SECTION 3

Meiosis

Where are genes located, and how do they pass information? Understanding reproduction is the first step to finding the answers.

There are two kinds of reproduction: asexual and sexual. Asexual reproduction results in offspring with genotypes that are exact copies of their parent's genotype. Sexual reproduction produces offspring that share traits with their parents but are not exactly like either parent.

Asexual Reproduction

In *asexual reproduction,* only one parent cell is needed. The structures inside the cell are copied, and then the parent cell divides, making two exact copies. This type of cell reproduction is known as *mitosis*. Most of the cells in your body and most single-celled organisms reproduce in this way.

Sexual Reproduction

In sexual reproduction, two parent cells join together to form offspring that are different from both parents. The parent cells are called *sex cells*. Sex cells are different from ordinary body cells. Human body cells have 46, or 23 pairs of, chromosomes. One set of human chromosomes is shown in **Figure 1.** Chromosomes that carry the same sets of genes are called **homologous** (hoh MAHL uh guhs) **chromosomes.** Imagine a pair of shoes. Each shoe is like a homologous chromosome. The pair represents a homologous pair of chromosomes. But human sex cells are different. They have 23 chromosomes—half the usual number. Each sex cell has only one of the chromosomes from each homologous pair. Sex cells have only one "shoe."

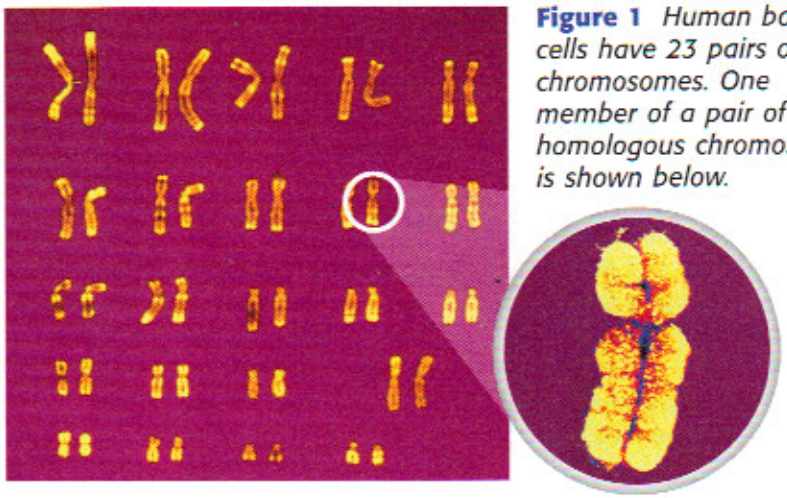


Figure 1 *Human body cells have 23 pairs of chromosomes. One member of a pair of homologous chromosomes is shown below.*

READING WARM-UP

Objectives

- Explain the difference between mitosis and meiosis.
- Describe how chromosomes determine sex.
- Explain why sex-linked disorders occur in one sex more often than in the other.
- Interpret a pedigree.

Terms to Learn

homologous chromosomes
meiosis
sex chromosome
pedigree

READING STRATEGY

Reading Organizer As you read this section, make a flowchart of the steps of meiosis.

homologous chromosomes chromosomes that have the same sequence of genes and the same structure

meiosis a process in cell division during which the number of chromosomes decreases to half the original number by two divisions of the nucleus, which results in the production of sex cells

Meiosis

Sex cells are made during meiosis (mie OH sis). **Meiosis** is a copying process that produces cells with half the usual number of chromosomes. Each sex cell receives one-half of each homologous pair. For example, a human egg cell has 23 chromosomes, and a sperm cell has 23 chromosomes. The new cell that forms when an egg cell and a sperm cell join has 46 chromosomes.

Reading Check **How many chromosomes does a human egg cell have?** *(See the Appendix for answers to Reading Checks.)*

Genes and Chromosomes

What does all of this have to do with the location of genes? Not long after Mendel's work was rediscovered, a graduate student named Walter Sutton made an important observation. Sutton was studying sperm cells in grasshoppers. Sutton knew of Mendel's studies, which showed that the egg and sperm must each contribute the same amount of information to the offspring. That was the only way the 3:1 ratio found in the second generation could be explained. Sutton also knew from his own studies that although eggs and sperm were different, they did have something in common: Their chromosomes were located inside a nucleus. Using his observations of meiosis, his understanding of Mendel's work, and some creative thinking, Sutton proposed something very important:

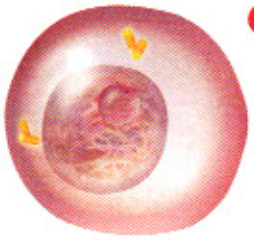
Genes are located on chromosomes!

Understanding meiosis was critical to finding the location of genes. Before you learn about meiosis, review mitosis, shown in **Figure 2.** Meiosis is outlined in **Figure 3** on the next two pages.

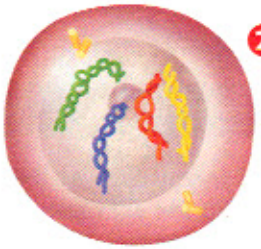
CONNECTION TO Language Arts

Greek Roots The word *mitosis* is related to a Greek word that means "threads." Threadlike spindles are visible during mitosis. The word *meiosis* comes from a Greek word that means "to make smaller." How do you think meiosis got its name?

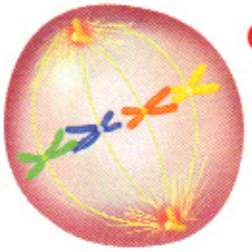
Figure 2 Mitosis Revisited



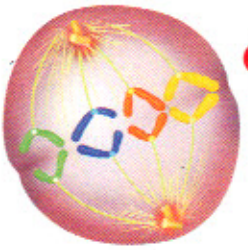
1 Each chromosome is copied.



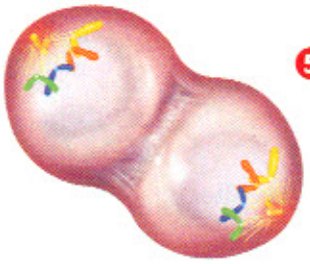
2 The chromosomes thicken and shorten. Each chromosome consists of two identical copies, called *chromatids.*



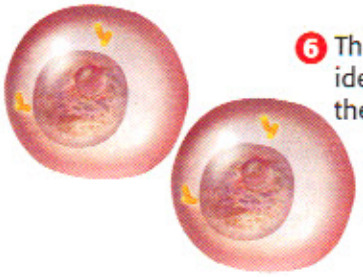
3 The nuclear membrane dissolves. The chromatids line up along the equator (center) of the cell.



4 The chromatids pull apart.



5 The nuclear membrane forms around the separated chromatids. The chromosomes unwind, and the cell divides.



6 The result is two identical copies of the original cell.

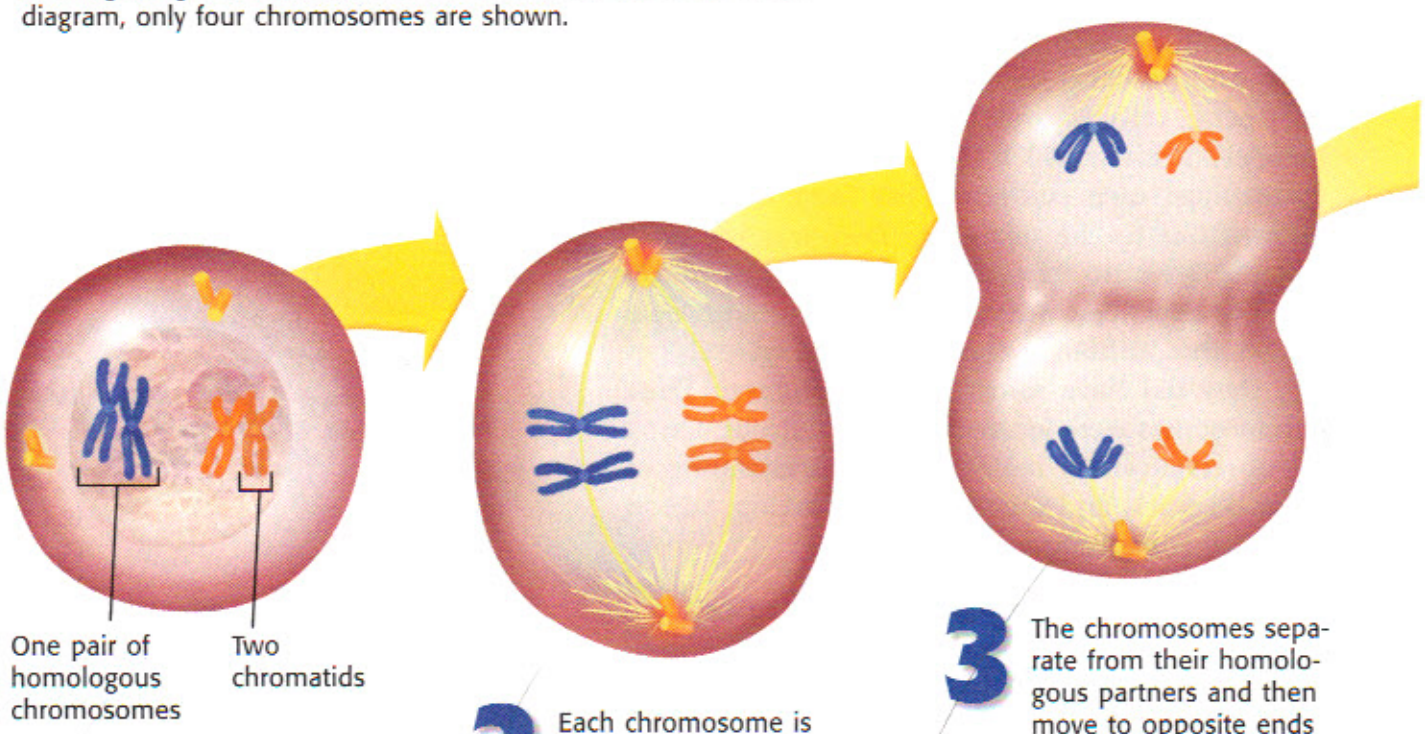
The Steps of Meiosis

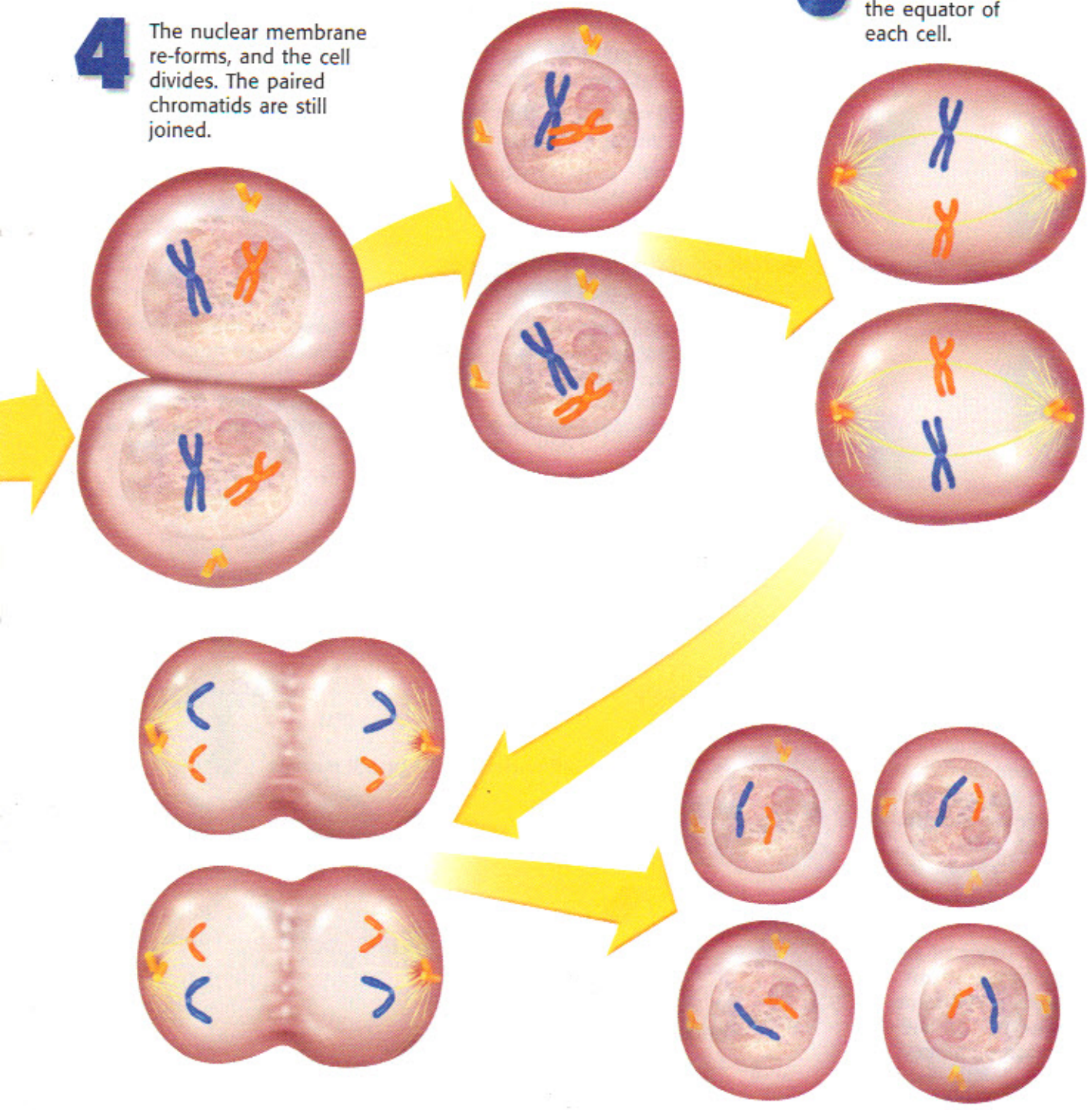
During mitosis, chromosomes are copied once, and then the nucleus divides once. During meiosis, chromosomes are copied once, and then the nucleus divides twice. The resulting sperm and eggs have half the number of chromosomes of a normal body cell. **Figure 3** shows all eight steps of meiosis. Read about each step as you look at the figure. Different types of living things have different numbers of chromosomes. In this illustration, only four chromosomes are shown.

Reading Check How many cells are made from one parent cell during meiosis?

Figure 3 **Steps of Meiosis**

Read about each step as you look at the diagram. Different types of living things have different numbers of chromosomes. In this diagram, only four chromosomes are shown.





5 Each cell contains one member of each homologous chromosome pair. The chromosomes are not copied again between the two cell divisions.

6 The chromosomes then line up at the equator of each cell.

4 The nuclear membrane re-forms, and the cell divides. The paired chromatids are still joined.

7 The chromatids pull apart and move to opposite ends of the cell. The nuclear membrane forms around the separated chromosomes, and the cells divide.

8 The result is that four new cells have formed from the original single cell. Each new cell has half the number of chromosomes present in the original cell.

INTERNET ACTIVITY

For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HL5HERW.**

Meiosis and Mendel

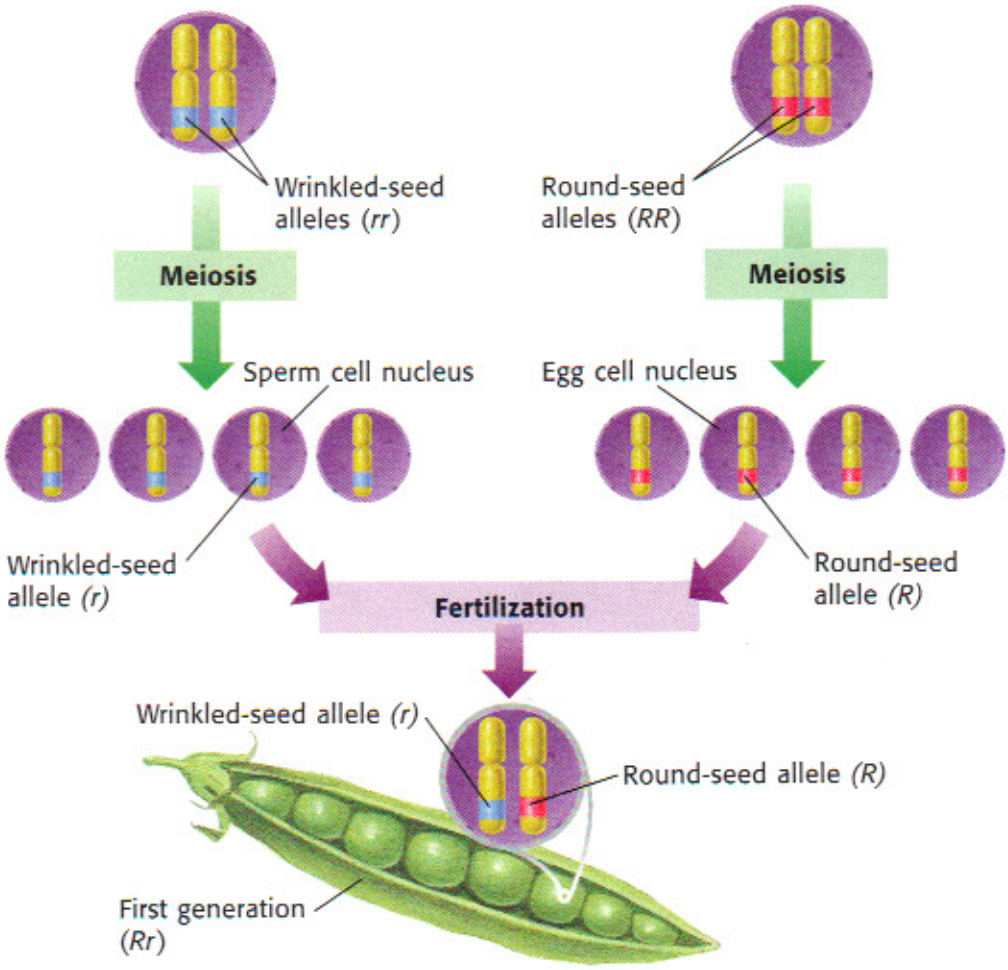
As Walter Sutton figured out, the steps in meiosis explained Mendel's results. **Figure 4** shows what happens to a pair of homologous chromosomes during meiosis and fertilization. The cross shown is between a plant that is true breeding for round seeds and a plant that is true breeding for wrinkled seeds.

Each fertilized egg in the first generation had one dominant allele and one recessive allele for seed shape. Only one genotype was possible because all sperm formed by the male parent during meiosis had the wrinkled-seed allele, and all of the female parent's eggs had the round-seed allele. Meiosis also helped explain other inherited characteristics.

Figure 4 **Meiosis and Dominance**

Male Parent In the plant-cell nucleus below, each homologous chromosome has an allele for seed shape, and each allele carries the same instructions: to make wrinkled seeds.

Female Parent In the plant-cell nucleus below, each homologous chromosome has an allele for seed shape, and each allele carries the same instructions: to make round seeds.



a Following **meiosis,** each sperm cell has a recessive allele for wrinkled seeds, and each egg cell has a dominant allele for round seeds.

b **Fertilization** of any egg by any sperm results in the same genotype (*Rr*) and the same phenotype (round). This result is exactly what Mendel found in his studies.

Sex Chromosomes

Information contained on chromosomes determines many of our traits. **Sex chromosomes** carry genes that determine sex. In humans, females have two X chromosomes. But human males have one X chromosome and one Y chromosome.

During meiosis, one of each of the chromosome pairs ends up in a sex cell. Females have two X chromosomes in each body cell. When meiosis produces the egg cells, each egg gets one X chromosome. Males have both an X chromosome and a Y chromosome in each body cell. Meiosis produces sperm with either an X or a Y chromosome. An egg fertilized by a sperm with an X chromosome will produce a female. If the sperm contains a Y chromosome, the offspring will be male, as shown in **Figure 5.**

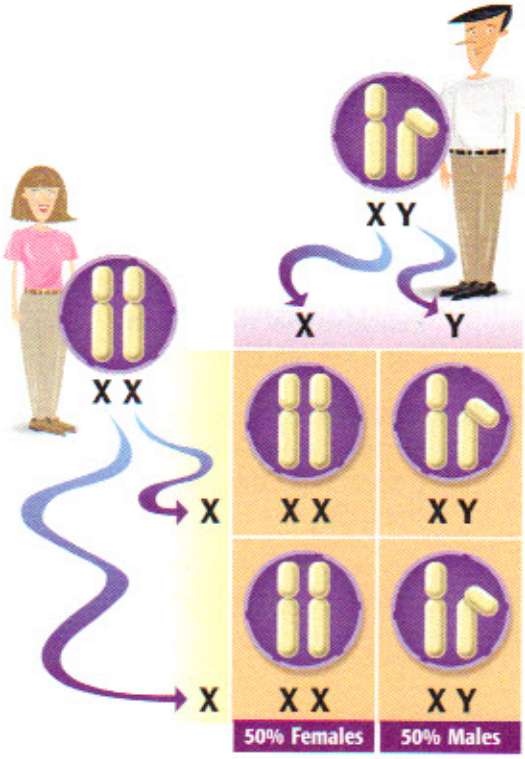


Figure 5 *Egg and sperm combine to form either the XX or XY combination.*

Sex-Linked Disorders

The Y chromosome does not carry all of the genes of an X chromosome. Females have two X chromosomes, so they carry two copies of each gene found on the X chromosome. This makes a backup gene available if one becomes damaged. Males have only one copy of each gene on their one X chromosome. The genes for certain disorders, such as colorblindness, are carried on the X chromosome. These disorders are called *sex-linked disorders*. Because the gene for such disorders is recessive, men are more likely to have sex-linked disorders.

People who are colorblind can have trouble distinguishing between shades of red and green. To help the colorblind, some cities have added shapes to their street lights, as shown in **Figure 6.** Hemophilia (HEE moh FIL ee uh) is another sex-linked disorder. Hemophilia prevents blood from clotting, and people with hemophilia bleed for a long time after small cuts. Hemophilia can be fatal.

sex chromosome one of the pair of chromosomes that determine the sex of an individual

Figure 6 *This stoplight in Canada is designed to help the colorblind see signals easily. This photograph was taken over a few minutes to show all three shapes.*

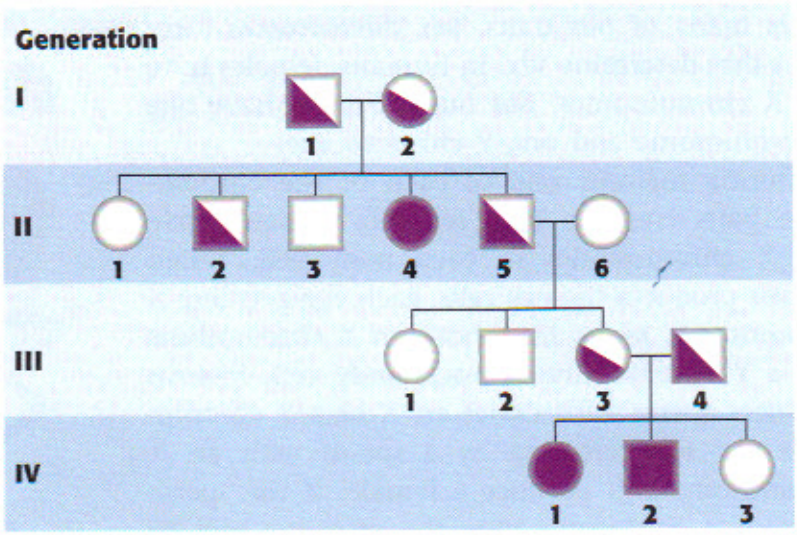
Figure 7 **Pedigree for a Recessive Disease**

Males Females

Vertical lines connect children to their parents.

or A solid square or circle indicates that the person has a certain trait.

or A half-filled square or circle indicates that the person is a carrier of the trait.



Genetic Counseling

Hemophilia and other genetic disorders can be traced through a family tree. If people are worried that they might pass a disease to their children, they may consult a genetic counselor. These counselors often make use of a diagram known as a **pedigree,** which is a tool for tracing a trait through generations of a family. By making a pedigree, a counselor can often predict whether a person is a carrier of a hereditary disease. The pedigree shown in **Figure 7** traces a disease called *cystic fibrosis* (SIS tik FIE broh sis). Cystic fibrosis causes serious lung problems. People with this disease have inherited two recessive alleles. Both parents need to be carriers of the gene for the disease to show up in their children.

Pedigrees can be drawn up to trace any trait through a family tree. You could even draw a pedigree that would show how you inherited your hair color. Many different pedigrees could be drawn for a typical family.

pedigree a diagram that shows the occurrence of a genetic trait in several generations of a family

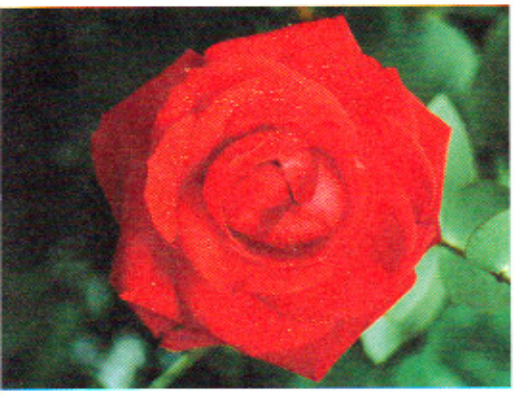


Figure 8 *Roses have been selectively bred to create large, bright flowers.*

Selective Breeding

For thousands of years, humans have seen the benefits of the careful breeding of plants and animals. In *selective breeding,* organisms with desirable characteristics are mated. You have probably enjoyed the benefits of selective breeding, although you may not have realized it. For example, you have probably eaten an egg from a chicken that was bred to produce more eggs. Your pet dog may be a result of selective breeding. Roses, like the one shown in **Figure 8,** have been selectively bred to produce large flowers. Wild roses are much smaller and have fewer petals than roses that you could buy at a nursery.

SECTION
Review

Summary

- In mitosis, chromosomes are copied once, and then the nucleus divides once. In meiosis, chromosomes are copied once, and then the nucleus divides twice.
- The process of meiosis produces sex cells, which have half the number of chromosomes. These two halves combine during reproduction.
- In humans, females have two X chromosomes. So, each egg contains one X chromosome. Males have both an X and a Y chromosome. So, each sperm cell contains either an X or a Y chromosome.
- Sex-linked disorders occur in males more often than in females. Colorblindness and hemophilia are examples of sex-linked disorders.
- A pedigree is a diagram used to trace a trait through many generations of a family.

Using Key Terms

1. Use each of the following terms in the same sentence: *meiosis* and *sex chromosomes*.

In each of the following sentences, replace the incorrect term with the correct term from the word bank.

pedigree	homologous chromosomes
meiosis	mitosis

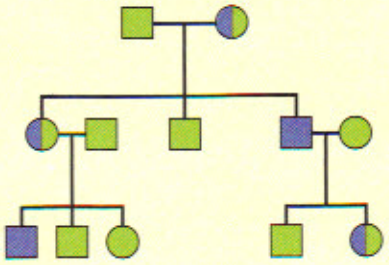
2. During fertilization, chromosomes are copied, and then the nucleus divides twice.
3. A Punnett square is used to show how inherited traits move through a family.
4. During meiosis, sex cells line up in the middle of the cell.

Understanding Key Ideas

5. Genes are found on
   - **a.** chromosomes.
   - **b.** proteins.
   - **c.** alleles.
   - **d.** sex cells.
6. If there are 14 chromosomes in pea plant cells, how many chromosomes are present in a sex cell of a pea plant?
7. Draw the eight steps of meiosis. Label one chromosome, and show its position in each step.

Interpreting Graphics

Use this pedigree to answer the question below.



8. Is this disorder sex linked? Explain your reasoning.

Critical Thinking

9. **Identifying Relationships** Put the following in order of smallest to largest: chromosome, gene, and cell.
10. **Applying Concepts** A pea plant has purple flowers. What alleles for flower color could the sex cells carry?

Using Scientific Methods

Model-Making Lab

Bug Builders, Inc.

Imagine that you are a designer for a toy company that makes toy alien bugs. The president of Bug Builders, Inc., wants new versions of the wildly popular Space Bugs, but he wants to use the bug parts that are already in the warehouse. It's your job to come up with a new bug design. You have studied how traits are passed from one generation to another. You will use this knowledge to come up with new combinations of traits and assemble the bug parts in new ways. Model A and Model B, shown below, will act as the "parent" bugs.

OBJECTIVES

Build models to further your understanding of inheritance.

Examine the traits of a population of offspring.

MATERIALS

- allele sacks (14) (supplied by your teacher)
- gumdrops, green and black (feet)
- map pins (eyes)
- marshmallows, large (head and body segments)
- pipe cleaners (tails)
- pushpins, green and blue (noses)
- scissors
- toothpicks, red and green (antennae)

SAFETY

Ask a Question

1. If there are two forms of each of the seven traits, then how many possible combinations are there?

Form a Hypothesis

2. Write a hypothesis that is a possible answer to the question above. Explain your reasoning.

Test the Hypothesis

3. Your teacher will display 14 allele sacks. The sacks will contain slips of paper with capital or lowercase letters on them. Take one piece of paper from each sack. (Remember: Capital letters represent dominant alleles, and lowercase letters represent recessive alleles.) One allele is from "Mom," and one allele is from "Dad." After you have recorded the alleles you have drawn, place the slips of paper back into the sack.

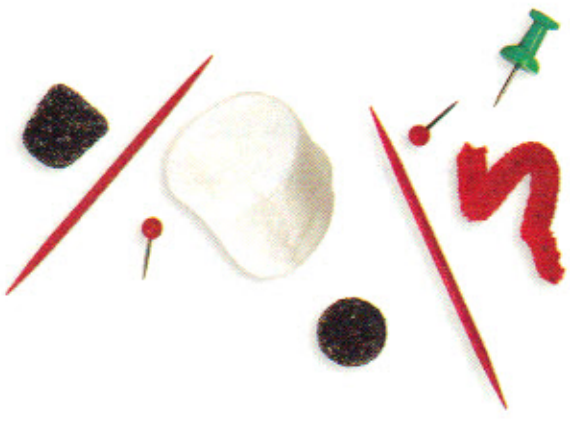
Model A ("Mom")
- red antennae
- 3 body segments
- curly tail
- 2 pairs of legs
- green nose
- black feet
- 3 eyes

Model B ("Dad")
- green antennae
- 2 body segments
- straight tail
- 3 pairs of legs
- blue nose
- green feet
- 2 eyes

Bug Family Traits				
Trait	Model A "Mom" allele	Model B "Dad" allele	New model "Baby" genotype	New model "Baby" phenotype
Antennae color				
Number of body segments				
Tail shape				
Number of leg pairs				
Nose color				
Foot color				
Number of eyes				

4. Create a table like the one above. Fill in the first two columns with the alleles that you selected from the sacks. Next, fill in the third column with the genotype of the new model ("Baby").
5. Use the information below to fill in the last column of the table.

Genotypes and Phenotypes	
RR or *Rr*–red antennae	*rr*–green antennae
SS or *Ss*–3 body segments	*ss*–2 body segments
CC or *Cc*–curly tail	*cc*–straight tail
LL or *Ll*–3 pairs of legs	*ll*–2 pairs of legs
BB or *Bb*–blue nose	*bb*–green nose
GG or *Gg*–green feet	*gg*–black feet
EE or *Ee*–2 eyes	*ee*–3 eyes



6. Now that you have filled out your table, you are ready to pick the parts you need to assemble your bug. (Toothpicks can be used to hold the head and body segments together and as legs to attach the feet to the body.)

Analyze the Results

1. **Organizing Data** Take a poll of the traits of the offspring. What are the ratios for each trait?
2. **Examining Data** Do any of the new models look exactly like the parents? Explain.

Draw Conclusions

3. **Interpreting Information** What are the possible genotypes of the parent bugs?
4. **Making Predictions** How many different genotypes are possible in the offspring?

Applying Your Data

Find a mate for your "Baby" bug. What are the possible genotypes and phenotypes of the offspring from this match?

Chapter Review

USING KEY TERMS

Complete each of the following sentences by choosing the correct term from the word bank.

sex cells	genotype
sex chromosomes	alleles
phenotype	meiosis

1. Sperm and eggs are known as _____.
2. The _____ is the expression of a trait and is determined by the combination of alleles called the _____.
3. _____ produces cells with half the normal number of chromosomes.
4. Different versions of the same genes are called _____.

UNDERSTANDING KEY IDEAS

Multiple Choice

5. Genes carry information that determines
   - **a.** alleles.
   - **b.** ribosomes.
   - **c.** chromosomes.
   - **d.** traits.
6. The process that produces sex cells is
   - **a.** mitosis.
   - **b.** photosynthesis.
   - **c.** meiosis.
   - **d.** probability.
7. The passing of traits from parents to offspring is called
   - **a.** probability.
   - **b.** heredity.
   - **c.** recessive.
   - **d.** meiosis.
8. If you cross a white flower with the genotype *pp* with a purple flower with the genotype *PP,* the possible genotypes in the offspring are
   - **a.** *PP* and *pp*.
   - **b.** all *Pp*.
   - **c.** all *PP*.
   - **d.** all *pp*.
9. For the cross in item 8, what would the phenotypes be?
   - **a.** all white
   - **b.** 3 purple and 1 white
   - **c.** all purple
   - **d.** half white, half purple
10. In meiosis,
    - **a.** chromosomes are copied twice.
    - **b.** the nucleus divides once.
    - **c.** four cells are produced from a single cell.
    - **d.** two cells are produced from a single cell.
11. When one trait is not completely dominant over another, it is called
    - **a.** recessive.
    - **b.** incomplete dominance.
    - **c.** environmental factors.
    - **d.** uncertain dominance.

Short Answer

12. Which sex chromosomes do females have? Which do males have?

13. In one or two sentences, define the term *recessive trait* in your own words.

14. How are sex cells different from other body cells?

15. What is a sex-linked disorder? Give one example of a sex-linked disorder that is found in humans.

CRITICAL THINKING

16. **Concept Mapping** Use the following terms to create a concept map: *meiosis, eggs, cell division, X chromosome, mitosis, Y chromosome, sperm,* and *sex cells*.

17. **Identifying Relationships** If you were a carrier of one allele for a certain recessive disorder, how could genetic counseling help you prepare for the future?

18. **Applying Concepts** If a child has blond hair and both of her parents have brown hair, what does that tell you about the allele for blond hair? Explain.

19. **Applying Concepts** What is the genotype of a pea plant that is true-breeding for purple flowers?

INTERPRETING GRAPHICS

Use the Punnett square below to answer the questions that follow.

	?	?
T	TT	TT
t	Tt	Tt

20. What is the unknown genotype?

21. If *T* represents the allele for tall pea plants and *t* represents the allele for short pea plants, what is the phenotype of each parent and of the offspring?

22. If each of the offspring were allowed to self-fertilize, what are the possible genotypes in the next generation?

23. What is the probability of each genotype in item 22?