# 3

# Heredity

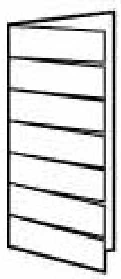


## About the PHOTO

The guinea pig in the middle has dark fur, and the other two have light orange fur. The guinea pig on the right has longer hair than the other two. Why do these guinea pigs look different from one another? The length and color of their fur was determined before they were born. These are just two of the many traits determined by genetic information. Genetic information is passed on from parents to their offspring.

## PRE-READING ACTIVITY

FOLDNOTES **Key-Term Fold** Before you read the chapter, create the FoldNote entitled "Key-Term Fold" described in the **Study Skills** section of the Appendix. Write a key term from the chapter on each tab of the key-term fold. Under each tab, write the definition of the key term.




## Clothing Combos

How do the same parents have children with many different traits?

### Procedure

1. Gather **three boxes**. Put **five hats** in the first box, **five gloves** in the second, and **five scarves** in the third.
2. Without looking in the boxes, select one item from each box. Repeat this process, five students at a time, until the entire class has picked "an outfit." Record what outfit each student chooses.

### Analysis

1. Were any two outfits exactly alike? Did you see all possible combinations? Explain your answer.
2. Choose a partner. Using your outfits, how many different combinations could you make by giving a third person one hat, one glove, and one scarf? How is this process like parents passing traits to their children?
3. After completing this activity, why do you think parents often have children who look very different from each other?

SECTION 1

# Mendel and His Peas

READING WARM-UP

**Objectives**

- Explain the relationship between traits and heredity.
- Describe the experiments of Gregor Mendel.
- Explain the difference between dominant and recessive traits.

**Terms to Learn**

heredity
dominant trait
recessive trait

READING STRATEGY

**Brainstorming** The key idea of this section is heredity. Brainstorm words and phrases related to heredity.

*Why don't you look like a rhinoceros? The answer to this question seems simple: Neither of your parents is a rhinoceros. But there is more to this answer than meets the eye.*

As it turns out, **heredity,** or the passing of traits from parents to offspring, is more complicated than you might think. For example, you might have curly hair, while both of your parents have straight hair. You might have blue eyes even though both of your parents have brown eyes. How does this happen? People have investigated this question for a long time. About 150 years ago, Gregor Mendel performed important experiments. His discoveries helped scientists begin to find some answers to these questions.

**heredity** the passing of genetic traits from parent to offspring

**Reading Check** What is heredity? *(See the Appendix for answers to Reading Checks.)*

## Who Was Gregor Mendel?

Gregor Mendel, shown in **Figure 1,** was born in 1822 in Heinzendorf, Austria. Mendel grew up on a farm and learned a lot about flowers and fruit trees.

When he was 21 years old, Mendel entered a monastery. The monks taught science and performed many scientific experiments. From there, Mendel was sent to Vienna where he could receive training in teaching. However, Mendel had trouble taking tests. Although he did well in school, he was unable to pass the final exam. He returned to the monastery and put most of his energy into research. Mendel discovered the principles of heredity in the monastery garden.

**Figure 1** *Gregor Mendel discovered the principles of heredity while studying pea plants.*

## Unraveling the Mystery

From working with plants, Mendel knew that the patterns of inheritance were not always clear. For example, sometimes a trait that appeared in one generation (parents) was not present in the next generation (offspring). In the generation after that, though, the trait showed up again. Mendel noticed these kinds of patterns in several other living things, too. Mendel wanted to learn more about what caused these patterns.

To keep his investigation simple, Mendel decided to study only one kind of organism. Because he had studied garden pea plants before, they seemed like a good choice.

## Self-Pollinating Peas

In fact, garden peas were a good choice for several reasons. Pea plants grow quickly, and there are many different kinds available. They are also able to self-pollinate. A *self-pollinating plant* has both male and female reproductive structures. So, pollen from one flower can fertilize the ovule of the same flower or the ovule of another flower on the same plant. The flower on the right side of **Figure 2** is self-pollinating.

Why is it important that pea plants can self-pollinate? Because eggs (in an ovule) and sperm (in pollen) from the same plant combine to make a new plant, Mendel was able to grow true-breeding plants. When a *true-breeding plant* self-pollinates, all of its offspring will have the same trait as the parent. For example, a true-breeding plant with purple flowers will always have offspring with purple flowers.

Pea plants can also cross-pollinate. In *cross-pollination,* pollen from one plant fertilizes the ovule of a flower on a different plant. There are several ways that this can happen. Pollen may be carried by insects to a flower on a different plant. Pollen can also be carried by the wind from one flower to another. The left side of **Figure 2** shows these kinds of cross-pollination.

**SCHOOL to HOME**

**Describing Traits**

How would you describe yourself? Would you say that you are tall or short, have curly hair or straight hair? Make a list of some of your physical traits. Make a second list of traits that you were not born with, such as "caring" or "good at soccer." Talk to your family about your lists. Do they agree with your descriptions?

**ACTIVITY**

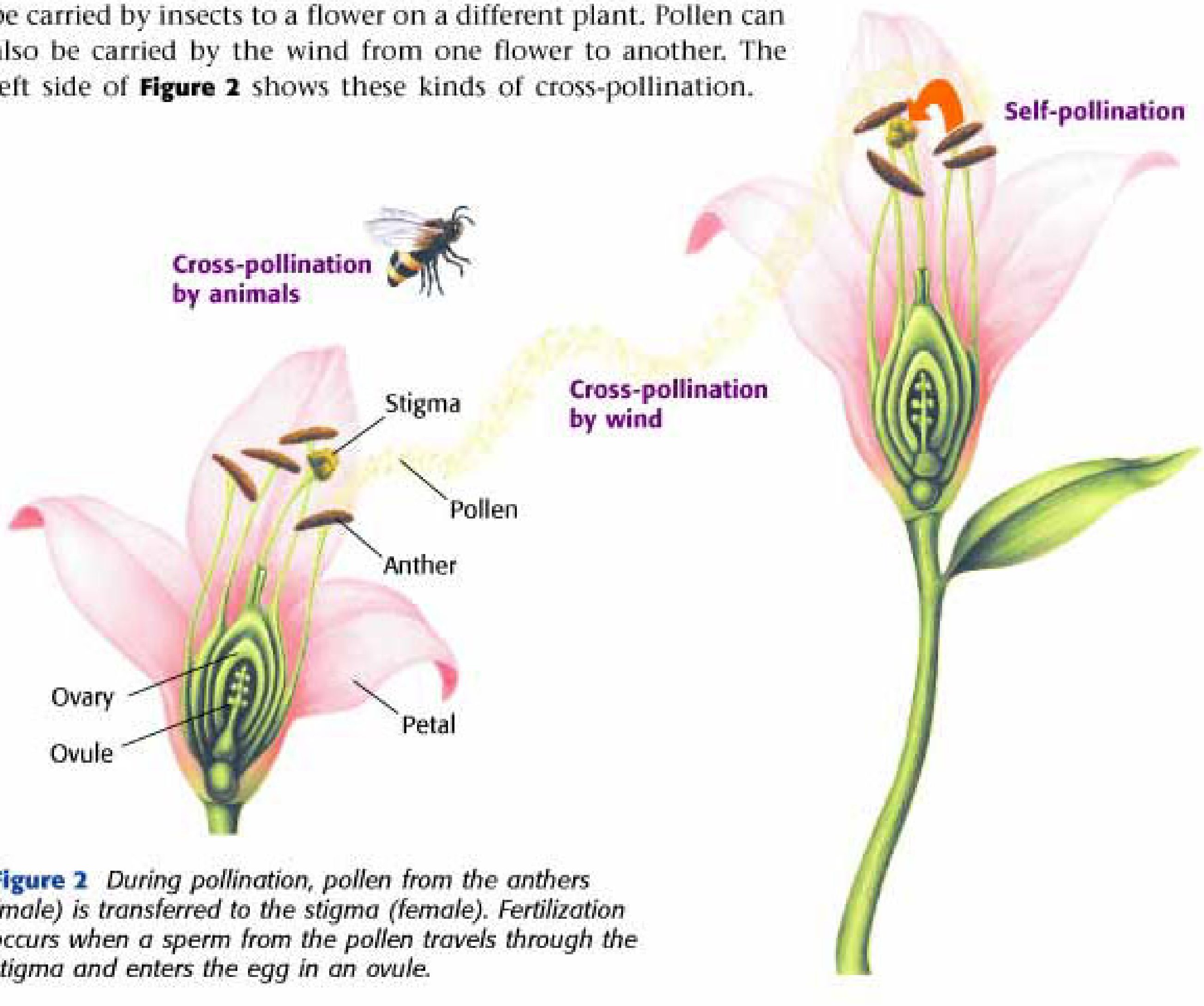



**Figure 2** *During pollination, pollen from the anthers (male) is transferred to the stigma (female). Fertilization occurs when a sperm from the pollen travels through the stigma and enters the egg in an ovule.*

## Characteristics

Mendel studied only one characteristic at a time. A *characteristic* is a feature that has different forms in a population. For example, hair color is a characteristic in humans. The different forms, such as brown or red hair, are called *traits*. Mendel used plants that had different traits for each of the characteristics he studied. For instance, for the characteristic of flower color, he chose plants that had purple flowers and plants that had white flowers. Three of the characteristics Mendel studied are shown in **Figure 3.**

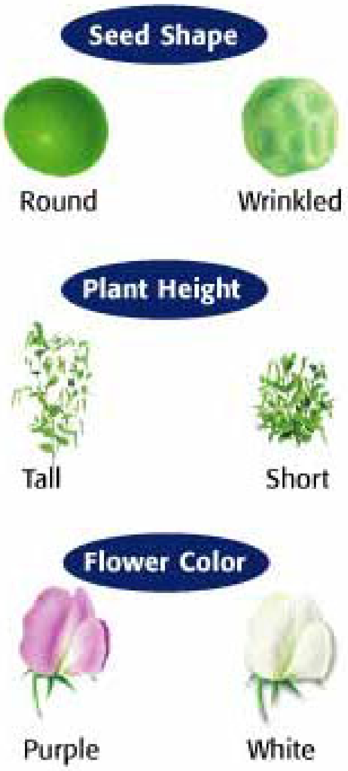



**Figure 3** *These are some of the plant characteristics that Mendel studied.*

## Mix and Match

Mendel was careful to use plants that were true breeding for each of the traits he was studying. By doing so, he would know what to expect if his plants were to self-pollinate. He decided to find out what would happen if he bred, or crossed, two plants that had different traits of a single characteristic. To be sure the plants cross-pollinated, he removed the anthers of one plant so that the plant could not self-pollinate. Then, he used pollen from another plant to fertilize the plant, as shown in **Figure 4.** This step allowed Mendel to select which plants would be crossed to produce offspring.

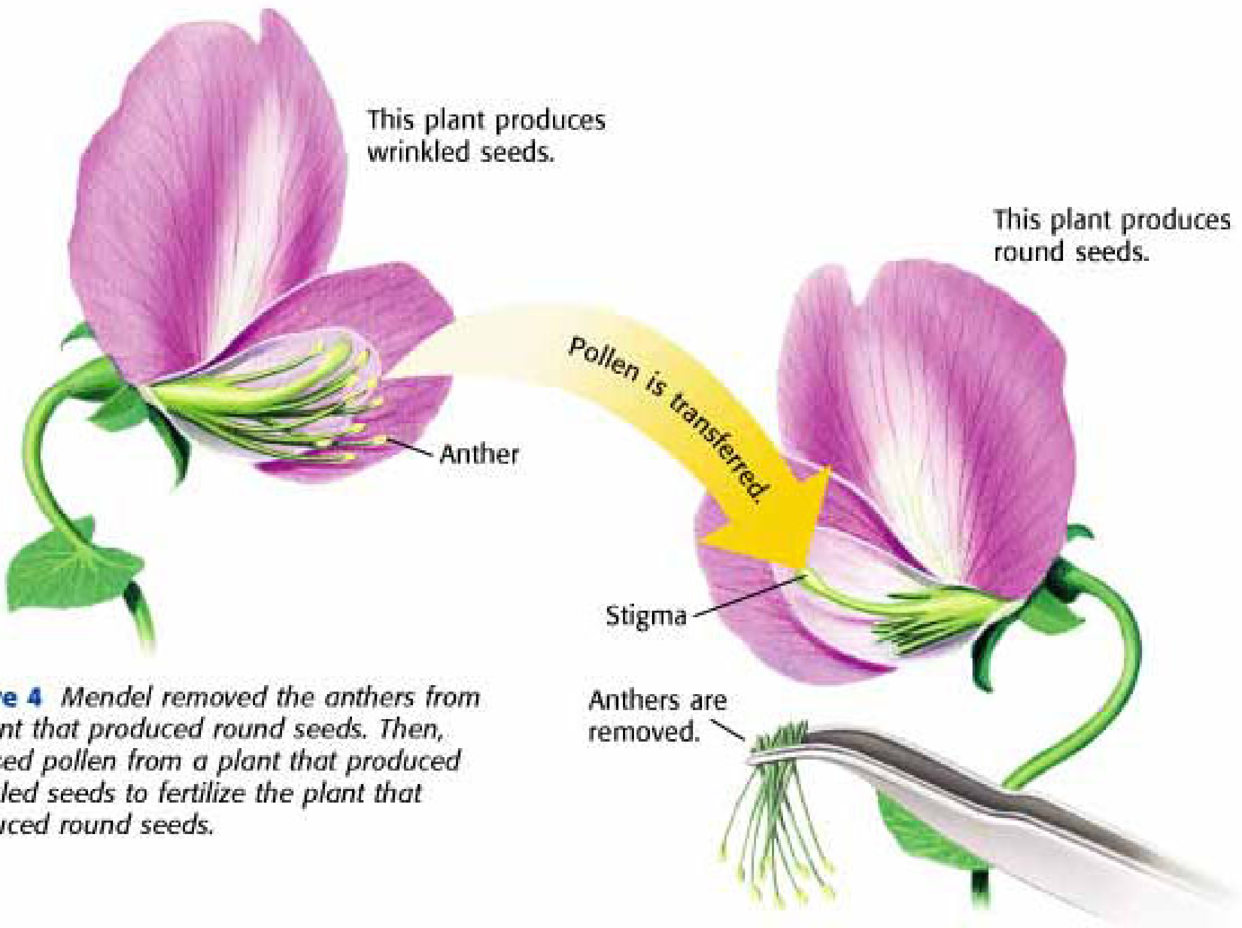



**Figure 4** *Mendel removed the anthers from a plant that produced round seeds. Then, he used pollen from a plant that produced wrinkled seeds to fertilize the plant that produced round seeds.*

## Mendel's First Experiments

In his first experiments, Mendel crossed pea plants to study seven different characteristics. In each cross, Mendel used plants that were true breeding for different traits for each characteristic. For example, he crossed plants that had purple flowers with plants that had white flowers. This cross is shown in the first part of **Figure 5.** The offspring from such a cross are called *first-generation plants*. All of the first-generation plants in this cross had purple flowers. Are you surprised by the results? What happened to the trait for white flowers?

Mendel got similar results for each cross. One trait was always present in the first generation, and the other trait seemed to disappear. Mendel chose to call the trait that appeared the **dominant trait.** Because the other trait seemed to fade into the background, Mendel called it the **recessive trait.** (To *recede* means "to go away or back off.") To find out what might have happened to the recessive trait, Mendel decided to do another set of experiments.

**dominant trait** the trait observed in the first generation when parents that have different traits are bred

**recessive trait** a trait that reappears in the second generation after disappearing in the first generation when parents with different traits are bred

## Mendel's Second Experiments

Mendel allowed the first-generation plants to self-pollinate. **Figure 5** also shows what happened when a first-generation plant with purple flowers was allowed to self-pollinate. As you can see, the recessive trait for white flowers reappeared in the second generation.

Mendel did this same experiment on each of the seven characteristics. In each case, some of the second-generation plants had the recessive trait.

**Reading Check** Describe Mendel's second set of experiments.

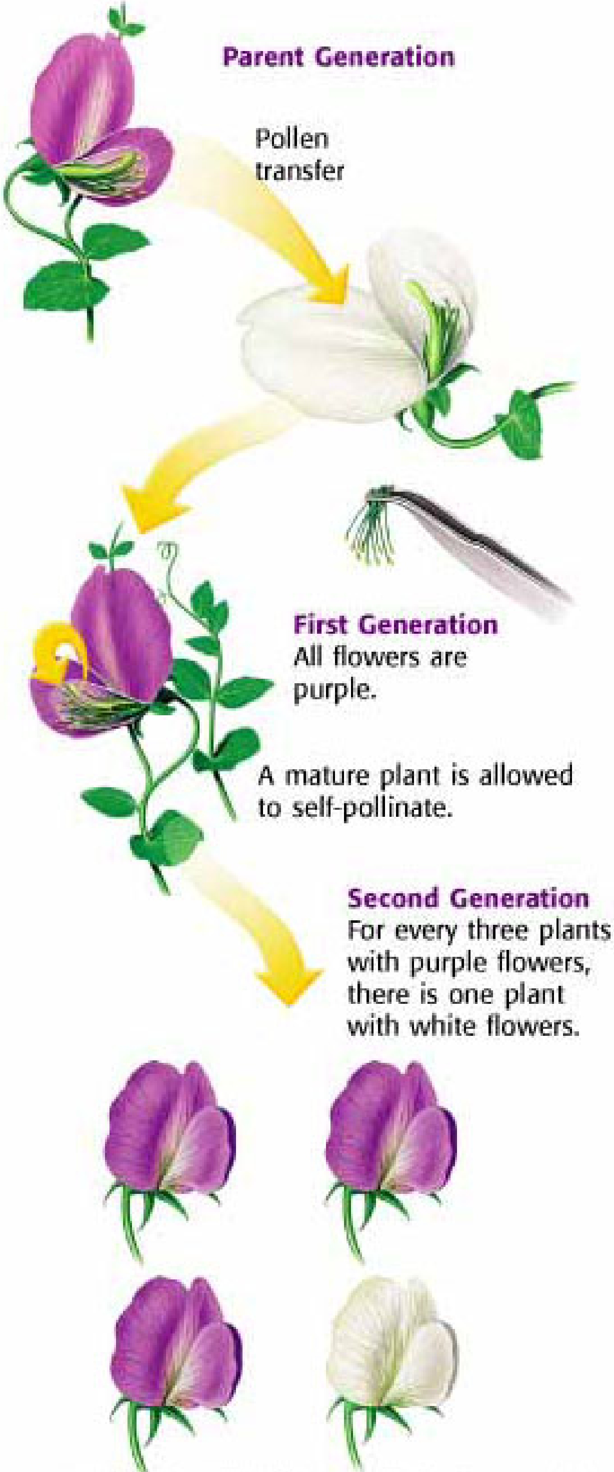



**Figure 5** *Mendel used the pollen from a plant with purple flowers to fertilize a plant with white flowers. Then, he allowed the offspring to self-pollinate.*

## Ratios in Mendel's Experiments

Mendel then decided to count the number of plants with each trait that turned up in the second generation. He hoped that this might help him explain his results. Take a look at Mendel's results, shown in **Table 1.**

As you can see, the recessive trait did not show up as often as the dominant trait. Mendel decided to figure out the ratio of dominant traits to recessive traits. A *ratio* is a relationship between two different numbers that is often expressed as a fraction. Calculate the dominant-to-recessive ratio for each characteristic. (If you need help, look at the Math Practice at left.) Do you notice anything interesting about the ratios? Round to the nearest whole number. Are the ratios all the same, or are they different?

**Reading Check** What is a ratio?

### MATH PRACTICE

**Understanding Ratios**

A ratio is a way to compare two numbers. Look at **Table 1.** The ratio of plants with purple flowers to plants with white flowers can be written as 705 to 224 or 705:224. This ratio can be reduced, or simplified, by dividing the first number by the second as follows:

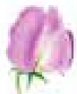
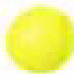
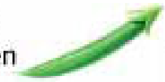
$$\frac{705}{224} = \frac{3.15}{1}$$

which is the same thing as a ratio of 3.15:1.

For every 3 plants with purple flowers, there will be roughly 1 plant with white flowers. Try this problem:

In a box of chocolates, there are 18 nougat-filled chocolates and 6 caramel-filled chocolates. What is the ratio of nougat-filled chocolates to caramel-filled chocolates?

**Table 1 Mendel's Results**

| Characteristic | Dominant traits | Recessive traits | Ratio |
|---|---|---|---|
| Flower color | 705 purple  | 224 white  | 3.15:1 |
| Seed color | 6,002 yellow  | 2,001 green  | ? |
| Seed shape | 5,474 round  | 1,850 wrinkled  | ? |
| Pod color | 428 green  | 152 yellow  | ? |
| Pod shape | 882 smooth  | 299 bumpy  | ? |
| Flower position | 651 along stem  | 207 at tip  | ? |
| Plant height | 787 tall  | 277 short  | ? |

## Gregor Mendel—Gone but Not Forgotten

Mendel realized that his results could be explained only if each plant had two sets of instructions for each characteristic. Each parent would then donate one set of instructions. In 1865, Mendel published his findings. But good ideas are sometimes overlooked or misunderstood at first. It wasn't until after his death, more than 30 years later, that Mendel's work was widely recognized. Once Mendel's ideas were rediscovered and understood, the door was opened to modern genetics. Genetic research, as shown in **Figure 6,** is one of the fastest changing fields in science today.

**Figure 6** *This researcher is continuing the work started by Gregor Mendel more than 100 years ago.*

# SECTION Review

## Summary

- Heredity is the passing of traits from parents to offspring.
- Gregor Mendel made carefully planned experiments using pea plants that could self-pollinate.
- When parents with different traits are bred, dominant traits are always present in the first generation. Recessive traits are not visible in the first generation but reappear in the second generation.
- Mendel found a 3:1 ratio of dominant-to-recessive traits in the second generation.

### Using Key Terms

1. Use each of the following terms in a separate sentence: *heredity, dominant trait,* and *recessive trait.*

### Understanding Key Ideas

2. A plant that has both male and female reproductive structures is able to
   a. self-replicate.
   b. self-pollinate.
   c. change colors.
   d. None of the above
3. Explain the difference between self-pollination and cross-pollination.
4. What is the difference between a trait and a characteristic? Give one example of each.
5. Describe Mendel's first set of experiments.
6. Describe Mendel's second set of experiments.

### Math Skills

7. In a bag of chocolate candies, there are 21 brown candies and 6 green candies. What is the ratio of brown to green? What is the ratio of green to brown?

### Critical Thinking

8. **Predicting Consequences** Gregor Mendel used only true-breeding plants. If he had used plants that were not true breeding, do you think he would have discovered dominant and recessive traits? Explain.
9. **Applying Concepts** In cats, there are two types of ears: normal and curly. A curly-eared cat mated with a normal-eared cat, and all of the kittens had curly ears. Are curly ears a dominant or recessive trait? Explain.
10. **Identifying Relationships** List three other fields of study that use ratios.

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For a variety of links related to this chapter, go to www.scilinks.org

Topic: Heredity; Dominant and Recessive Traits

SciLinks code: HSM0738; HSM0423

SECTION 2

# Traits and Inheritance

*Mendel calculated the ratio of dominant traits to recessive traits. He found a ratio of 3:1. What did this tell him about how traits are passed from parents to offspring?*

**READING WARM-UP**

### Objectives

- Explain how genes and alleles are related to genotype and phenotype.
- Use the information in a Punnett square.
- Explain how probability can be used to predict possible genotypes in offspring.
- Describe three exceptions to Mendel's observations.

### Terms to Learn

gene
allele
phenotype
genotype
probability

**READING STRATEGY**

**Paired Summarizing** Read this section silently. In pairs, take turns summarizing the material. Stop to discuss ideas that seem confusing.

## A Great Idea

Mendel knew from his experiments with pea plants that there must be two sets of instructions for each characteristic. The first-generation plants carried the instructions for both the dominant trait and the recessive trait. Scientists now call these instructions for an inherited trait **genes.** Each parent gives one set of genes to the offspring. The offspring then has two forms of the same gene for every characteristic—one from each parent. The different forms (often dominant and recessive) of a gene are known as **alleles** (uh LEELZ). Dominant alleles are shown with a capital letter. Recessive alleles are shown with a lowercase letter.

**Reading Check** **What is the difference between a gene and an allele?** *(See the Appendix for answers to Reading Checks.)*

### Phenotype

Genes affect the traits of offspring. An organism's appearance is known as its **phenotype** (FEE noh TIEP). In pea plants, possible phenotypes for the characteristic of flower color would be purple flowers or white flowers. For seed color, yellow and green seeds are the different phenotypes.

Phenotypes of humans are much more complicated than those of peas. Look at **Figure 1** below. The man has an inherited condition called *albinism* (AL buh NIZ uhm). Albinism prevents hair, skin, and eyes from having normal coloring.

**gene** one set of instructions for an inherited trait

**allele** one of the alternative forms of a gene that governs a characteristic, such as hair color

**phenotype** an organism's appearance or other detectable characteristic

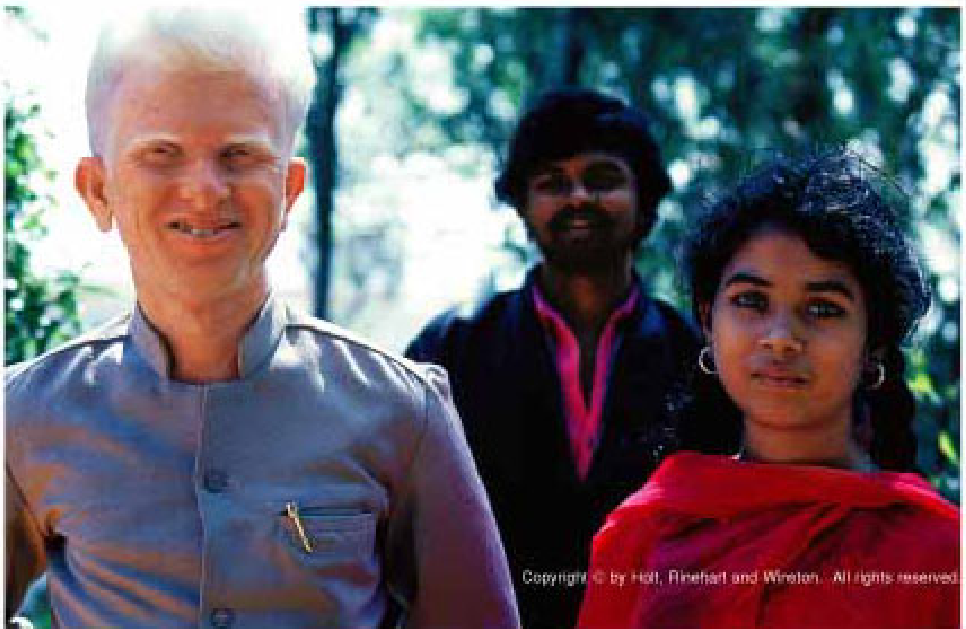


**Figure 1** *Albinism is an inherited disorder that affects a person's phenotype in many ways.*

## Genotype

Both inherited alleles together form an organism's **genotype.** Because the allele for purple flowers (*P*) is dominant, only one *P* allele is needed for the plant to have purple flowers. A plant with two dominant or two recessive alleles is said to be *homozygous* (HOH moh ZIE guhs). A plant that has the genotype *Pp* is said to be *heterozygous* (HET uhr OH ZIE guhs).

## Punnett Squares

A Punnett square is used to organize all the possible combinations of offspring from particular parents. The alleles for a true-breeding, purple-flowered plant are written as *PP*. The alleles for a true-breeding, white-flowered plant are written as *pp*. The Punnett square for this cross is shown in **Figure 2.** All of the offspring have the same genotype: *Pp*. The dominant allele, *P*, in each genotype ensures that all of the offspring will be purple-flowered plants. The recessive allele, *p*, may be passed on to the next generation. This Punnett square shows the results of Mendel's first experiments.

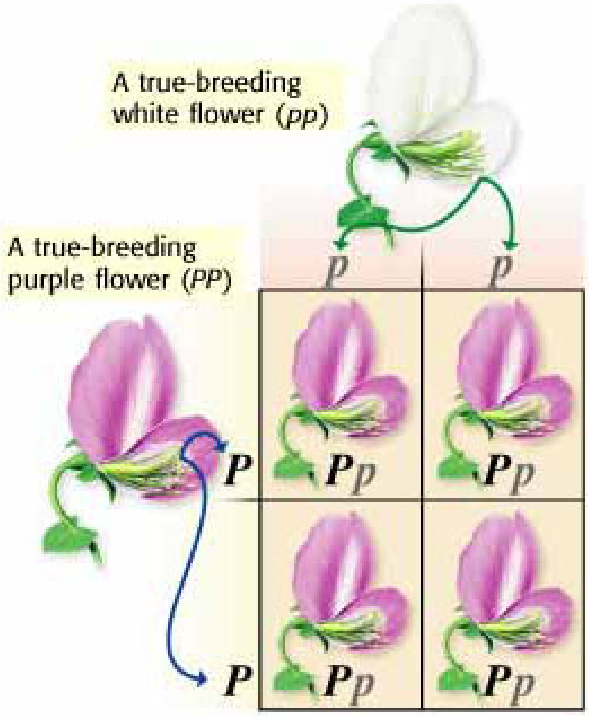


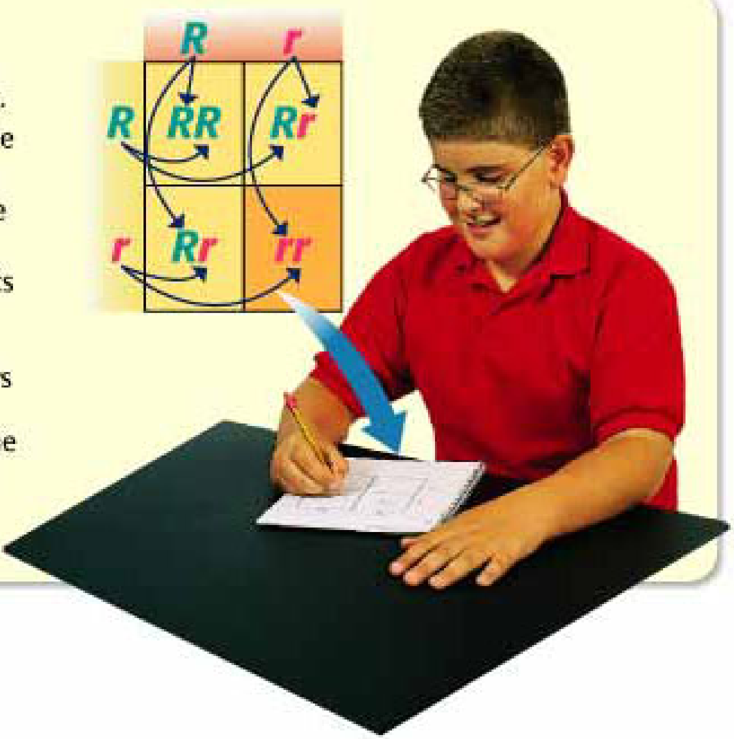

**Figure 2** *All of the offspring for this cross have the same genotype—Pp.*

**genotype** the entire genetic makeup of an organism; also the combination of genes for one or more specific traits

## Quick Lab

### Making a Punnett Square

1. Draw a square, and divide it into four sections.
2. Write the letters that represent alleles from one parent along the top of the box.
3. Write the letters that represent alleles from the other parent along the side of the box.
4. The cross shown at right is between two plants that produce round seeds. The genotype for each is *Rr*. Round seeds are dominant, and wrinkled seeds are recessive. Follow the arrows to see how the inside of the box was filled. The resulting alleles inside the box show all the possible genotypes for the offspring from this cross. What would the phenotypes for these offspring be?



## Quick Lab

### Taking Your Chances

You have two guinea pigs. Each has brown fur and the genotype *Bb*. You want to predict what their offspring might look like. Try this to find out.

1. Stick a **piece of masking tape** on each side of **two quarters.**
2. Label one side with a capital *B* and the other side with a lowercase *b*.
3. Toss both coins 10 times, making note of your results each time.
4. How many times did you get the *bb* combination?
5. What is the probability that the next toss will result in *bb*?
6. What are the chances that the guinea pigs' offspring will have white fur (with the genotype *bb*)?

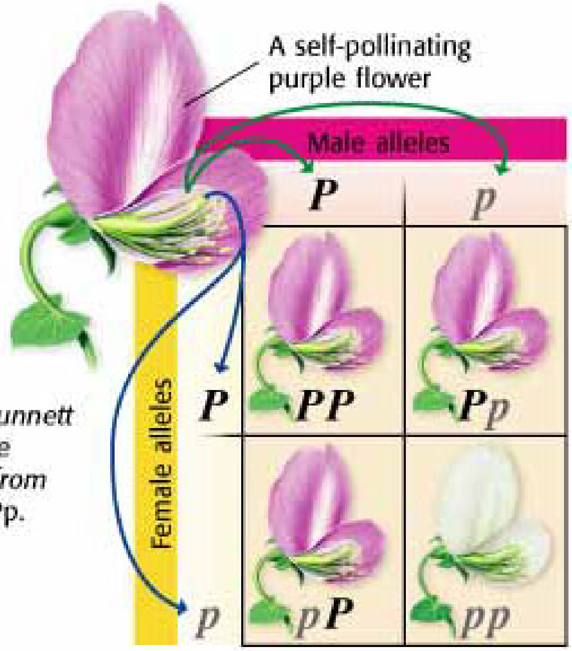



**Figure 3** *This Punnett square shows the possible results from the cross* Pp × Pp.

### More Evidence for Inheritance

In Mendel's second experiments, he allowed the first generation plants to self-pollinate. **Figure 3** shows a self-pollination cross of a plant with the genotype *Pp*. What are the possible genotypes of the offspring?

Notice that one square shows the genotype *Pp,* while another shows *pP*. These are exactly the same genotype. The other possible genotypes of the offspring are *PP* and *pp*. The combinations *PP, Pp,* and *pP* have the same phenotype—purple flowers. This is because each contains at least one dominant allele (*P*).

Only one combination, *pp,* produces plants that have white flowers. The ratio of dominant to recessive is 3:1, just as Mendel calculated from his data.

## What Are the Chances?

Each parent has two alleles for each gene. When these alleles are different, as in *Pp,* offspring are equally likely to receive either allele. Think of a coin toss. There is a 50% chance you'll get heads and a 50% chance you'll get tails. The chance of receiving one allele or another is as random as a coin toss.

### Probability

**probability** the likelihood that a possible future event will occur in any given instance of the event

The mathematical chance that something will happen is known as **probability.** Probability is most often written as a fraction or percentage. If you toss a coin, the probability of tossing tails is 1/2—you will get tails half the time.

***Reading Check*** **What is probability?**

## MATH FOCUS

**Probability** If you roll a pair of dice, what is the probability that you will roll 2 threes?

**Step 1:** Count the number of faces on a single die. Put this number in the denominator: 6.

**Step 2:** Count how many ways you can roll a three with one die. Put this number in the numerator: 1/6.

**Step 3:** To find the probability that you will throw 2 threes, multiply the probability of throwing the first three by the probability of throwing the second three: $1/6 \times 1/6 = 1/36$.

**Now It's Your Turn**

If you roll a single die, what is the probability that you will roll an even number?

### Calculating Probabilities

To find the probability that you will toss two heads in a row, multiply the probability of tossing the first head (1/2) by the probability of tossing the second head (1/2). The probability of tossing two heads in a row is 1/4.

**Figure 4** *These kittens inherited one allele from their mother for each trait.*

### Genotype Probability

To have white flowers, a pea plant must receive a *p* allele from each parent. Each offspring of a $Pp \times Pp$ cross has a 50% chance of receiving either allele from either parent. So, the probability of inheriting two *p* alleles is $1/2 \times 1/2$, which equals 1/4, or 25%. Traits in pea plants are easy to predict because there are only two choices for each trait, such as purple or white flowers and round or wrinkled seeds. Look at **Figure 4.** Do you see only two distinct choices for fur color?

**CONNECTION TO Chemistry**

**Round and Wrinkled** Round seeds may look better, but wrinkled seeds taste sweeter. The dominant allele for seed shape, *R*, causes sugar to be changed into starch (which is a storage molecule for sugar). This change makes the seed round. Seeds with the genotype *rr* do not make or store this starch. Because the sugar has not been changed into starch, the seed tastes sweeter. If you had a pea plant with round seeds (*Rr*), what would you cross it with to get some offspring with wrinkled seeds? Draw a Punnett square showing your cross.

ACTIVITY

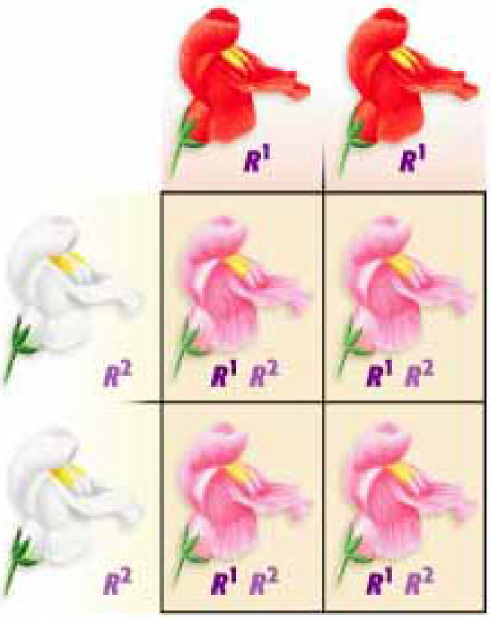



**Figure 5** *Cross-breeding two true-breeding snapdragons provides a good example of incomplete dominance.*

## More About Traits

As you may have already discovered, things are often more complicated than they first appear to be. Gregor Mendel uncovered the basic principles of how genes are passed from one generation to the next. But as scientists learned more about heredity, they began to find exceptions to Mendel's principles. A few of these exceptions are explained below.

### Incomplete Dominance

Since Mendel's discoveries, researchers have found that sometimes one trait is not completely dominant over another. These traits do not blend together, but each allele has its own degree of influence. This is known as *incomplete dominance*.

One example of incomplete dominance is found in the snapdragon flower. **Figure 5** shows a cross between a true-breeding red snapdragon ($R^1R^1$) and a true-breeding white snapdragon ($R^2R^2$). As you can see, all of the possible phenotypes for their offspring are pink because both alleles of the gene have some degree of influence.

**Reading Check** What is incomplete dominance?

### One Gene, Many Traits

Sometimes one gene influences more than one trait. An example of this phenomenon is shown by the white tiger in **Figure 6.** The white fur is caused by a single gene, but this gene influences more than just fur color. Do you see anything else unusual about the tiger? If you look closely, you'll see that the tiger has blue eyes. Here, the gene that controls fur color also influences eye color.

**Figure 6** *The gene that gave this tiger white fur also influenced its eye color.*

## Many Genes, One Trait

Some traits, such as the color of your skin, hair, and eyes, are the result of several genes acting together. Therefore, it's difficult to tell if some traits are the result of a dominant or a recessive gene. Different combinations of alleles result in different eye-color shades, as shown in **Figure 7.**

**Figure 7** *At least two genes determine human eye color. That's why many shades of a single color are possible.*

## The Importance of Environment

Genes aren't the only influences on traits. A guinea pig could have the genes for long fur, but its fur could be cut. In the same way, your environment influences how you grow. Your genes may make it possible that you will grow to be tall, but you need a healthy diet to reach your full potential height.

# SECTION Review

## Summary

- Instructions for an inherited trait are called *genes*. For each gene, there are two alleles, one inherited from each parent. Both alleles make up an organism's genotype. Phenotype is an organism's appearance.
- Punnett squares show all possible offspring genotypes.
- Probability can be used to describe possible outcomes in offspring and the likelihood of each outcome.
- Incomplete dominance occurs when one allele is not completely dominant over the other allele.
- Some genes influence more than one trait.

### Using Key Terms

**1.** Use the following terms in the same sentence: *gene* and *allele.*

**2.** In your own words, write a definition for each of the following terms: *genotype* and *phenotype.*

### Understanding Key Ideas

**3.** Use a Punnett square to determine the possible genotypes of the offspring of a $BB \times Bb$ cross.

**a.** all *BB* **c.** *BB, Bb, bb*
**b.** *BB, Bb* **d.** all *bb*

**4.** How are genes and alleles related to genotype and phenotype?

**5.** Describe three exceptions to Mendel's observations.

### Math Skills

**6.** What is the probability of rolling a five on one die three times in a row?

### Critical Thinking

**7. Applying Concepts** The allele for a cleft chin, *C,* is dominant among humans. What are the results of a cross between parents with genotypes *Cc* and *cc*?

### Interpreting Graphics

The Punnett square below shows the alleles for fur color in rabbits. Black fur, *B,* is dominant over white fur, *b.*

| | ? | ? |
|---|---|---|
| ? | *Bb* | *Bb* |
| ? | *Bb* | *Bb* |

**8.** Given the combinations shown, what are the genotypes of the parents?

**9.** If black fur had incomplete dominance over white fur, what color would the offspring be?

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For a variety of links related to this chapter, go to www.scilinks.org

Topic: Genotypes; Phenotypes
SciLinks code: HSM0664; HSM1135

SECTION 3

# Meiosis

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

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.

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."

**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

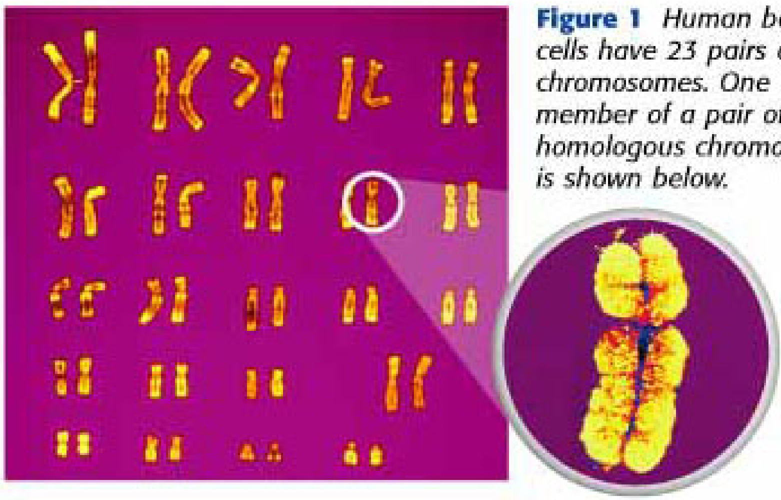


**Figure 1** *Human body cells have 23 pairs of chromosomes. One member of a pair of homologous chromosomes is shown below.*

## 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!**

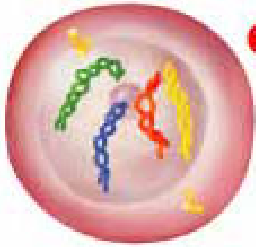
Understanding meiosis was critical to finding the location of genes. Before you learn about meiosis, review mitosis, shown in **Figure 2.** Meiosis is outlined in **Figure 3** on the next two pages.

**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**

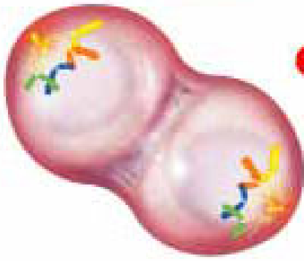
1 Each chromosome is copied.



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.

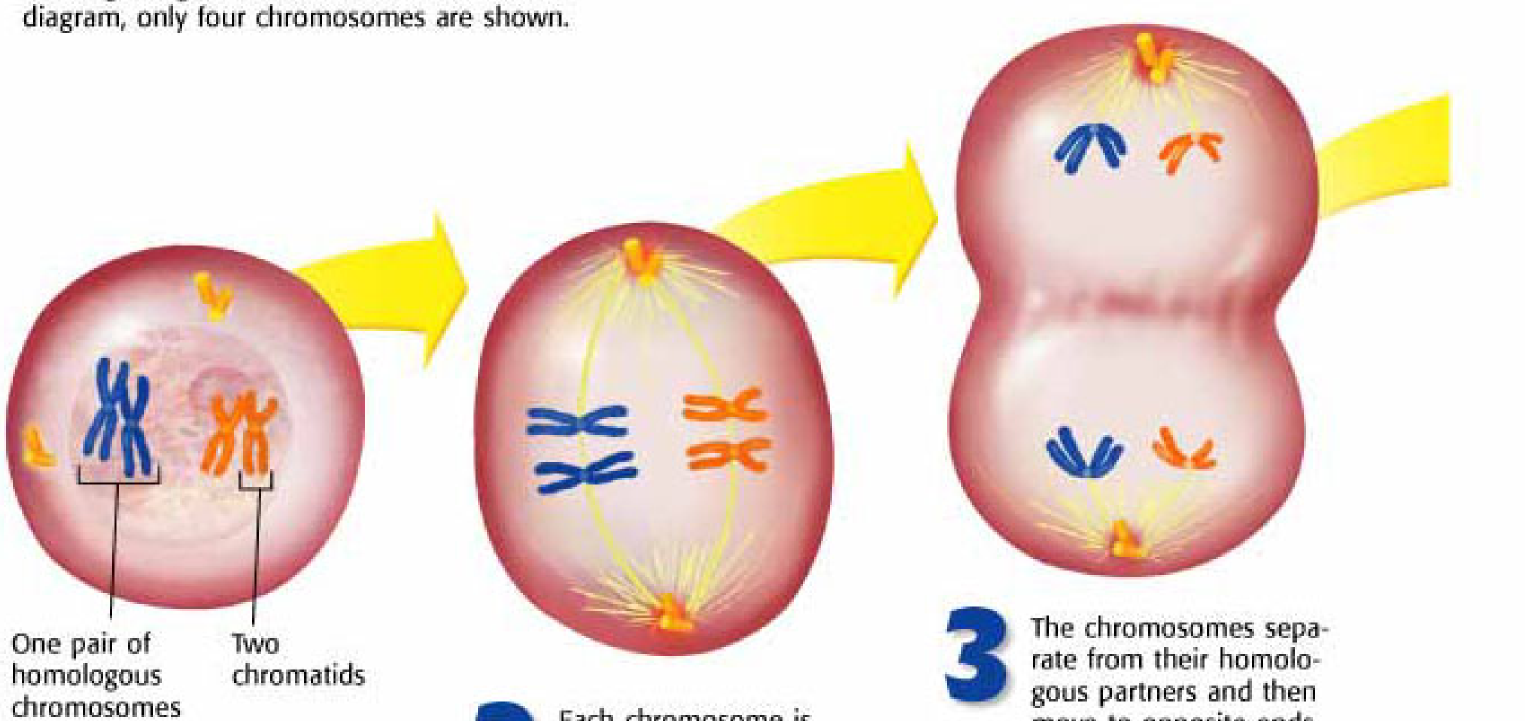
## The Steps of Meiosis

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

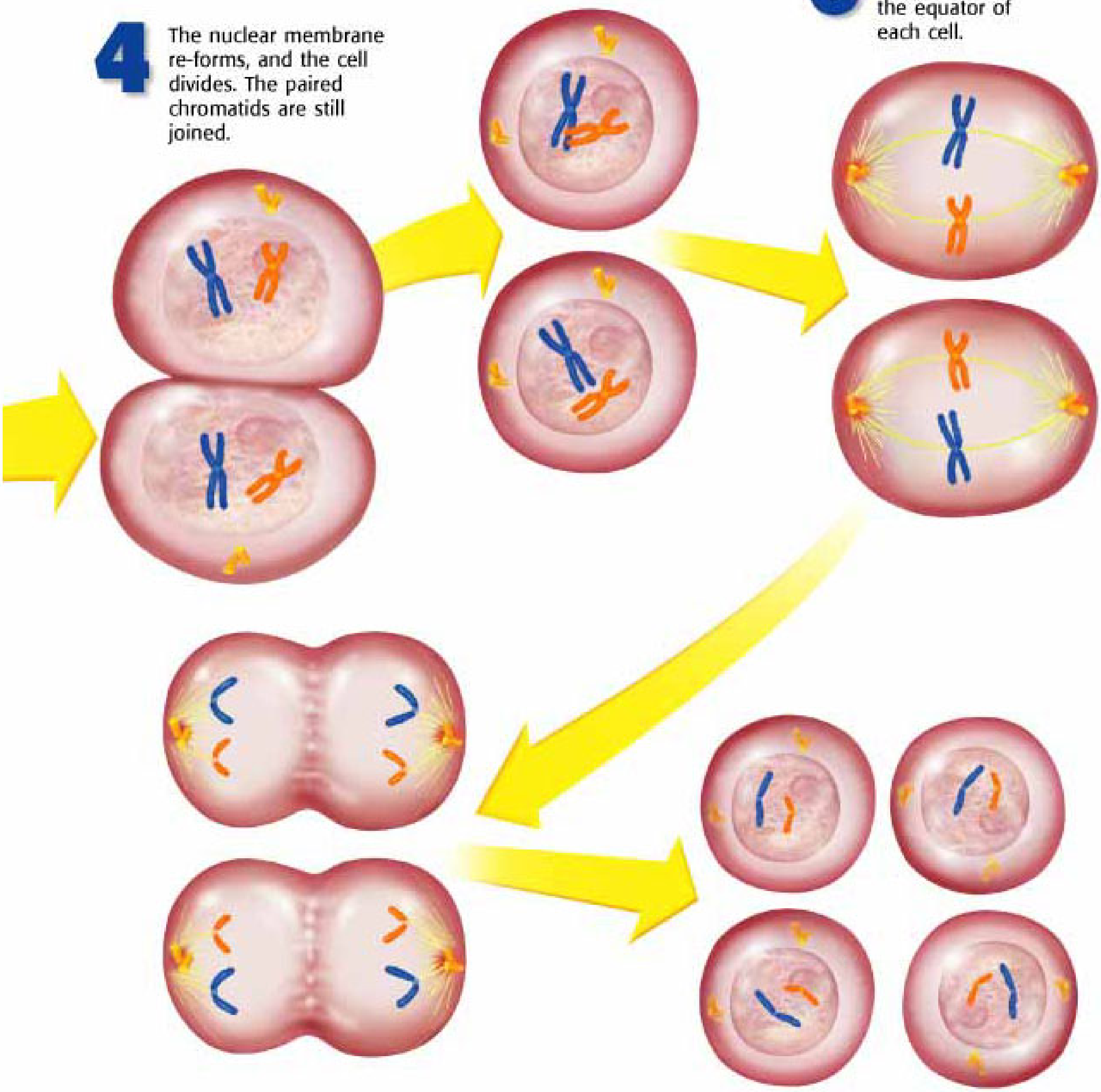
Read about each step as you look at the diagram. Different types of living things have different numbers of chromosomes. In this diagram, only four chromosomes are shown.




**1** Before meiosis begins, the chromosomes are in a threadlike form. Each chromosome makes an exact copy of itself, forming two halves called *chromatids*. The chromosomes then thicken and shorten into a form that is visible under a microscope. The nuclear membrane disappears.

**2** Each chromosome is now made up of two identical chromatids. Similar chromosomes pair with one another, and the paired homologous chromosomes line up at the equator of the cell.

**3** The chromosomes separate from their homologous partners and then move to opposite ends of the cell.



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

**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.

**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

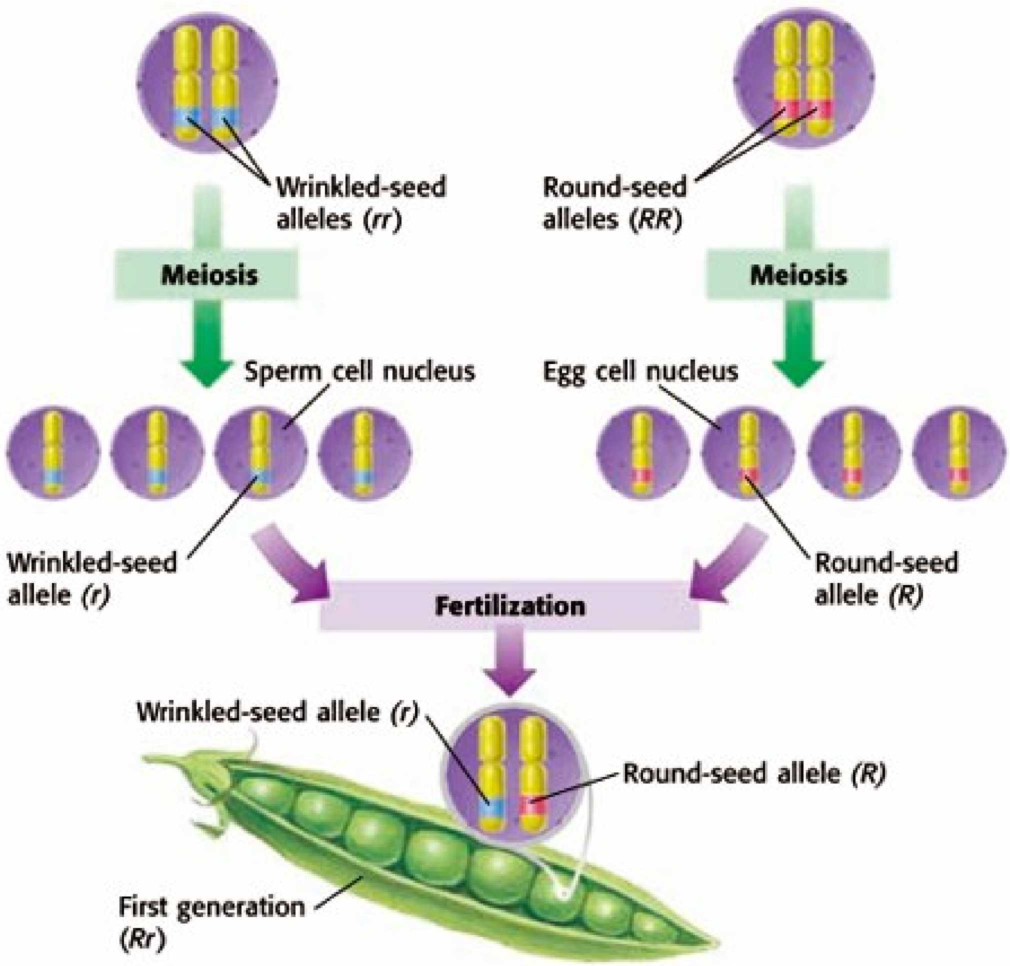
As Walter Sutton figured out, the steps in meiosis explained Mendel's results. **Figure 4** shows what happens to a pair of homologous chromosomes during meiosis and fertilization. The cross shown is between a plant that is true breeding for round seeds and a plant that is true breeding for wrinkled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

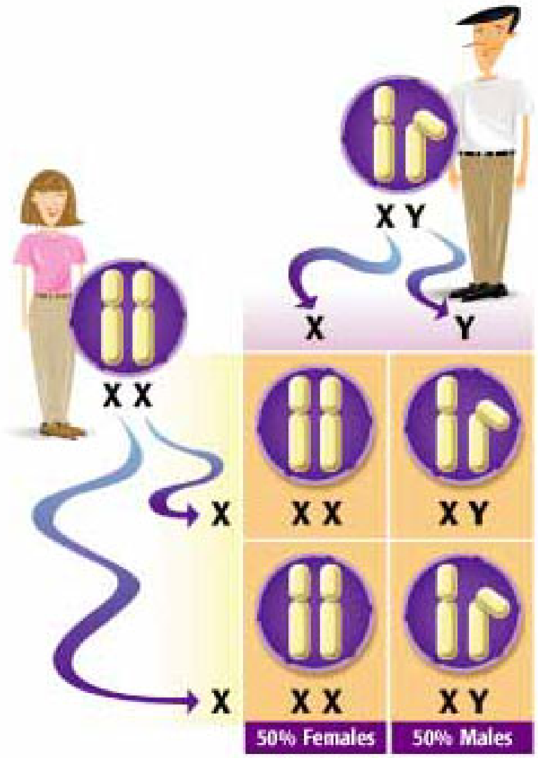



**Figure 5** *Egg and sperm combine to form either the XX or XY combination.*

## Sex-Linked Disorders

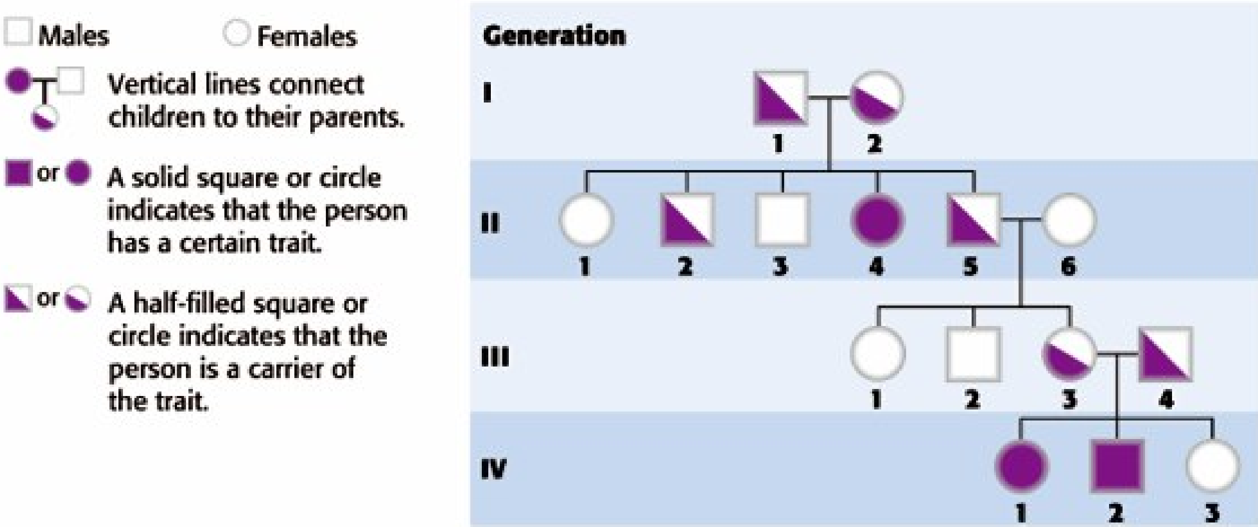
The Y chromosome does not carry all of the genes of an X chromosome. Females have two X chromosomes, so they carry two copies of each gene found on the X chromosome. This makes a backup gene available if one becomes damaged. Males have only one copy of each gene on their one X chromosome. The genes for 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.

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

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.

**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**




## 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.

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

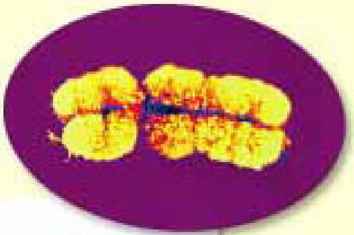
Pedigrees can be drawn up to trace any trait through a family tree. You could even draw a pedigree that would show how you inherited your hair color. Many different pedigrees could be drawn for a typical family.

## 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.

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

# 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

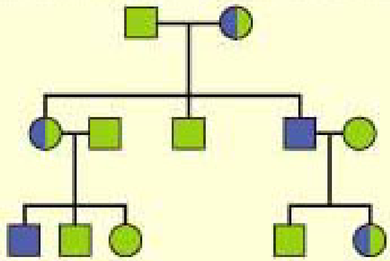
**a.** chromosomes.
**b.** proteins.
**c.** alleles.
**d.** sex cells.

**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?

SCILINKS. NSTA

For a variety of links related to this chapter, go to www.scilinks.org

Topic: Meiosis; Genetic Diseases, Screening, Counseling

SciLinks code: HSM0935; HSM0651

## Using Scientific Methods

# Model-Making Lab

## Bug Builders, Inc.

### 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

**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.**

### 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 | | | | |

DO NOT WRITE IN BOOK

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?

# Standardized Test Preparation

## READING

Read the passages below. Then, answer the questions that follow each passage.

**Passage 1** The different versions of a gene are called *alleles*. When two different alleles occur together, one is often expressed while the other has no obvious effect on the organism's appearance. The expressed form of the trait is dominant. The trait that was not expressed when the dominant form of the trait was present is called *recessive*. Imagine a plant that has both purple and white alleles for flower color. If the plant blooms purple, then purple is the dominant form of the trait. Therefore, white is the recessive form.

**1.** According to the passage, which of the following statements is true?

- **A** All alleles are expressed all of the time.
- **B** All traits for flower color are dominant.
- **C** When two alleles are present, the expressed form of the trait is dominant.
- **D** A recessive form of a trait is always expressed.

**2.** According to the passage, a trait that is not expressed when the dominant form is present is called

- **F** recessive.
- **G** an allele.
- **H** heredity.
- **I** a gene.

**3.** According to the passage, which allele for flower color is dominant?

- **A** white
- **B** pink
- **C** purple
- **D** yellow

**Passage 2** Sickle cell anemia is a recessive genetic disorder. People inherit this disorder only when they inherit the disease-causing recessive allele from both parents. The disease causes the body to make red blood cells that bend into a sickle (or crescent moon) shape. The sickle-shaped red blood cells break apart easily. Therefore, the blood of a person with sickle cell anemia carries less oxygen. Sickle-shaped blood cells also tend to get stuck in blood vessels. When a blood vessel is blocked, the blood supply to organs can be cut off. But the sickle-shaped blood cells can also protect a person from malaria. Malaria is a disease caused by an organism that invades red blood cells.

**1.** According to the passage, sickle cell anemia is a

- **A** recessive genetic disorder.
- **B** dominant genetic disorder.
- **C** disease caused by an organism that invades red blood cells.
- **D** disease also called *malaria*.

**2.** According to the passage, sickle cell anemia can help protect a person from

- **F** blocked blood vessels.
- **G** genetic disorders.
- **H** malaria.
- **I** low oxygen levels.

**3.** Which of the following is a fact in the passage?

- **A** When blood vessels are blocked, vital organs lose their blood supply.
- **B** When blood vessels are blocked, it causes the red blood cells to bend into sickle shapes.
- **C** The blood of a person with sickle cell anemia carries more oxygen.
- **D** Healthy red blood cells never get stuck in blood vessels.

## INTERPRETING GRAPHICS

The Punnett square below shows a cross between two flowering plants. Use this Punnett square to answer the questions that follow.

| | *R* | *r* |
|---|---|---|
| *r* | | *rr* |
| *r* | *Rr* | |

1. What is the genotype of the offspring represented in the upper left-hand box of the Punnett square?
   **A** *RR*
   **B** *Rr*
   **C** *rr*
   **D** *rrr*

2. What is the genotype of the offspring represented in the lower right-hand box of the Punnett square?
   **F** *RR*
   **G** *Rr*
   **H** *rr*
   **I** *rrr*

3. What is the ratio of *Rr* (purple-flowered plants) to *rr* (white-flowered plants) in the offspring?
   **A** 1:3
   **B** 2:2
   **C** 3:1
   **D** 4:0

## MATH

Read each question below, and choose the best answer.

1. What is another way to write $4 \times 4 \times 4$?
   **A** $4^2$
   **B** $4^3$
   **C** $3^3$
   **D** $3^4$

2. Jane was making a design on top of her desk with pennies. She put 4 pennies in the first row, 7 pennies in the second row, and 13 pennies in the third row. If Jane continues this pattern, how many pennies will she put in the sixth row?
   **F** 25
   **G** 49
   **H** 97
   **I** 193

3. In which of the following lists are the numbers in order from smallest to greatest?
   **A** 0.012, 0.120, 0.123, 1.012
   **B** 1.012, 0.123, 0.120, 0.012
   **C** 0.123, 0.120, 0.012, 1.012
   **D** 0.123, 1.012, 0.120, 0.012

4. In which of the following lists are the numbers in order from smallest to greatest?
   **F** −12.0, −15.5, 2.2, 4.0
   **G** −15.5, −12.0, 2.2, 4.0
   **H** −12.0, −15.5, 4.0, 2.2
   **I** 2.2, 4.0, −12.0, −15.5

5. Which of the following is equal to −11?
   **A** 7 + 4
   **B** −4 + 7
   **C** −7 + 4
   **D** −7 + −4

6. Catherine earned $75 for working 8.5 h. How much did she earn per hour?
   **F** $10.12
   **G** $9.75
   **H** $8.82
   **I** $8.01

# Science in Action

## Science, Technology, and Society

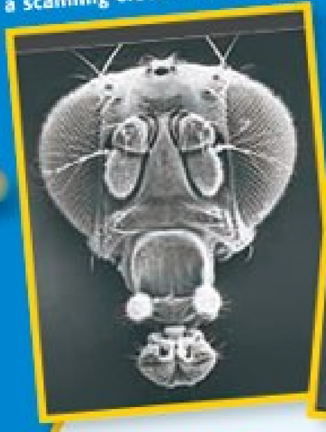
### Mapping the Human Genome

In 2003, scientists finished one of the most ambitious research projects ever. Researchers with the Human Genome Project (HGP) mapped the human body's complete set of genetic instructions, which is called the *genome*. You might be wondering whose genome the scientists are decoding. Actually, it doesn't matter—only 0.1% of each person's genetic material is unique. The researchers' goals are to identify how tiny differences in that 0.1% make each of us who we are and to begin to understand how some differences can cause disease. Scientists are already using the map to think of new ways to treat genetic diseases, such as asthma, diabetes, and kidney disease.

### Social Studies ACTIVITY

**WRITING SKILL** Research DNA fingerprinting. Write a short report describing how DNA fingerprinting has affected the way criminals are caught.

This is a normal fruit fly under a scanning electron microscope.



This fruit fly has legs growing where its antennae should be.

## Weird Science

### Lab Rats with Wings

*Drosophila melanogaster* (droh SAHF i luh muh LAN uh GAS tuhr) is the scientific name for the fruit fly. This tiny insect has played a big role in helping scientists understand many illnesses. Because fruit flies reproduce every 2 weeks, scientists can alter a fruit fly gene and see the results of the experiment very quickly. Another important reason for using these "lab rats with wings" is that their genetic code is simple and well understood. Fruit flies have 12,000 genes, but humans have more than 25,000. Scientists use fruit flies to find out about diseases like cancer, Alzheimer's, and muscular dystrophy.

### Language Arts ACTIVITY

**WRITING SKILL** The mythical creature called the *Chimera* (kie MIR uh) was said to be part lion, part goat, and part serpent. According to legend, the Chimera terrorized people for years until it was killed by a brave hero. The word *chimera* now refers to any organism that has parts from many organisms. Write a short story about the Chimera that describes what it looks like and how it came to be.

# Careers

## Stacey Wong

**Genetic Counselor** If your family had a history of a particular disease, what would you do? Would you eat healthier foods, get more exercise, or visit your doctor regularly? All of those are good ideas, but Stacey Wong went a step farther. Her family's history of cancer helped her decide to become a genetic counselor. "Genetic counselors are usually part of a team of health professionals," she says, which can include physicians, nurses, dieticians, social workers, laboratory personnel, and others. "If a diagnosis is made by the geneticist," says Wong, "then I provide genetic counseling." When a patient visits a genetic counselor, the counselor asks many questions and builds a family medical history. Although counseling involves discussing what it means to have a genetic condition, Wong says "the most important part is to get to know the patient or family we are working with, listen to their concerns, gain an understanding of their values, help them to make decisions, and be their advocate."

### Math Activity

The probability of inheriting genetic disease *A* is 1/10,000. The probability of inheriting genetic disease *B* is also 1/10,000. What is the probability that one person would inherit both genetic diseases *A* and *B*?

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