (true)

Alternative Assessment — GENERAL

Instruct students to make two columns on a piece of paper. Have students head each column with one of the two types of reproduction. Have students list at least two advantages and two disadvantages of that particular type of reproduction under each heading. On the back of the sheet, have them make three columns, heading each of the columns with one of the three kinds of sexual life cycles. In each column, have students make a simple diagram of the life cycle named. ELL students may wish to label the diagram in English as well as their native language.

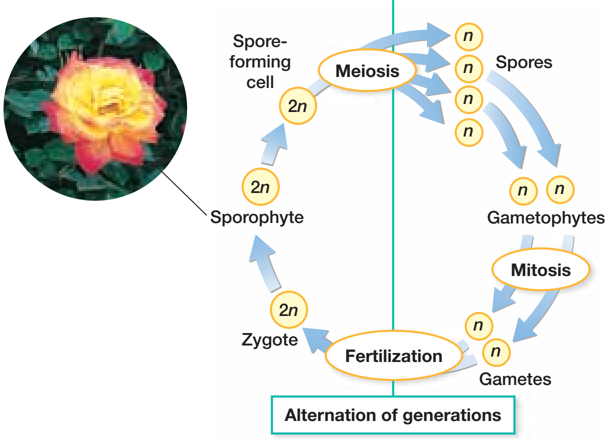
Alternation of Generations

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.

Figure 8 **Alternation of generations**

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



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.

Section 2 Review

1. **Identify** the type of reproduction that results in offspring that are genetically identical to their parent.
2. **Describe** two different types of eukaryotic asexual reproduction.
3. **Compare** the haploid life cycle found in *Chlamydomonas* with a diploid life cycle.
4. **Summarize** the process of alternation of generations.
5. **Critical Thinking** **Evaluating Information** Evaluate the significance of mutations and repair of mutations to the evolution of sexual reproduction.
6. **Standardized 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.

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Answers to Section Review

1. asexual
2. *fission*—parent separates into two or more individuals of equal size; *fragmentation*—the body breaks into several pieces; *budding*—new individuals split off from existing ones.
3. The haploid cells of *Chlamydomonas* give rise to haploid multicellular individuals that produce gametes by mitosis. The gametes fuse to form a diploid zygote, which undergoes meiosis, creating new haploid cells. In a diploid life cycle, haploid gametes are produced by meiosis. The gametes join by fertilization to form a diploid zygote.
4. Spore-forming cells in the sporophyte undergo meiosis to produce spores, which develop into gametophytes. The gametophyte produces gametes by mitosis. The gametes fuse and give rise to the sporophyte.
5. Sexual reproduction is believed to have evolved as a way for cells to repair damaged or mutated DNA.
6. **A.** Correct. **B.** Incorrect. Fission is a type of asexual reproduction. **C.** Incorrect. Mitosis produces genetically identical cells. **D.** Incorrect. Budding produces genetically identical individuals.

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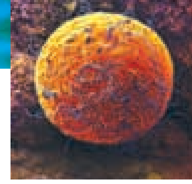
Study ZONE

CHAPTER HIGHLIGHTS



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.

Key Terms

Section 1

meiosis (144)
crossing-over (144)
independent assortment (146)
spermatogenesis (148)
sperm (148)
oogenesis (148)
ovum (149)

Section 2

asexual reproduction (150)
clone (150)
sexual reproduction (150)
life cycle (152)
fertilization (153)
sporophyte (154)
spore (154)
gametophyte (154)

BIOLOGY INTERACTIVE TUTOR

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

Study ZONE

Alternative Assessment — GENERAL

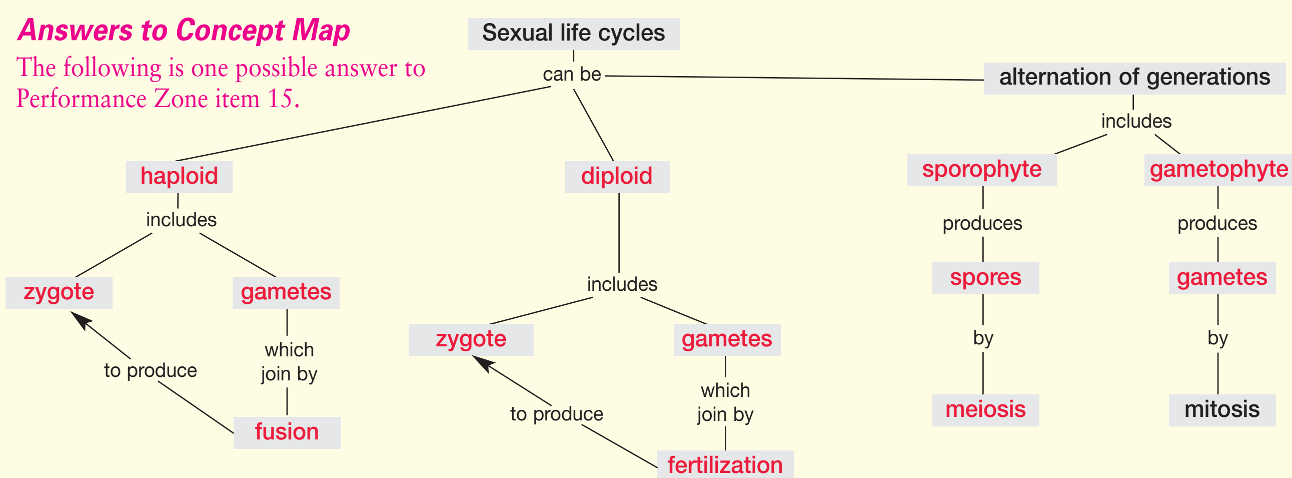
Have students design a concept map that relates the two forms of cell division to the human life cycle. Be sure they include the terms *haploid*, *diploid*, *mitosis*, *meiosis*, and *gamete*.

Chapter Resource File

- Science Skills Worksheet GENERAL
- Critical Thinking Worksheet ADVANCED
- Test Prep Pretest GENERAL
- Chapter Test GENERAL

Answers to Concept Map

The following is one possible answer to Performance Zone item 15.



ANSWERS

Understanding Key Ideas

1. a
2. b
3. a
4. b
5. a
6. ABcdE; ABcde; aBCDE; aBCDe
7. Mitosis produces two genetically identical diploid cells. Meiosis produces four haploid cells that are not genetically identical to the original cell. In metaphase I of meiosis, homologous chromosomes pair up along the equator. In metaphase of mitosis, homologous chromosomes line up independently along the equator. Crossing-over occurs in meiosis but not mitosis. The stages of meiosis II are identical to mitosis.
8. Nurse cells donate organelles to a growing egg cell.
9. Proposed hypotheses include copying of egg chromosomes (self-fertilization) and an unknown signal (such as a hormone) triggers eggs to start dividing in the absence of males. The strength of the self-fertilization hypothesis is the fact that parthenogenesis has been observed in female snakes confined in zoos; a weakness of this hypothesis is that parthenogenesis also occurs in some snakes in the wild. A strength of the hormone hypothesis is the fact that we know that many complex reproductive cycles are controlled by hormones; a weakness is that no "parthenogenesis hormone" has ever been isolated. Student answers will vary.

Performance ZONE

CHAPTER REVIEW

Understanding Key Ideas

1. Which of the following events occurs during prophase I of meiosis?
a. crossing-over
b. duplication of chromatids
c. reduction in chromosome number
d. separation of chromatids to opposite poles

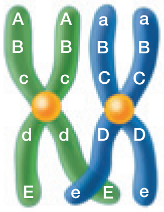
2. Homologous pairs of chromosomes move to opposite poles during
a. prophase I. **c.** metaphase II.
b. anaphase I. **d.** anaphase II.

3. Spermatogenesis produces
a. four haploid cells.
b. four diploid cells.
c. four polar bodies.
d. two haploid cells.

4. Sexual reproduction may have originated as a way for cells to
a. shuffle genetic material.
b. repair damaged DNA.
c. produce diploid individuals.
d. increase their population growth at a maximum rate.

5. In plants, the sporophyte generation produces ______ spores through meiosis.
a. haploid
b. triploid
c. diploid
d. mutated

6. After crossing-over as shown below, what would the sequence of genes be for each of the chromatids?



7. Compare and contrast the processes of mitosis and meiosis. (**Hint:** See Chapter 6, Section 4.)

8. BIOWatch What is the function of a nurse cell in egg formation?

9. Exploring Further Review two hypotheses that have been proposed to explain parthenogenesis according to the strengths and weaknesses of those hypotheses. Which hypothesis do you think is more supportable, and why?

10. **Concept Mapping** Make a concept map that shows the three sexual life cycles in eukaryotic organisms. Include the following words in your map: *meiosis, fusion, gametes, spores, fertilization, zygote, gametophyte, sporophyte, haploid,* and *diploid*.

Critical Thinking

11. Evaluating Results Occasionally homologous chromosomes fail to separate during meiosis I. Using the hypothetical example of an adult organism that has two pairs of chromosomes, describe the chromosomal makeup of the eggs that would result from this error in meiosis.

12. Evaluating Results If normal human sperm fertilized the eggs described above, what would the chromosomal makeup of the resulting zygote be?

13. Applying Information How do independent assortment, crossing-over, and random fertilization affect the rate of evolution?

14. Critiquing Hypotheses A student states that organisms that reproduce asexually are at a disadvantage in a stable environment. If you agree with this hypotheses, name one or more of its strengths. If you disagree, name one or more of its weaknesses.

Alternative Assessment

15. Interactive Tutor Unit 4 Cell Reproduction Write a report summarizing the effects of various treatments for infertility. Find out how the production of gametes may be affected in some people who are infertile.

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10. One possible answer to the concept map is found at the bottom of the Study Zone page.

Critical Thinking

11. If one of the pairs of chromosomes failed to separate, eggs would have either three chromosomes or one chromosome.
12. Zygotes would be diploid.
13. They increase the rate of evolution by increasing the level of genetic variation.
14. Most students should disagree. In a stable environment, asexual reproduction allows organisms to produce offspring without using energy to produce gametes or to find a mate.

Alternative Assessment

15. Answers will vary but might include summaries of one or more of the following types of treatments for infertility: in vitro fertilization (IVF); donor egg IVF; artificial insemination; tubal embryo transfer (TET); gamete intrafallopian transfer (GIFT); and drug treatments (such as clomiphine citrate, pergonal, and metrodin).

Assignment Guide

Section	Questions
1	1, 2, 3, 6, 7, 8, 11, 12, 15
2	4, 5, 9, 10, 14

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Standardized Test Prep

Understanding Concepts

***Directions (1–4):* For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1. How do most multicellular eukaryotes form specialized reproductive cells?
   A. binary fission
   B. fragmentation
   C. meiosis
   D. mitosis

2. How does meiosis differ from mitosis?
   F. Mitosis includes cytokinesis, while meiosis does not.
   G. The DNA is replicated before mitosis but not before meiosis.
   H. Meiosis produces haploid cells, while mitosis produces diploid cells.
   I. Mitosis produces gametes, while meiosis produces offspring cells.

3. What is the process that contributes to the formation of an embryo from the zygote?
   A. fission
   B. meiosis
   C. mitosis
   D. oogenesis

4. During what process are genes exchanged between homologous chromosomes?
   F. crossing-over
   G. fertilization
   H. meiosis
   I. telophase II

***Directions (5):* For the following question, write a short response.**

5. Plants experience alternation of generations with a sporophyte phase and a gametophyte phase. How are sporophytes and gametophytes different in terms of the number of chromosomes they have?

Test TIP

If you are unsure of the answer to a particular question, put a question mark beside it and go on to the next question. If you have time, go back and reconsider any question that you skipped. (Do not write in this book.)

Reading Skills

***Directions (6):* Read the passage below. Then answer the question.**

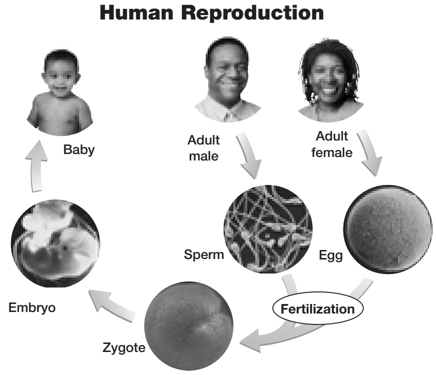
Many zoos have captive breeding programs for endangered species. These programs attempt to increase genetic diversity through selective breeding. However, this can be difficult if the number of individuals in a breeding program is low. Researchers can document the genetic makeup of each individual in the breeding program in order to mate individuals that are genetically varied.

6. Why might the genetic variation of captive-bred animals be different from the genetic variation of wild animals?
   A. Wild animals usually produce offspring that cannot reproduce.
   B. Wild animals are more likely to live longer than captive-bred animals.
   C. Captive-bred animals are more likely to have mutations that lead to diversity.
   D. Captive-bred animals can mate only with the individuals in their enclosed habitat.

Interpreting Graphics

***Directions (7):* Base your answer to question 7 on the diagram below.**

Human Reproduction



7. Which type of eukaryotic life cycle does this diagram represent?
   F. asexual
   G. cloning
   H. diploid
   I. haploid

Answers

1. C
2. H
3. C
4. F
5. Sporophytes are diploid, while gametophytes are haploid.
6. D
7. H

TEST DOCTOR

Question 2 Answer H is the correct choice. Meiosis of a diploid cell produces four haploid cells. Mitosis of a diploid cell produces two diploid cells. Answer F is incorrect because both meiosis and mitosis include cytokinesis. Answer G is incorrect because DNA is replicated before both processes. Answer I is incorrect because meiosis produces gametes, while mitosis produces daughter cells.

Question 5 In alternation of generations, the sporophytes are diploid (two complete sets of chromosomes), while the gametophytes are haploid (one complete set of chromosomes).

Question 6 Answer D is the correct choice. There is a smaller gene pool when there are fewer individuals that can mate, leading to less genetic diversity. Answer A is incorrect because wild animals produce infertile offspring at the same rate as captive-bred offspring. Answer B is incorrect because the opposite is true. Captive-bred animals are less at risk of predation and starvation. Answer C is incorrect because both wild and captive-bred animals experience mutations.

Question 7 Answer H is the correct choice. Humans have a diploid life cycle. Answer F is incorrect because asexual reproduction does not involve fusion of haploid cells. Answer G is incorrect because cloning is a form of asexual reproduction and does not involve fusion of haploid cells. Answer I is incorrect because, in a haploid life cycle, the adult is haploid and produces gametes through mitosis.

Exploration Lab

Modeling Meiosis

Teacher's Notes

Time Required One 45-minute class period

Ratings

EASY → HARD

- Teacher Preparation: 1
- Student Setup: 1
- Concept Level: 2
- Cleanup: 1

Skills Acquired
- Communicating
- Constructing Models
- Identifying/Recognizing Patterns
- Interpreting
- Predicting

Scientific Methods

In this lab, students will:
- Make Observations
- Ask Questions
- Test the Hypothesis
- Analyze the Results
- Draw Conclusions
- Communicate the Results

Materials and Equipment

Materials for this lab can be purchased from a local craft store or ordered from WARD'S. See *Master Materials List* at the front of this book for catalog numbers. For each model, students need 4 pipe cleaners of one color and 4 pipe cleaners of another color, 4 wooden beads, 90 cm of yarn, and 16 small white labels.

Safety Cautions
- Review all safety symbols with students before beginning the lab.

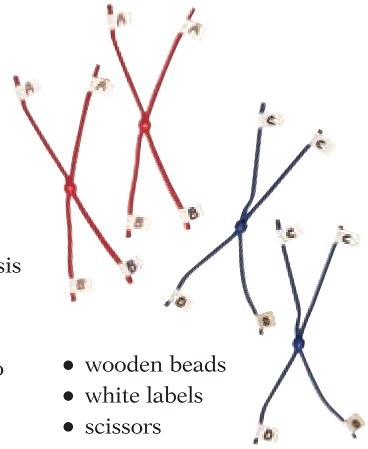
Exploration Lab

Modeling Meiosis

SKILLS
- Modeling
- Using scientific methods

OBJECTIVES
- **Describe** the events that occur in each stage of the process of meiosis.
- **Relate** the process of meiosis to genetic variation.

MATERIALS
- pipe cleaners of at least two different colors
- yarn
- wooden beads
- white labels
- scissors



Glass frog with eggs

Before You Begin

Meiosis is the process that results in the production of cells with half the normal number of chromosomes. It occurs in all organisms that undergo **sexual reproduction**. In this lab, you will build a model that will help you understand the events of meiosis. You can also use the model to demonstrate the effects of events such as **crossing-over** to explain results such as **genetic recombination**.

1. Write a definition for each boldface term in the paragraph above and for the following terms: homologous chromosomes, gamete.
2. In what organs in the human body do cells undergo meiosis?
3. During interphase of the cell cycle, how does a cell prepare for dividing?
4. Based on the objectives for this lab, write a question you would like to explore about meiosis.

Procedure

Part A: Design a Model

1. Work with the members of your lab group to design a model of a cell using the materials listed for this lab. Be sure that your model cell has at least two pairs of chromosomes.
2. Write out the plan for building your model. Have your teacher approve the plan before you begin building the model.

You Choose

As you design your experiment, decide the following:

a. what question you will explore
b. how to construct a cell membrane
c. how to show that your cell is diploid
d. how to show the locations of at least two genes on each chromosome
e. how to show that chromosomes are duplicated before meiosis begins

3. Build the cell model your group designed. **CAUTION: Sharp or pointed objects can cause injury. Handle scissors carefully.** Use your model to demonstrate the phases of meiosis. Draw and label each phase you model.
4. Use your model to explore one of the questions written by your group for step 4 of **Before You Begin.** Describe the steps you took to explore your question.

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Tips and Tricks

Review the stages of meiosis before beginning the lab. If students have difficulty in building their models, ask the following questions:

1. Which of these materials would make the best cell membrane? (yarn)
2. Which would make the best spindle fibers? (yarn)
3. Which would make the best chromosomes? (pipe cleaners)
4. Which would make the best centromeres? (beads)

Emphasize that each pair of chromatids represents one chromosome. Be sure students show that homologous chromosomes pair during metaphase I of meiosis.

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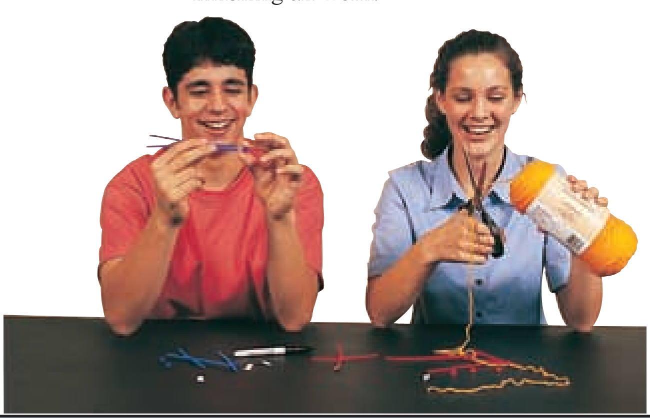
PART B: Test Hypotheses

Answer each of the following questions by writing a hypothesis. Use your model to test each hypothesis, and describe your results.

5. In humans, gametes (eggs and sperm) result from meiosis. Will all gametes produced by one parent be identical?
6. When an egg and a sperm fuse during sexual reproduction, the resulting cell (the first cell of a new organism) is called a zygote. How many copies of each chromosome and each gene will be found in a zygote?
7. Crossing-over frequently occurs between the chromatids of homologous chromosomes during meiosis. Under what circumstances does crossing-over result in new combinations of genes in gametes?
8. Synapsis (the pairing of homologous chromosomes) must occur before crossing-over can take place. How would the outcome of meiosis be different if synapsis did not occur?

PART C: Cleanup and Disposal

9. Dispose of paper and yarn scraps in the designated waste container.
10. Clean up your work area and all lab equipment. Return lab equipment to its proper place. Wash your hands thoroughly before you leave the lab and after finishing all work.



Analyze and Conclude

1. **Analyzing Results** How do the nuclei you made by modeling meiosis compare with the nucleus of the cell you started with? Explain your result.
2. **Recognizing Relationships** How are homologous chromosomes different from chromatids?
3. **Forming Reasoned Opinions** How is synapsis important to the outcome of meiosis? Explain.
4. **Evaluating Methods** How could you modify your model to better illustrate the process of meiosis?
5. **Drawing Conclusions** How are the processes of meiosis similar to those of mitosis? How are they different?
6. **Predicting Outcomes** What would happen to the chromosome number of an organism's offspring if the gametes for sexual reproduction were made by mitosis instead of by meiosis?
7. **Further Inquiry** Write a new question about meiosis or sexual reproduction that could be explored with your model.

Do You Know?

Do research in the library or media center to answer these questions:

1. What types of human abnormalities arise when chromosomes do not separate properly during meiosis?
2. How do chemicals such as nicotine affect meiosis?

Use the following Internet resources to explore your own questions about meiosis and gamete formation.

internet connect

www.scilinks.org
Topic: Meiosis
Keyword: HX4120
SCILINKS. Maintained by the National Science Teachers Association

Answers to Before You Begin

1. See the Glossary in the Appendix of this textbook for the definitions of the listed terms. Homologous chromosomes are chromosomes that are the same size and shape and carry genes for the same traits. A gamete is a reproductive cell, either a sperm or an egg.
2. ovaries and testes
3. A cell's chromosomes duplicate, and certain organelles replicate.
4. Answers will vary. For example: How many chromosomes will each new nucleus have after meiosis has occurred?

Answers to Procedure

2. Plans will vary. For example, students may use the yarn to represent the cell membrane and spindle fibers, the pipe cleaners to represent the chromosomes, and the beads to represent the centromeres.
3. Drawings will vary.
4. Answers will vary.
5. Hypotheses will vary. Students should find that the gametes will be identical only if the parent is homozygous for every one of its genetic traits.
6. Hypotheses will vary. Students should find two copies of each chromosome and two copies of each gene in a zygote.
7. Hypotheses will vary. Students should find that crossing-over can produce new combinations of genes when an organism has different versions of the genes on the parts that cross over.
8. Hypotheses will vary. Students may find the wrong chromosome number in a gamete if the homologous pairs do not separate properly during anaphase I. Also, there would be less genetic variation.

Answers to Analyze and Conclude

1. The nuclei made by meiosis have half the original chromosome number. Two divisions of the nuclear material occur.
2. Homologous chromosomes are the same size and have genes for the same traits, but they are not identical, as are chromatids.
3. Synapsis ensures that each new cell will get one member of each pair of homologous chromosomes.
4. Answers will vary. Students may suggest using different materials.
5. Mitosis and meiosis are both forms of nuclear division. Both consist of prophase, metaphase, anaphase, and telophase. Mitosis consists of one division and results in two cells that are genetically the same and have the same number of chromosomes as the original cell. Meiosis consists of two divisions and results in four cells that each have half the number of chromosomes as the original cell and are not the same genetically.
6. The chromosome number would be twice that in its parents' cells.
7. Answers will vary. For example: How do mitosis and meiosis compare?

Answers to Do You Know?

1. Answers will vary but might include Down syndrome, Klinefelter syndrome, and Turner syndrome.
2. Chemicals can affect the ability of chromosomes to separate normally during meiosis.

CHAPTER 8

Mendel and Heredity

Chapter Planning Guide

PACING	CLASSROOM RESOURCES	LABS, ACTIVITIES, AND DEMONSTRATIONS
BLOCK 1 • 45 min pp. 160–161 **Chapter Opener**		SE **Quick Review,** p. 161 ■ SE **Reading Activity,** p. 161 ■ TE **Using the Figure,** p. 160 GENERAL TE **Opening Activity,** p. 160 GENERAL
BLOCKS 2 & 3 • 90 min pp. 162–165 **Section 1** The Origins of Genetics	OSP **Lesson Plan*** TR **Bellringer*** TR **Section Outline*** TR **C1 Three Steps of Mendel's Experiment***	TE **Demonstration,** p. 162 BASIC TE **Group Activity** Benefits of Peas, p. 163 ADVANCED TE **Using the Figure,** p. 164 GENERAL SE **Math Lab** Calculating Mendel's Ratios, p. 165 ■ CRF **Datasheets for In-Text Labs** Calculating Mendel's Ratios*
BLOCKS 4 & 5 • 90 min pp. 166–169 **Section 2** Mendel's Theory	OSP **Lesson Plan*** TR **Bellringer*** TR **Section Outline*** TR **C5 Monohybrid Cross of Homozygous Plants*** TR **C6 Monohybrid Cross of Heterozygous Plants*** TR **C3 Mendel's Factors***	TE **Using the Figure,** p. 167 SE **Quick Lab** Identifying Dominant or Recessive Traits, p. 168 ■ CRF **Datasheets for In-Text Labs** Identifying Dominant or Recessive Traits* TE **Activity** Graphic Organizer, p. 168 GENERAL TE **Activity** Hairy Knuckles, p. 169 GENERAL CRF **Inquiry Lab** Corn Seed Germination* ◆ GENERAL
BLOCKS 6 & 7 • 90 min pp. 170–176 **Section 3** Studying Heredity	OSP **Lesson Plan*** TR **Bellringer*** TR **Section Outline*** TR **C4 Probability with Two Coins***	TE **Using the Figure,** p. 171 BASIC SE **Data Lab** Analyzing a Test Cross, p. 172 ■ CRF **Datasheets for In-Text Labs** Analyzing a Test Cross* TE **Demonstration,** p. 173 GENERAL TE **Using the Figure,** p. 174 and p. 175 GENERAL SE **Math Lab** Predicting the Results of Crosses Using Probabilities, p. 174 ■ CRF **Datasheets for In-Text Labs** Predicting the Results of Crosses Using Probabilities* SE **Data Lab** Evaluating a Pedigree, p. 176 ■ CRF **Datasheets for In-Text Labs** Evaluating a Pedigree*
BLOCKS 8 & 9 • 90 min pp. 177–182 **Section 4** Complex Patterns of Heredity	OSP **Lesson Plan*** TR **Bellringer*** TR **Section Outline*** TR **C30 Some Human Genetic Disorders***	TE **Demonstration,** p. 178 GENERAL TE **Demonstration,** p. 179 BASIC TE **Using the Figure,** p. 179 GENERAL TE **Activity** Using Punnet Squares, p. 179 GENERAL TE **Demonstration,** p. 179 BASIC TE **Group Activity** Patterns of Heredity, p. 181 GENERAL CRF **Quick Lab** Interpreting Information in a Pedigree* BASIC SE **Skills Practice Lab** Modeling Monohybrid Crosses, p. 186* ■ CRF **Datasheets for In-Text Labs** Modeling Monohybrid Crosses*

BLOCKS 10 & 11 • 90 min

Chapter Review and Assessment Resources

- SE **Study Zone,** p. 183 ■
- SE **Performance Zone,** p. 184 ■
- SE **Standardized Test Prep,** p. 185 ■
- TR **Concept Mapping***
- CRF **Vocabulary Review Worksheet*** ■ GENERAL
- CRF **Test Prep Pretest*** ■ GENERAL
- CRF **Chapter Test*** ■ GENERAL
- CRF **Chapter Test*** ADVANCED
- OSP **Test Generator***
- OSP **Test Item Listing***
- OSP **Modified Chapter Test*** BASIC

Online and Technology Resources

Holt Online Learning

Visit **go.hrw.com** for access to Holt Online Learning or enter the keyword **HF6 Home** for a variety of free online resources.

One-Stop Planner® CD-ROM

This CD-ROM package includes
- Lab Materials QuickList Software
- Holt Calendar Planner
- Customizable Lesson Plans
- Printable Worksheets
- ExamView® Test Generator
- Interactive Teacher Edition
- Holt PuzzlePro® Resources
- Holt PowerPoint® Resources

Guided Reading Audio CDs

These CDs are designed to help auditory learners and reluctant readers. (Audio CDs are also available in Spanish.)

Back Print

Compression guide:
To shorten your instruction because of time limitations, omit blocks 1, 2, and 3.

KEY

TE Teacher Edition	**CRF** Chapter Resource File	* Also on One-Stop Planner
SE Student Edition	**TR** Teaching Transparency	■ Also Available in Spanish
OSP One-Stop Planner		◆ Requires Advance Prep

SKILLS DEVELOPMENT AND PRACTICE	SECTION REVIEW AND ASSESSMENT	CORRELATIONS
		National Science Education Standards
TE Skill Builder Math, p. 164 GENERAL **TE** Reading Skill Builder K-W-L, p. 163 GENERAL **CRF** Directed Reading Worksheet* BASIC **CRF** Active Reading Worksheet* GENERAL	**SE** Section 1 Review ■ **TE** Reteaching, p. 165 BASIC **TE** Quiz, p. 165 GENERAL **TE** Alternative Assessment, p. 165 GENERAL **CRF** Quiz* ■ BASIC	LSCell1, LSCell2, LSGene1, LSGene2
CRF Directed Reading Worksheet* BASIC **CRF** Active Reading Worksheet* GENERAL	**SE** Section 2 Review ■ **TE** Reteaching, p. 169 BASIC **TE** Quiz, p. 169 GENERAL **TE** Alternative Assessment, p. 169 GENERAL **CRF** Quiz* ■ BASIC	
TE Skill Builder Writing, p. 174 ADVANCED **TE** Skill Builder Vocabulary, p. 175 GENERAL **CRF** Directed Reading Worksheet* BASIC **CRF** Active Reading Worksheet* GENERAL	**SE** Section 3 Review ■ **TE** Reteaching, p. 176 BASIC **TE** Quiz, p. 176 GENERAL **TE** Alternative Assessment, p. 176 ADVANCED **CRF** Quiz* ■ BASIC	
TE Reading Skill Builder Discussion, p. 179 GENERAL **CRF** Directed Reading Worksheet* BASIC **CRF** Active Reading Worksheet* GENERAL **CRF** Critical Thinking Worksheet* ADVANCED **CRF** Science Skills Worksheet* GENERAL	**SE** Section 4 Review ■ **TE** Reteaching, p. 182 BASIC **TE** Quiz, p. 182 GENERAL **TE** Alternative Assessment, p. 182 ADVANCED **CRF** Quiz* ■ BASIC Modified Worksheet* BASIC	

Holt Biology Interactive Tutor CD-ROM

This CD-ROM consists of interactive activities that give students a fun way to extend their knowledge of biology concepts.

Unit 5 Heredity

www.scilinks.org

Maintained by the **National Science Teachers Association**

Topic: Genetic Counseling
SciLinks Code: HX4090

Topic: Genetic Disorders
SciLinks Code: HX4091

CNN Videos

Each video segment is accompanied by a Critical Thinking Worksheet.*

Segment 7 Gene Progress

Overview

Tell students the purpose of this chapter is to explain how genetic traits are passed from one generation to another. The passing on of different genetic traits is fundamental to evolutionary change. The genetic variation provided by the possible combinations of parental genes and by crossing-over allows populations to change, and increases the probability that evolution will occur within a given population. Genetic mutations make evolution possible by introducing random changes into the inherited information that is passed on.

Using the Figure

Ask students to look at the show jumper and ask them if they know why racehorses and show jumpers have been selectively bred. (for speed, strength, and size). Thoroughbred horses have been selectively breed since the 1600's. All thoroughbreds can be traced back to three stallions (the Darley Arabian, the Godolphin Barb and the Byerly Turk). With such a limited gene pool, inbreeding becomes a significant problem. The fertility rate is around 67%, which is much lower than other animals, such as cattle (85%). In addition, the performance of the animals is not greatly improving, even though they are bred for speed.

Assessing Prior Knowledge

Before beginning this chapter, be sure your students can answer the questions in the ***Quick Review*** on the facing page. If they cannot, encourage them to reread the sections indicated.

Show jumper

160

Standards Correlations

National Science Education Standards

LSCell1 Cells have particular structures that underlie their functions.

LSCell2 Most cell functions involve chemical reactions.

LSGene1 In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T).

LSGene2 Most of the cells in a human contain two copies of each of 22 different chromosomes. In addition, there is a pair of chromosomes that determines sex.

Back Print

CHAPTER

8 Mendel and Heredity

Quick Review

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

1. **Define** the term *gamete*. *(Chapter 6, Section 1)*
2. **Summarize** the relationship between chromosomes and genes. *(Chapter 6, Section 1)*
3. **Differentiate** between autosomes and sex chromosomes. *(Chapter 6, Section 1)*
4. **Describe** how independent assortment during meiosis contributes to genetic variation. *(Chapter 7, Section 1)*

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

Reading Activity

Before you read this chapter, write a short list of all the things you know about inheritance. Then write a list of the things that you want to know about inheritance. Save your list, and to assess what you have learned, see how many questions you can answer after reading this chapter.

Looking Ahead

internet connect

www.scilinks.org
National Science Teachers Association *sci*LINKS Internet resources are located throughout this chapter.

SCILINKS. Maintained by the National Science Teachers Association

Horses like this show jumper are bred for certain characteristics, such as speed and agility. Most characteristics are inherited—passed down from parents to offspring.

Opening Activity — GENERAL

Physical Resemblance in Families

Have students volunteer to bring photographs of parents or siblings to class. Ask them to try and match the names of fellow students with each photograph. After the students have matched the photographs, show each picture individually and ask the students whose relative is pictured to stand. Ask students to identify how the two are similar and different. Then ask them what techniques they think scientists might use to find a family connection. Be sensitive to those students who may be adopted.
LS Interpersonal

Quick Review Answers

1. A gamete is a haploid cell that participates in fertilization by fusing with another haploid cell.
2. A gene is a segment of DNA that codes for a protein or RNA molecule, while a chromosome is a structure on which genes are located and which is composed of DNA and associated proteins.
3. A sex chromosome is one of a pair of chromosomes that is involved in determining the sex of an individual, while autosomes are chromosomes not directly involved in determining the sex of an individual.
4. Independent assortment during meiosis contributes to genetic variation because each homologous chromosome pair of an individual segregates (separates) independently of every other pair, the number of combinations is 2^n; where n = the haploid chromosome number.

Chapter Resource File
- Vocabulary Worksheets
- Concept Mapping

Reading Activity Answers

Students may know that phenotypic traits such as hair and eye color are inherited. Some students may be aware that all instructions for the construction of the body are inherited. Students may want to know how these traits are inherited.

Focus

Overview

Before beginning this section review with your students the objectives listed in the Student Edition. This section explains Mendel's discoveries in modern terms and explains traits expressed as ratios.

Bellringer

Ask students to list on paper five characteristics that are passed on in families (eye, hair and skin color, height, and so on), and to name one characteristic that may also be inherited but that is also influenced by behavior or environment (muscle size, body weight, having a sun tan, and so on). **LS Intrapersonal**

Motivate

Demonstration — Basic

Display large pictures of a few flowering plants or bring in real plants. Ask students to come up with a list of traits that could be inherited in plants. Encourage students to think of many different traits, such as flower shape, flower color, flower position on stem, leaf shape, leaf color, pattern of veins, pattern of stem growth, presence of hairs on stems, and inner structure of flower. Ask them if they think the traits are inherited together or separately. **LS Visual**

Section 1 The Origins of Genetics

Objectives

- **Identify** the investigator whose studies formed the basis of modern genetics.
- **List** characteristics that make the garden pea a good subject for genetic study.
- **Summarize** the three major steps of Gregor Mendel's garden pea experiments.
- **Relate** the ratios that Mendel observed in his crosses to his data.

Key Terms

heredity
genetics
monohybrid cross
true-breeding
P generation
F_1 generation
F_2 generation

Mendel's Studies of Characters

Many of your characteristics—or *characters*—including the color and shape of your eyes and the texture of your hair resemble those of your parents. The passing of characters from parents to offspring is called **heredity.** From the beginning of recorded history, humans have attempted to alter crop plants and domestic animals to give them traits that are more useful to us. Before DNA and chromosomes were discovered, heredity was one of the greatest mysteries of science.

Mendel's Breeding Experiments

The scientific study of heredity began more than a century ago with the work of an Austrian monk named Gregor Johann Mendel, shown in **Figure 1.** Mendel carried out experiments in which he bred different varieties of the garden pea *Pisum sativum,* shown in **Figure 2** and in **Table 1.** British farmers had performed similar breeding experiments more than 200 years earlier. But Mendel was the first to develop rules that accurately predict patterns of heredity. The patterns that Mendel discovered form the basis of **genetics,** the branch of biology that focuses on heredity.

Mendel's parents were peasants, so he learned much about agriculture. This knowledge became invaluable later in his life. As a young man, Mendel studied theology and was ordained as a priest. Three years after being ordained, he went to the University of Vienna to study science and mathematics. There he learned how to study science through experimentation and how to use mathematics to explain natural phenomena.

Figure 1 **Gregor Mendel.** Mendel's experiments with garden peas led to our modern understanding of heredity.

Mendel later repeated the experiments of a British farmer, T. A. Knight. Knight had crossed a variety of the garden pea that had purple flowers with a variety that had white flowers. (The term *cross* refers to the mating or breeding of two individuals.) All of the offspring of Knight's crosses had purple flowers. However, when two of the purple-flowered offspring were crossed, their offspring showed both white and purple flowers. The white trait had reappeared in the second generation!

Mendel's experiments differed from Knight's because Mendel counted the number of each kind of offspring and analyzed the data.

Chapter Resource File

- Directed Reading Basic
- Active Reading General
- Data Sheet for Math Lab General

One-Stop Planner CD-ROM

- Reading Organizers Basic
- Reading Strategies Basic
- Problem Solving Worksheet Ratios and Proportions General

Transparencies

TR Bellringer
TR C1 Three Steps of Mendel's Experiment

Back Print

…fer in Mendel's experiments

To cross-pollinate flowers of different colors, Mendel first removed the stamens—the pollen-producing structures—from one flower.

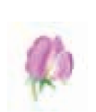
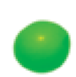
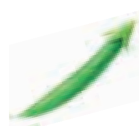
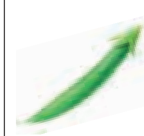
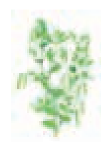
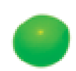
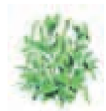
Mendel transferred pollen from a second flower to the pistil of the original flower.

Useful Features in Peas

The garden pea is a good subject for studying heredity for several reasons. **Table 1** shows the seven characters that Mendel chose to study.

1. Several characters of the garden pea exist in two clearly different forms. For example, the flower color is either purple or white—there are no intermediate forms. Note that the term *character* is used to mean inherited characteristic, such as flower color. *Trait* refers to a single form of a character—having purple flowers is a trait.
2. The male and female reproductive parts of garden peas are enclosed within the same flower. You can control mating by allowing a flower to fertilize itself (self-fertilization), or you can transfer the pollen to another flower on a different plant (cross-pollination). To cross-pollinate two pea plants, Mendel removed the stamens (the male reproductive organs that produce pollen) from the flower of one plant. As shown in Figure 2, he then dusted the pistil (the female reproductive organ that produces eggs) of that plant with pollen from a different pea plant.
3. The garden pea is small, grows easily, matures quickly, and produces many offspring. Thus, results can be obtained quickly, and there are plenty of subjects to count.

Table 1 The Seven Characters Mendel Studied and Their Contrasting Traits

Flower color	Seed color	Seed shape	Pod color	Pod shape	Flower position	Plant height
						
						

Teach

READING SKILL BUILDER — GENERAL

K-W-L Before they read this chapter, have each student write a short list of all the things they already **K**now (or think they know) about inheritance. Ask them to contribute their entries to a group list on the board or overhead projector. Then have the students list things they **W**ant to know about inheritance. Have students save their lists for later use in section 4.

Teaching Tip — BASIC

Genetic make-up Bring photos or stuffed toys of animals with different traits. Use these props to emphasize that many genes are involved in giving an animal its overall appearance, and that the genes for most traits have two or more versions. Ask them if they can estimate how many genes animals have in common with each other. For example, chimpanzees and humans share approximately 98% of their genetic makeup.
LS Visual

Group Activity — ADVANCED

Benefits of Peas Divide the class into small groups. Have each group design newspaper ads that would have attracted someone like Mendel to purchase peas for genetic research. The ads should mention all of the benefits of *Pisum sativum* that make it useful for genetic research. Ask students to use illustrations in their ads. Encourage students to be creative. They may use butcher paper, computer paper, construction paper, and so on. Post the ads on the bulletin board and lead a discussion on the benefits of the garden-pea for genetic research. English Language Learners

Trends in Genomics

Cats and Humans Researchers working on the genomes of organisms have found that when it comes to the arrangement of genes on our chromosomes, we are closer to cats than to any other groups studied so far except for primates. Stephen J. O'Brien, a geneticist and chief of the National Cancer Institute's Laboratory of Genomic Diversity, began studying the genetics of the house cat in the 1970's. The Cat Genome Project is a comprehensive genetic analysis of *Felis catus*. The results of this research have proved useful in boosting human AIDS research and have been useful in criminal forensics.

BIOLOGY INTERACTIVE TUTOR

- **Unit 5—Heredity: Introduction**
  This engaging tutorial introduces students to principles and practical applications of Mendelian genetics.

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Teach, *continued*

Teaching Tip — GENERAL

Hidden traits Ask students if they can tell by looking at the purple pea flowers in **Figure 3** which ones are true-breeding for the purple trait and which ones are not. Point out that you cannot always tell the genetic makeup of an organism by looking at it. Ask students how a cross helps determine if a plant is true-breeding for a trait.

Using the Figure — GENERAL

Point out to students the male and female flower structures illustrated in **Figure 2,** (pistil on the left, stamen on the right). Explain the difference between cross-pollination and self-pollination, and the significance of removing the stamens from the flower on the left. (In cross-pollination, the pollen from one flower is transported to the female structures of a different flower. In self-pollination, the pollen from one flower is transported to the female structures of the same flower. By removing the male stamens of a flower, all offspring will be the result of cross-pollination.)

SKILL BUILDER — GENERAL

Math Skills Ask students to practice reducing ratios to their simplest forms. Survey the class for some numbers to work with. For example, ask how many students own a cat. Have them divide each number (class size; cat owners) by the smallest number (cat owners) and write it as a ratio. If there are 30 students in class and 10 own a cat, the ratio is 30 to 10. Simplified, $\frac{30}{10} = 3$ and $\frac{10}{10} = 1$, the ratio is 3:1. **LS Logical**

Traits Expressed as Simple Ratios

Mendel's initial experiments were monohybrid crosses. A **monohybrid cross** is a cross that involves *one* pair of contrasting traits. For example, crossing a plant with purple flowers and a plant with white flowers is a monohybrid cross. Mendel carried out his experiments in three steps, as summarized in **Figure 3.**

Step 1 Mendel allowed each variety of garden pea to self-pollinate for several generations. This ensured that each variety was **true-breeding** for a particular character; that is, all the offspring would display only one form of the character. For example, a true-breeding purple-flowering plant should produce only plants with purple flowers in subsequent generations.

These true-breeding plants served as the parental generation in Mendel's experiments. The parental generation, or **P generation,** are the first two individuals that are crossed in a breeding experiment.

Step 2 Mendel then cross-pollinated two P generation plants that had contrasting traits, such as purple flowers and white flowers. Mendel called the offspring of the P generation the first *filial* generation, or **F_1 generation.** He then examined each F_1 plant and recorded the number of F_1 plants expressing each trait.

Step 3 Finally, Mendel allowed the F_1 generation to self-pollinate. He called the offspring of the F_1 generation plants the second filial generation, or **F_2 generation.** Again, each F_2 plant was characterized and counted.

WORD Origins

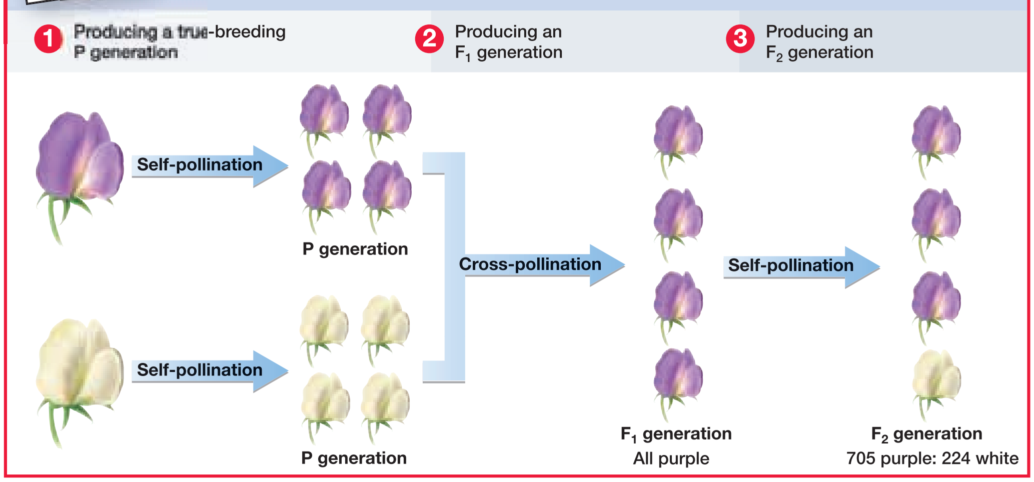
The word *filial* is from the Latin *filialis,* meaning "of a son or daughter." Thus F (filial) generations are all those generations that follow a P (parental) generation.

BIO graphic

Figure 3

Three Steps of Mendel's Experiments

Mendel studied traits in three generations of plants.



Trends in Genetics

Flies and Worms Many scientists who study genetics use the fruit fly *Drosophila melanogaster* or the roundworm *Caenorhabditis elegans* in their research. These organisms show a variety of traits, are easy to obtain and breed, have short generation time (less than 2 weeks for fruit flies; less than 3 days for roundworms), and produce a large number of offspring. How long would it take to study three generations of humans?

Mendel's Results

Each of Mendel's F_1 plants showed only one form of the trait. The contrasting form of the trait had disappeared! But when the F_1 generation was allowed to self-pollinate, the missing trait *reappeared* in some of the plants in the F_2 generation. When Mendel crossed purple flowers with white flowers, all of the offspring in the F_1 generation had purple flowers. In the F_2 generation, 705 plants had purple flowers and 224 plants had white flowers—a ratio of 705 to 224.

A ratio is a comparison of two numbers and can be written as a fraction ($\frac{705}{224}$) or with a colon (705:224). You can see patterns more easily in data if you reduce a ratio to its simplest form. To do this, divide each term by the smaller of the two terms. This reduces 705:224 to 3.15, which is then rounded to 3:1.

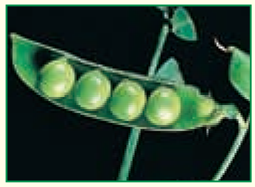
$$\frac{705}{224} \div \frac{224}{224} = 3.15 \text{ (or about 3)}$$

For each of the seven traits Mendel studied, he found the same 3:1 ratio of plants expressing the contrasting traits in the F_2 generation.

MATH LAB: Calculating Mendel's Ratios

Background

You can calculate the ratios Mendel obtained in the F_2 generation for the traits he studied. First copy the partially completed table below on a separate piece of paper.



Analysis

1. **Calculate** the ratio for each contrasting trait. Use colon form.
2. **State** the ratio for each contrasting trait in words and as a fraction.
3. **Critical Thinking Interpreting Results** Do the data confirm a 3:1 ratio in the F_2 generation for each of the traits he studied?

Contrasting traits	F_2 generation results		Ratio
Flower color	705 purple	224 white	3.15:1
Seed color	6,022 yellow	2,001 green	
Seed shape	5,474 round	1,850 wrinkled	
Pod color	428 green	152 yellow	
Pod shape	882 round	299 constricted	
Flower position	651 axial	207 top	
Plant height	787 tall	277 dwarf	

MATH LAB: Calculating Mendel's ratios

Skills Acquired

Interpreting, identifying patterns, organizing data

Teacher's Notes

Provide an example of how to calculate ratios. For example, the ratio of students who own a dog to those who do not. Imagine the ratio is 20 to 5. Explain that the ratio is simplified by dividing each number by the smaller of the two numbers ($\frac{20}{5}$ and $\frac{5}{5}$). The simplest ratio is 4:1. (4 to 1 in words and $\frac{4}{1}$ as a fraction.)

Answers

1. 3.01:1, 2.96:1, 2.82:1, 2.95:1, 3.14:1, 2.84:1
2. Three yellow seeds to one green seed, $\frac{3}{1}$; three round to one wrinkled, $\frac{3}{1}$; three green pods to one yellow pod, $\frac{3}{1}$; three round pods to one constricted pod, $\frac{3}{1}$; three axial to one top, $\frac{3}{1}$; three tall to one dwarf, $\frac{3}{1}$.
3. Yes.

Section 1 Review

1. **Describe** the contribution of Mendel to the foundation of modern genetics.
2. **Describe** why garden-pea plants are good subjects for genetic experiments.
3. **Summarize** the design of Mendel's pea-plant studies.
4. **State** the ratio Mendel obtained in each F_2 generation for each of the traits he studied.
5. **Critical Thinking Evaluating Outcomes** What differences would be expected in experiments with squash plants, which usually do not self-pollinate?
6. **Standardized Test Prep** When two true-breeding pea plants that show contrasting forms of a trait are crossed, all of the offspring show
   - **A** both forms of the trait.
   - **B** one form of the trait.
   - **C** one-fourth of each trait.
   - **D** a different trait.

Answers to Section Review

1. Mendel was the first to develop rules that accurately predict patterns of heredity.
2. Garden-pea plants have many characters with two clearly different forms. Mating is easy to control. The plants are small, easy to grow, mature quickly, and produce many offspring.
3. Mendel self-pollinated different varieties of pea flowers for several generations to produce true-breeding P generations. He then cross-pollinated P generation plants with contrasting forms of a character and recorded the number of F_1 plants expressing each trait. He also self-pollinated F_1 plants and recorded the number of F_2 plants expressing each trait.
4. A ratio of about 3:1.
5. Without a true-breeding (self-pollinating) P generation, there would not be a consistent ratio of traits in the F_1 or F_2 generations.
6. **A.** Incorrect. For both traits to appear, both parents must have at least one of the recessive traits. **B.** Correct. When one of each contrasting trait is inherited, one trait is masked by the other. **C.** Incorrect. See answer A. **D.** Incorrect. Only parental traits appear in the offspring, unless there is a mutation.

Close

Reteaching — BASIC

Ask students to replicate the three steps in Mendel's experiments as illustrated in **Figure 3,** substituting another trait from **Table 1.**

Quiz — GENERAL

1. Why did Mendel allow the pea plants to self-pollinate for several generations before beginning with his crosses? (To ensure that each variety was true breeding.)
2. Define heredity. (Heredity is the passing of traits from parents to offspring.)

Alternative Assessment — GENERAL

Ask students to select an organism that would be useful for genetics research and list the reasons why. (Examples include fruit flies, roundworms, and garden peas.)