Chapter 4

Genetics: The Science of Heredity

The BIG Idea

Reproduction and Heredity

How are traits passed from parents to offspring?

Chapter Preview

These spaniel puppies and their mother resemble each other in many ways.

Discovery CHANNEL SCHOOL

Genetics: The Science of Heredity

- ▶ Video Preview
- Video Field Trip
- Video Assessment

Lab zone™ **Chapter Project**

All in the Family

Did you ever wonder why some offspring resemble their parents while others do not? In this chapter, you'll learn how offspring come to have traits similar to those of their parents. You'll create a family of "paper pets" to explore how traits pass from parents to offspring.

Your Goal To create a "paper pet" that will be crossed with a classmate's pet, and to determine what traits the offspring will have

To complete this project successfully, you must

- create your own unique paper pet with five different traits
- cross your pet with another pet to produce six offspring
- determine what traits the offspring will have, and explain how they came to have those traits
- follow the safety guidelines in Appendix A

Plan It! Cut out your pet from either blue or yellow construction paper. Choose other traits for your pet from this list: square eyes or round eyes; oval nose or triangular nose; pointed teeth or square teeth. Then create your pet using materials of your choice.

Section 1

Mendel's Work

Reading Preview

Key Concepts

- What were the results of Mendel's experiments, or crosses?
- What controls the inheritance of traits in organisms?

Key Terms

- heredity • trait • genetics
- fertilization • purebred • gene
- alleles • dominant allele
- recessive allele • hybrid

Target Reading Skill

Outlining As you read, make an outline about Mendel's work. Use the red headings for the main ideas and the blue headings for the supporting ideas.

Mendel's Work
I. Mendel's experiments
A. Crossing pea plants
B.
C.

Lab zone Discover Activity

What Does the Father Look Like?

1. Observe the colors of the kitten in the photo. Record the kitten's coat colors and pattern. Include as many details as you can.
2. Observe the mother cat in the photo. Record her coat color and pattern.

Think It Over

Inferring Based on your observations, describe what you think the kitten's father might look like. Identify the evidence on which you based your inference.

In the mid nineteenth century, a priest named Gregor Mendel tended a garden in a central European monastery. Mendel's experiments in that peaceful garden would one day revolutionize the study of heredity. **Heredity** is the passing of physical characteristics from parents to offspring.

Mendel wondered why different pea plants had different characteristics. Some pea plants grew tall, while others were short. Some plants produced green seeds, while others had yellow seeds. Each different form of a characteristic, such as stem height or seed color, is called a **trait.** Mendel observed that the pea plants' traits were often similar to those of their parents. Sometimes, however, the plants had different traits from those of their parents.

Mendel experimented with thousands of pea plants to understand the process of heredity. Today, Mendel's discoveries form the foundation of **genetics,** the scientific study of heredity.

Gregor Mendel ▶

Mendel's Experiments

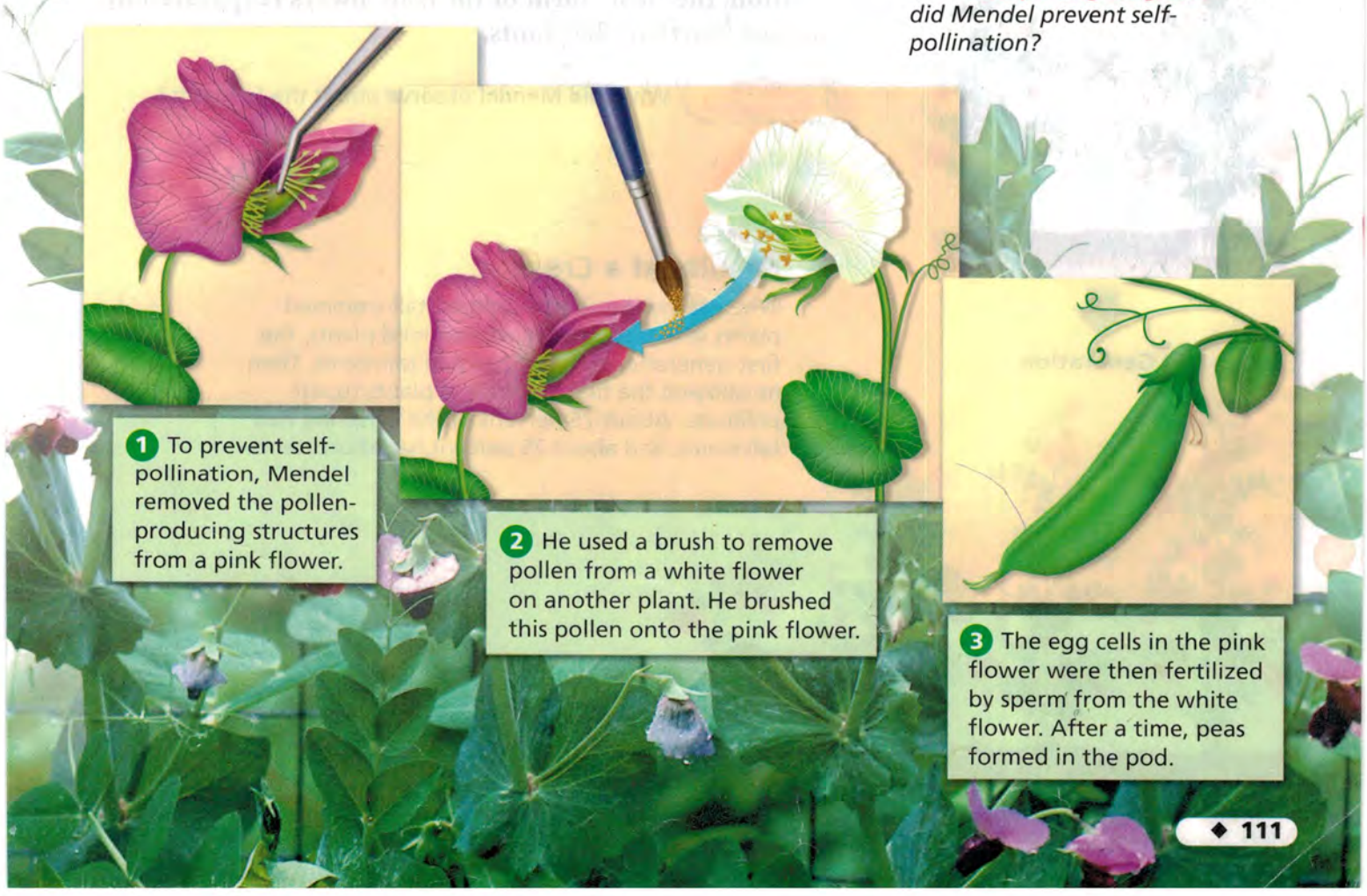
Figure 1 shows a pea plant's flower. The flower's petals surround the pistil and the stamens. The pistil produces female sex cells, or eggs. The stamens produce pollen, which contains the male sex cells, or sperm. A new organism begins to form when egg and sperm join in the process called **fertilization.** Before fertilization can happen in pea plants, pollen must reach the pistil of a pea flower. This process is called pollination.

Pea plants are usually self-pollinating. In self-pollination, pollen from a flower lands on the pistil of the same flower. Mendel developed a method by which he cross-pollinated, or "crossed," pea plants. To cross two plants, he removed pollen from a flower on one plant. He then brushed the pollen onto a flower on a second plant.

Crossing Pea Plants Suppose you wanted to study the inheritance of traits in pea plants. What could you do? Mendel decided to cross plants with contrasting traits—for example, tall plants and short plants. He started his experiments with purebred plants. A **purebred** organism is the offspring of many generations that have the same trait. For example, purebred short pea plants always come from short parent plants.

FIGURE 1
Crossing Pea Plants

Gregor Mendel crossed pea plants that had different traits. The illustrations show how he did this. **Interpreting Diagrams** *How did Mendel prevent self-pollination?*



The F_1 Offspring In one experiment, Mendel crossed purebred tall plants with purebred short plants. Scientists today call these parent plants the parental generation, or P generation. The offspring from this cross are the first filial (FIL ee ul) generation, or the F_1 generation. The word *filial* comes from *filia* and *filius*, the Latin words for "daughter" and "son."

In Figure 2, notice that all the offspring in the F_1 generation were tall. Even though one of the parent plants was short, none of the offspring were short. The shortness trait seemed to disappear!

The F_2 Offspring When the plants in the F_1 generation were full-grown, Mendel allowed them to self-pollinate. Surprisingly, the plants in the F_2 (second filial) generation were a mix of tall and short plants. The shortness trait had reappeared, even though none of the F_1 parent plants were short. Mendel counted the tall and short plants. About three fourths of the plants were tall, while one fourth were short.

Experiments With Other Traits Mendel also crossed pea plants with other contrasting traits. Compare the two forms of each trait in Figure 3. **In all of Mendel's crosses, only one form of the trait appeared in the F_1 generation. However, in the F_2 generation, the "lost" form of the trait always reappeared in about one fourth of the plants.**

Reading Checkpoint **What did Mendel observe about the F_2 plants?**

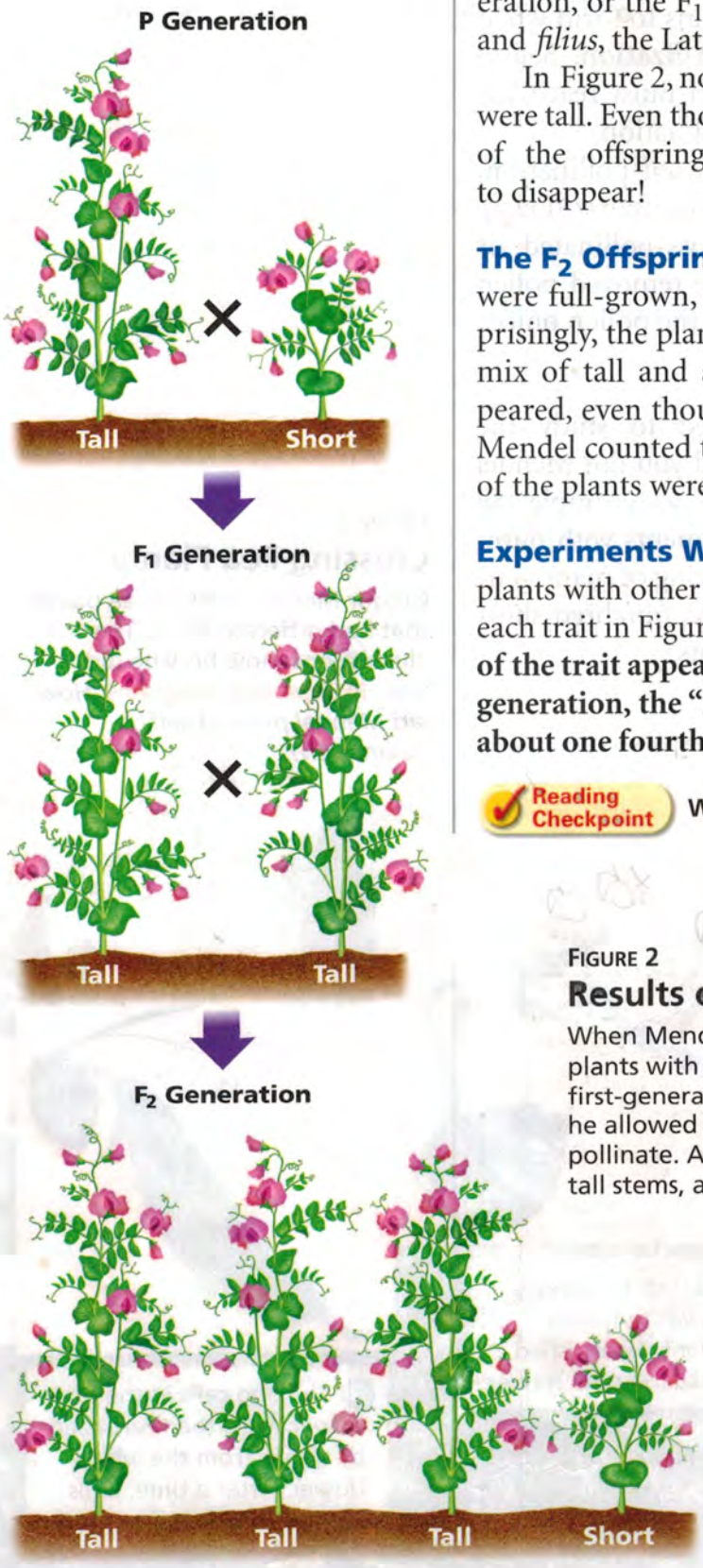


FIGURE 2
Results of a Cross
When Mendel crossed purebred tall-stemmed plants with purebred short-stemmed plants, the first-generation offspring all had tall stems. Then he allowed the first-generation plants to self-pollinate. About 75 percent of the offspring had tall stems, and about 25 percent had short stems.

Genetics of Pea Plants

Traits	Seed Shape	Seed Color	Seed Coat Color	Pod Shape	Pod Color	Flower Position	Stem Height
Controlled by Dominant Allele	Round	Yellow	Gray	Smooth	Green	Side	Tall
Controlled by Recessive Allele	Wrinkled	Green	White	Pinched	Yellow	End	Short

Dominant and Recessive Alleles

Mendel reached several conclusions on the basis of his experimental results. He reasoned that individual factors, or sets of genetic "information," must control the inheritance of traits in peas. The factors that control each trait exist in pairs. The female parent contributes one factor, while the male parent contributes the other factor. Finally, one factor in a pair can mask, or hide, the other factor. The tallness factor, for example, masked the shortness factor.

Genes and Alleles Today, scientists use the word **gene** for the factors that control a trait. **Alleles** (uh LEELZ) are the different forms of a gene. The gene that controls stem height in peas, for example, has one allele for tall stems and one allele for short stems. Each pea plant inherits two alleles from its parents—one allele from the egg and the other from the sperm. A pea plant may inherit two alleles for tall stems, two alleles for short stems, or one of each.

An organism's traits are controlled by the alleles it inherits from its parents. Some alleles are dominant, while other alleles are recessive. A **dominant allele** is one whose trait always shows up in the organism when the allele is present. A **recessive allele,** on the other hand, is hidden whenever the dominant allele is present. A trait controlled by a recessive allele will only show up if the organism does not have the dominant allele. Figure 3 shows dominant and recessive alleles in Mendel's crosses.

FIGURE 3
Mendel studied several traits in pea plants.
Interpreting Diagrams *Is yellow seed color controlled by a dominant allele or a recessive allele?*

Lab zone Skills **Activity**

Predicting

In fruit flies, long wings are dominant over short wings. A scientist crossed a purebred long-winged male fruit fly with a purebred short-winged female. Predict the wing length of the F_1 offspring. If the scientist crossed a hybrid male F_1 fruit fly with a hybrid F_1 female, what would their offspring probably be like?

In pea plants, the allele for tall stems is dominant over the allele for short stems. Pea plants with one allele for tall stems and one allele for short stems will be tall. The allele for tall stems masks the allele for short stems. Only pea plants that inherit two recessive alleles for short stems will be short.

Alleles in Mendel's Crosses In Mendel's cross for stem height, the purebred tall plants in the P generation had two alleles for tall stems. The purebred short plants had two alleles for short stems. The F_1 plants each inherited an allele for tall stems from the tall parent and an allele for short stems from the short parent. Therefore, each F_1 plant had one allele for tall stems and one for short stems. The F_1 plants are called hybrids. A **hybrid** (HY brid) organism has two different alleles for a trait. All the F_1 plants are tall because the dominant allele for tall stems masks the recessive allele for short stems.

When Mendel crossed the F_1 plants, some of the offspring in the F_2 generation inherited two dominant alleles for tall stems. These plants were tall. Other F_2 plants inherited one dominant allele for tall stems and one recessive allele for short stems. These plants were also tall. The rest of the F_2 plants inherited two recessive alleles for short stems. These plants were short.

Symbols for Alleles Geneticists use letters to represent alleles. A dominant allele is represented by a capital letter. For example, the allele for tall stems is represented by *T*. A recessive allele is represented by the lowercase version of the letter. So, the allele for short stems would be represented by *t*. When a plant inherits two dominant alleles for tall stems, its alleles are written as *TT*. When a plant inherits two recessive alleles for short stems, its alleles are written as *tt*. When a plant inherits one allele for tall stems and one allele for short stems, its alleles are written as *Tt*.

FIGURE 4
Black Fur, White Fur
In rabbits, the allele for black fur is dominant over the allele for white fur. **Inferring** *What combination of alleles must the white rabbit have?*

Significance of Mendel's Contribution Mendel's discovery of genes and alleles eventually changed scientists' ideas about heredity. Before Mendel, most people thought that the traits of an individual organism were simply a blend of their parents' characteristics. According to this idea, if a tall plant and a short plant were crossed, the offspring would all have medium height.

However, when Mendel crossed purebred tall and purebred short pea plants, the offspring were all tall. Mendel's experiments demonstrated that parents' traits do not simply blend in the offspring. Instead, traits are determined by individual, separate alleles inherited from each parent. Some of these alleles, such as the allele for short height in pea plants, are recessive. If a trait is determined by a recessive allele, the trait can seem to disappear in the offspring.

Unfortunately, the importance of Mendel's discovery was not recognized during his lifetime. Then, in 1900, three different scientists rediscovered Mendel's work. These scientists quickly recognized the importance of Mendel's ideas. Because of his work, Mendel is often called the Father of Genetics.

Reading Checkpoint **If an allele is represented by a capital letter, what does this indicate?**

FIGURE 5
The Mendel Medal
Every year, to honor the memory of Gregor Mendel, an outstanding scientist is awarded the Mendel Medal.

Section 1 Assessment

Target Reading Skill **Outlining** Use the information in your outline about Mendel's work to help you answer the questions below.

Reviewing Key Concepts

1. a. **Identifying** In Mendel's cross for stem height, what contrasting traits did the pea plants in the P generation exhibit?
   b. **Explaining** What trait or traits did the plants in the F_1 generation exhibit? When you think of the traits of the parent plants, why is this result surprising?
   c. **Comparing and Contrasting** Contrast the offspring in the F_1 generation to the offspring in the F_2 generation. What did the differences in the F_1 and F_2 offspring show Mendel?
2. a. **Defining** What is a dominant allele? What is a recessive allele?
   b. **Relating Cause and Effect** Explain how dominant and recessive alleles for the trait of stem height determine whether a pea plant will be tall or short.
   c. **Applying Concepts** Can a short pea plant ever be a hybrid for the trait of stem height? Why or why not? As part of your explanation, write the letters that represent the alleles for stem height of a short pea plant.

Lab zone At-Home Activity

Gardens and Heredity Some gardeners save the seeds produced by flowers and plant them in the spring. If there are gardeners in your family, ask them how closely the plants that grow from these seeds resemble the parent plants. Are the offspring's traits ever different from those of the parents?

Lab zone Skills Lab

Go Online
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Take a Class Survey

Problem

Are traits controlled by dominant alleles more common than traits controlled by recessive alleles?

Skills Focus

developing hypotheses, interpreting data

Materials

- mirror (optional)

Procedure

PART 1 Dominant and Recessive Alleles

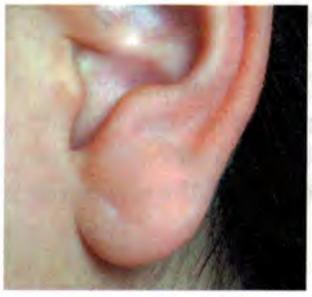
1. Write a hypothesis reflecting your ideas about the problem. Then copy the data table.
2. For each of the traits listed in the data table, work with a partner to determine which trait you have. Circle that trait in your data table.
3. Count the number of students in your class who have each trait. Record that number in your data table. Also record the total number of students.

PART 2 Are Your Traits Unique?

4. Look at the circle of traits on the opposite page. All the traits in your data table appear in the circle. Place the eraser end of your pencil on the trait in the small central circle that applies to you—either free ear lobes or attached ear lobes.
5. Look at the two traits touching the space your eraser is on. Move your eraser onto the next description that applies to you. Continue using your eraser to trace your traits until you reach a number on the outside rim of the circle. Share that number with your classmates.

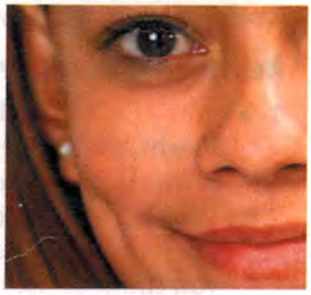
Analyze and Conclude

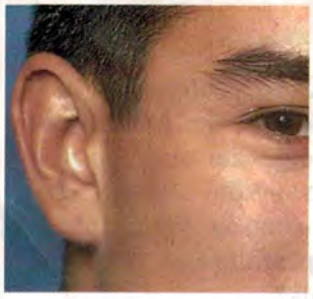
1. **Observing** The traits listed under Trait 1 in the data table are controlled by dominant alleles. The traits listed under Trait 2 are controlled by recessive alleles. Which traits controlled by dominant alleles were shown by a majority of students? Which traits controlled by recessive alleles were shown by a majority of students?


Free ear lobe


Widow's peak


Cleft chin

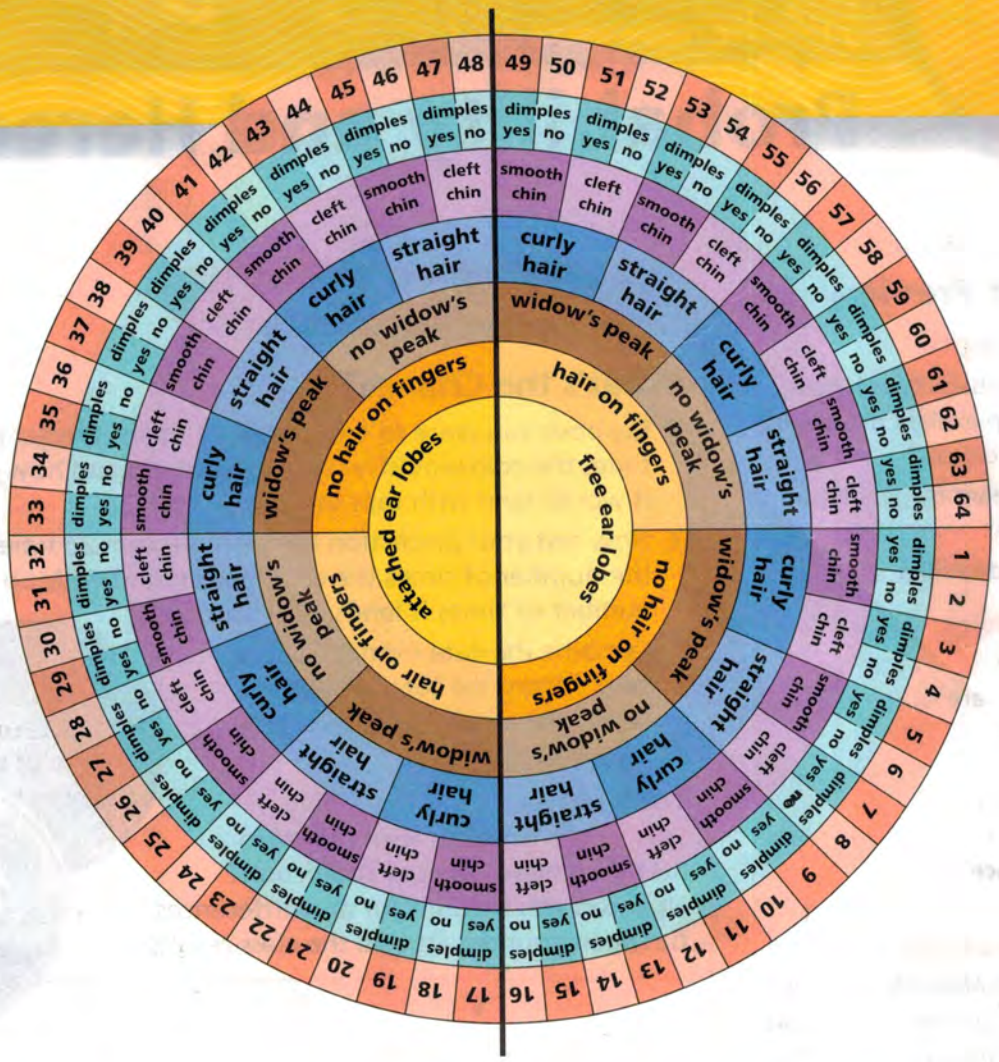

Dimple


Attached ear lobe


No widow's peak


No cleft chin


No dimple



2. **Interpreting Data** How many students ended up on the same number on the circle of traits? How many students were the only ones to have their number? What do the results suggest about each person's combination of traits?
3. **Developing Hypotheses** Do your data support the hypothesis you proposed in Step 1? Write an answer with examples.

Design an Experiment

Do people who are related to each other show more genetic similarity than unrelated people? Write a hypothesis. Then design an experiment to test your hypothesis. *Obtain your teacher's permission before carrying out your investigation.*

Data Table				
Total Number of Students_____				
	Trait 1	Number	Trait 2	Number
A	Free ear lobes		Attached ear lobes	
B	Hair on fingers		No hair on fingers	
C	Widow's peak		No widow's peak	
D	Curly hair		Straight hair	
E	Cleft chin		Smooth chin	
F	Smile dimples		No smile dimples	

Section 2

Integrating Mathematics

Probability and Heredity

Reading Preview

Key Concepts

- What is probability and how does it help explain the results of genetic crosses?
- What is meant by genotype and phenotype?
- What is codominance?

Key Terms

- probability
- Punnett square
- phenotype
- genotype
- homozygous
- heterozygous
- codominance

Target Reading Skill

Building Vocabulary After you read the section, reread the paragraphs that contain definitions of Key Terms. Use all the information you have learned to write a definition of each Key Term in your own words.

Lab zone

Discover Activity

What's the Chance?

1. Suppose you were to toss a coin 20 times. Predict how many times the coin would land with heads up and how many times it would land with tails up.
2. Now test your prediction by tossing a coin 20 times. Record the number of times the coin lands with heads up and the number of times it lands with tails up.
3. Combine the data from the entire class. Record the total number of tosses, the number of heads, and the number of tails.

Think It Over

Predicting How did your results in Step 2 compare to your prediction? How can you account for any differences between your results and the class results?

On a brisk fall afternoon, the stands are packed with cheering football fans. Today is the big game between Riverton's North and South high schools, and it's almost time for the kickoff. Suddenly, the crowd becomes silent, as the referee is about to toss a coin. The outcome of the coin toss will decide which team kicks the ball and which receives it. The captain of the visiting North High team says "heads." If the coin lands with heads up, North High wins the toss and the right to decide whether to kick or receive the ball.

What is the chance that North High will win the coin toss? To answer this question, you need to understand the principles of probability.

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Principles of Probability

If you did the Discover activity, you used the principles of **probability** to predict the results of a particular event. In this case, the event was the toss of a coin. **Probability is a number that describes how likely it is that an event will occur.**

Mathematics of Probability Each time you toss a coin, there are two possible ways that the coin can land—heads up or tails up. Each of these two events is equally likely to occur. In mathematical terms, you can say that the probability that a tossed coin will land with heads up is 1 in 2. There is also a 1 in 2 probability that the coin will land with tails up. A 1 in 2 probability can also be expressed as the fraction $\frac{1}{2}$ or as a percent—50 percent.

The laws of probability predict what is likely to occur, not necessarily what will occur. If you tossed a coin 20 times, you might expect it to land with heads up 10 times and with tails up 10 times. However, you might not get these results. You might get 11 heads and 9 tails, or 8 heads and 12 tails. The more tosses you make, the closer your actual results will be to the results predicted by probability.

Reading Checkpoint **What is probability?**

Independence of Events When you toss a coin more than once, the results of one toss do not affect the results of the next toss. Each event occurs independently. For example, suppose you toss a coin five times and it lands with heads up each time. What is the probability that it will land with heads up on the next toss? Because the coin landed heads up on the previous five tosses, you might think that it would be likely to land heads up on the next toss. However, this is not the case. The probability of the coin landing heads up on the next toss is still 1 in 2, or 50 percent. The results of the first five tosses do not affect the result of the sixth toss.

Math Skills

Percentage

One way you can express a probability is as a percentage. A percentage (%) is a number compared to 100. For example, 50% means 50 out of 100.

Suppose that 3 out of 5 tossed coins landed with heads up. Here's how you can calculate what percent of the coins landed with heads up.

1. Write the comparison as a fraction.

$$\text{3 out of 5} = \frac{3}{5}$$

2. Multiply the fraction by 100% to express it as a percentage.

$$\frac{3}{5} \times \frac{100\%}{1} = 60\%$$

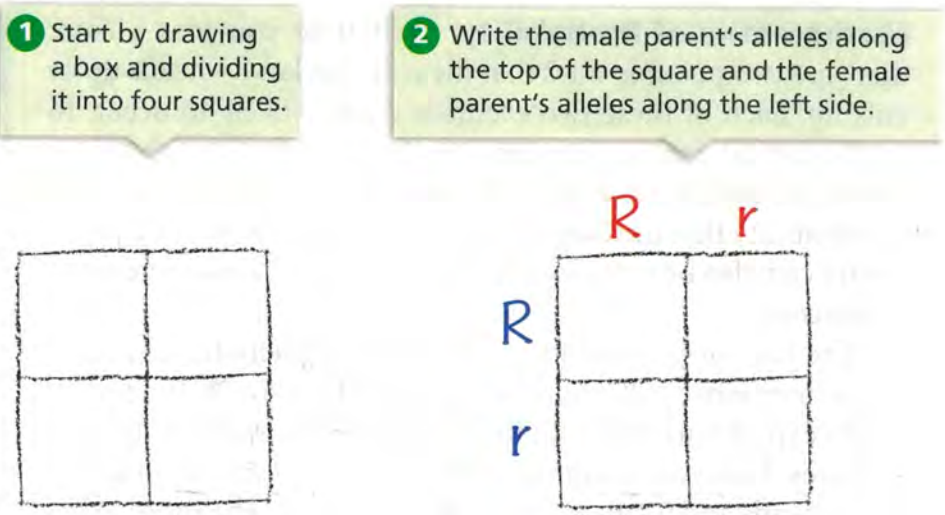
Practice Problem Suppose 3 out of 12 coins landed with tails up. How can you express this as a percent?

FIGURE 6
A Coin Toss
The result of a coin toss can be explained by probability.

FIGURE 7

How to Make a Punnett Square

The diagrams show how to make a Punnett square. In this cross, both parents are heterozygous for the trait of seed shape. *R* represents the dominant round allele, and *r* represents the recessive wrinkled allele.



Probability and Genetics

How is probability related to genetics? To answer this question, think back to Mendel's experiments with peas. Remember that Mendel carefully counted the offspring from every cross that he carried out. When Mendel crossed two plants that were hybrid for stem height (*Tt*), three fourths of the F_1 plants had tall stems. One fourth of the plants had short stems.

Each time Mendel repeated the cross, he obtained similar results. Mendel realized that the mathematical principles of probability applied to his work. He could say that the probability of such a cross producing a tall plant was 3 in 4. The probability of producing a short plant was 1 in 4. Mendel was the first scientist to recognize that the principles of probability can be used to predict the results of genetic crosses.

Punnett Squares A tool that can help you understand how the laws of probability apply to genetics is called a Punnett square. A **Punnett square** is a chart that shows all the possible combinations of alleles that can result from a genetic cross. Geneticists use Punnett squares to show all the possible outcomes of a genetic cross, and to determine the probability of a particular outcome.

Figure 7 shows how to construct a Punnett square. In this case, the Punnett square shows a cross between two hybrid pea plants with round seeds (*Rr*). The allele for round seeds (*R*) is dominant over the allele for wrinkled seeds (*r*). Each parent can pass either of its alleles, *R* or *r*, to its offspring. The boxes in the Punnett square represent the possible combinations of alleles that the offspring can inherit.

Reading Checkpoint **What is a Punnett square?**

Lab zone **Try This Activity**

Coin Crosses

Here's how you can use coins to model Mendel's cross between two *Tt* pea plants.

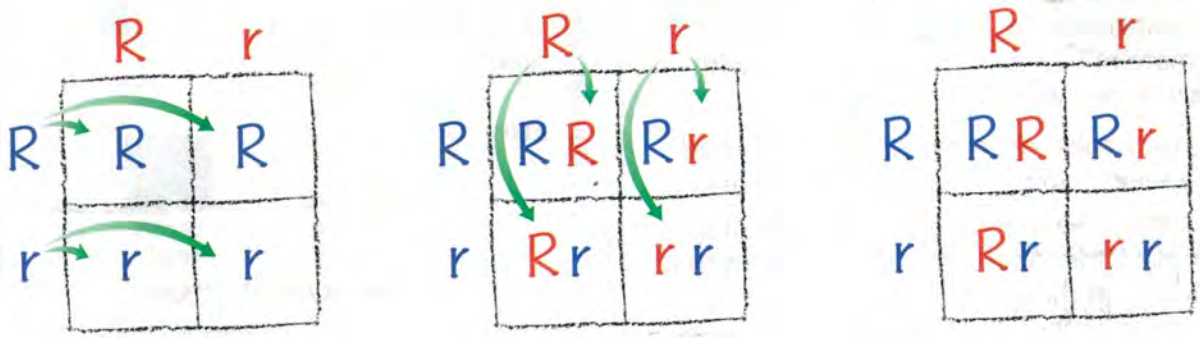
1. Place a small piece of masking tape on each side of two coins.
2. Write a *T* (for tall) on one side of each coin and a *t* (for short) on the other.
3. Toss both coins together 20 times. Record the letter combinations that you obtain from each toss.

Interpreting Data How many of the offspring would be tall plants? (*Hint:* What different letter combinations would result in a tall plant?) How many would be short? Convert your results to percentages. Then compare your results to Mendel's.

3 Copy the female parent's alleles into the boxes to their right.

4 Copy the male parent's alleles into the boxes beneath them.

5 The completed Punnett square shows all the possible allele combinations in the offspring.

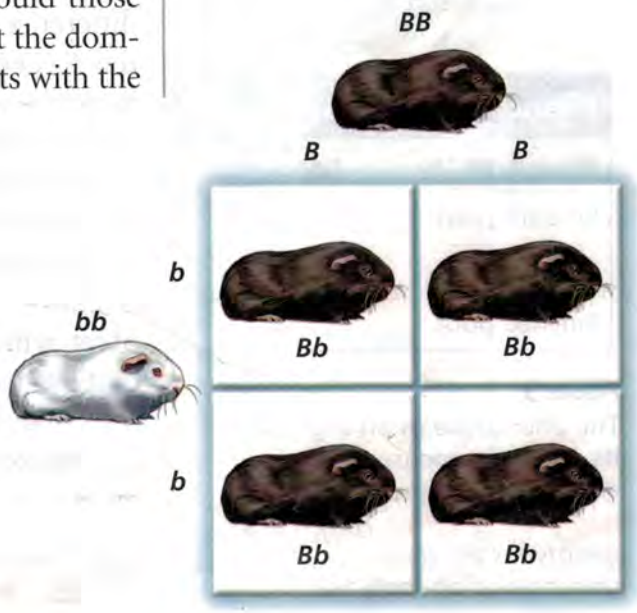


Using a Punnett Square You can use a Punnett square to calculate the probability that offspring with a certain combination of alleles will result. **In a genetic cross, the allele that each parent will pass on to its offspring is based on probability.** The completed Punnett square in Figure 7 shows four possible combinations of alleles. The probability that an offspring will be *RR* is 1 in 4, or 25 percent. The probability that an offspring will be *rr* is also 1 in 4, or 25 percent. Notice, however, that the *Rr* allele combination appears in two boxes in the Punnett square. This is because there are two possible ways in which this combination can occur. So the probability that an offspring will be *Rr* is 2 in 4, or 50 percent.

When Mendel crossed hybrid plants with round seeds, he discovered that about three fourths of the plants (75 percent) had round seeds. The remaining one fourth of the plants (25 percent) produced wrinkled seeds. Plants with the *RR* allele combination would produce round seeds. So too would those plants with the *Rr* allele combination. Remember that the dominant allele masks the recessive allele. Only those plants with the *rr* allele combination would have wrinkled seeds.

Predicting Probabilities You can use a Punnett square to predict probabilities. For example, Figure 8 shows a cross between a purebred black guinea pig and a purebred white guinea pig. The allele for black fur is dominant over the allele for white fur. Notice that only one allele combination is possible in the offspring—*Bb*. All of the offspring will inherit the dominant allele for black fur. Because of this, all of the offspring will have black fur. There is a 100 percent probability that the offspring will have black fur.

FIGURE 8
Guinea Pig Punnett Square
This Punnett square shows a cross between a black guinea pig (*BB*) and a white guinea pig (*bb*).
Calculating *What is the probability that an offspring will have white fur?*

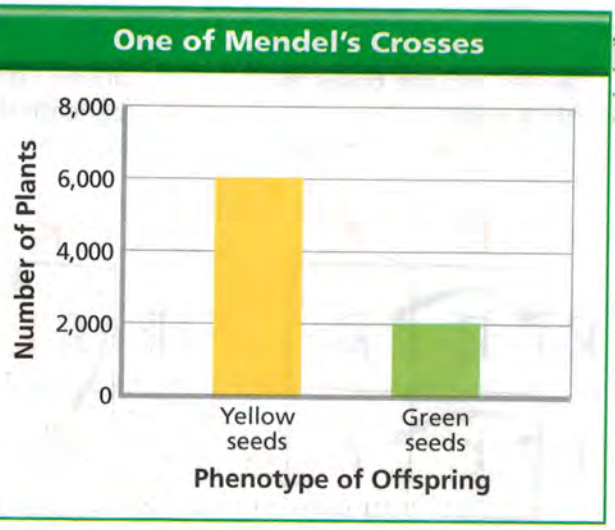


Math Analyzing Data

What Are the Genotypes?

Mendel allowed several F_1 pea plants with yellow seeds to self-pollinate. The graph shows the approximate numbers of the F_2 offspring with yellow seeds and with green seeds.

1. **Reading Graphs** How many F_2 offspring had yellow seeds? How many had green seeds?
2. **Calculating** Use the information in the graph to calculate the total number of offspring that resulted from this cross. Then calculate the percentage of the offspring with yellow peas, and the percentage with green peas.
3. **Inferring** Use the answers to Question 2 to infer the probable genotypes of the parent plants. (*Hint:* Construct Punnett squares with the possible genotypes of the parents.)



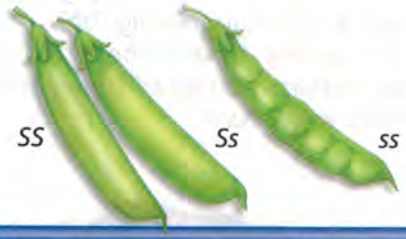
Phenotypes and Genotypes

Two useful terms that geneticists use are **phenotype** (FEE noh typ) and **genotype** (JEN uh typ). **An organism's phenotype is its physical appearance, or visible traits. An organism's genotype is its genetic makeup, or allele combinations.**

To understand the difference between phenotype and genotype, look at Figure 9. The allele for smooth pea pods (*S*) is dominant over the allele for pinched pea pods (*s*). All of the plants with at least one dominant allele have the same phenotype—they all produce smooth pods. However, the plants can have two different genotypes—*SS* or *Ss*. If you were to look at the plants with smooth pods, you would not be able to tell the difference between those with the *SS* genotype and those with the *Ss* genotype. The plants with pinched pods, on the other hand, would all have the same phenotype—pinched pods—as well as the same genotype—*ss*.

Geneticists use two additional terms to describe an organism's genotype. An organism that has two identical alleles for a trait is said to be **homozygous** (hoh moh ZY gus) for that trait. A smooth-pod plant that has the alleles *SS* and a pinched-pod plant with the alleles *ss* are both homozygous. An organism that has two different alleles for a trait is **heterozygous** (het ur oh ZY gus) for that trait. A smooth-pod plant with the alleles *Ss* is heterozygous. Mendel used the term *hybrid* to describe heterozygous pea plants.

Reading Checkpoint **If a pea plant's genotype is *Ss*, what is its phenotype?**



Phenotypes and Genotypes

Phenotype	Genotype
Smooth pods	*SS*
Smooth pods	*Ss*
Pinched pods	*ss*

FIGURE 9
The phenotype of an organism is its physical appearance. Its genotype is its genetic makeup. **Interpreting Tables** *How many genotypes are there for the smooth-pod phenotype?*

Codominance

For all of the traits that Mendel studied, one allele was dominant while the other was recessive. This is not always the case. For some alleles, an inheritance pattern called **codominance** exists. **In codominance, the alleles are neither dominant nor recessive. As a result, both alleles are expressed in the offspring.**

Look at Figure 10. Mendel's principle of dominant and recessive alleles does not explain why the heterozygous chickens have both black and white feathers. The alleles for feather color are codominant—neither dominant nor recessive. As you can see, neither allele is masked in the heterozygous chickens. Notice also that the codominant alleles are written as capital letters with superscripts—F^B for black feathers and F^W for white feathers. As the Punnett square shows, heterozygous chickens have the F^BF^W allele combination.

Reading Checkpoint **How are the symbols for codominant alleles written?**

FIGURE 10
Codominance
The offspring of the cross in this Punnett square will have both black and white feathers.
Classifying *Will the offspring be heterozygous or homozygous? Explain your answer.*

Section 2 Assessment

Target Reading Skill **Building Vocabulary** Use your definitions to help you answer the questions.

Reviewing Key Concepts

1. a. **Reviewing** What is probability?
   b. **Explaining** If you know the parents' alleles for a trait, how can you use a Punnett square to predict the probable genotypes of the offspring?
   c. **Predicting** A pea plant with round seeds has the genotype *Rr*. You cross this plant with a wrinkled-seed plant, genotype *rr*. What is the probability that the offspring will have wrinkled seeds? (Use a Punnett square to help with the prediction.)
2. a. **Defining** Define *genotype* and *phenotype*.
   b. **Relating Cause and Effect** Explain how two organisms can have the same phenotype but different genotypes. Give an example.
   c. **Applying Concepts** A pea plant has a tall stem. What are its possible genotypes?
3. a. **Explaining** What is codominance? Give an example of codominant alleles and explain why they are codominant.
   b. **Applying Concepts** What is the phenotype of a chicken with the genotype F^BF^W?

Math Practice

4. **Ratios** A scientist crossed a tall pea plant with a short pea plant. Of the offspring, 13 were tall and 12 were short. Write the ratio of each phenotype to the total number of offspring. Express the ratios as fractions.
5. **Percentage** Use the fractions to calculate the percentage of the offspring that were tall and the percentage that were short.

Lab zone **Skills Lab**

Make the Right Call!

Problem

How can you predict the possible results of genetic crosses?

Skills Focus

making models, interpreting data

Materials

- 2 small paper bags
- marking pen
- 3 blue marbles
- 3 white marbles

Procedure

1. Label one bag "Bag 1, Female Parent." Label the other bag "Bag 2, Male Parent." Then read over Part 1, Part 2, and Part 3 of this lab. Write a prediction about the kinds of offspring you expect from each cross.

PART 1 Crossing Two Homozygous Parents

2. Copy the data table and label it *Data Table 1*. Then place two blue marbles in Bag 1. This pair of marbles represents the female parent's alleles. Use the letter *B* to represent the dominant allele for blue color.
3. Place two white marbles in Bag 2. Use the letter *b* to represent the recessive allele for white color.
4. For Trial 1, remove one marble from Bag 1 without looking in the bag. Record the result in your data table. Return the marble to the bag. Again, without looking in the bag, remove one marble from Bag 2. Record the result in your data table. Return the marble to the bag.
5. In the column labeled Offspring's Alleles, write *BB* if you removed two blue marbles, *bb* if you removed two white marbles, or *Bb* if you removed one blue marble and one white marble.
6. Repeat Steps 4 and 5 nine more times.

PART 2 Crossing Homozygous and Heterozygous Parents

7. Place two blue marbles in Bag 1. Place one white marble and one blue marble in Bag 2. Copy the data table again, and label it *Data Table 2*.
8. Repeat Steps 4 and 5 ten times.

Data Table

Number _____

Trial	Allele From Bag 1 (Female Parent)	Allele From Bag 2 (Male Parent)	Offspring's Alleles
1			
2			
3			
4			
5			
6			

PART 3 Crossing Two Heterozygous Parents

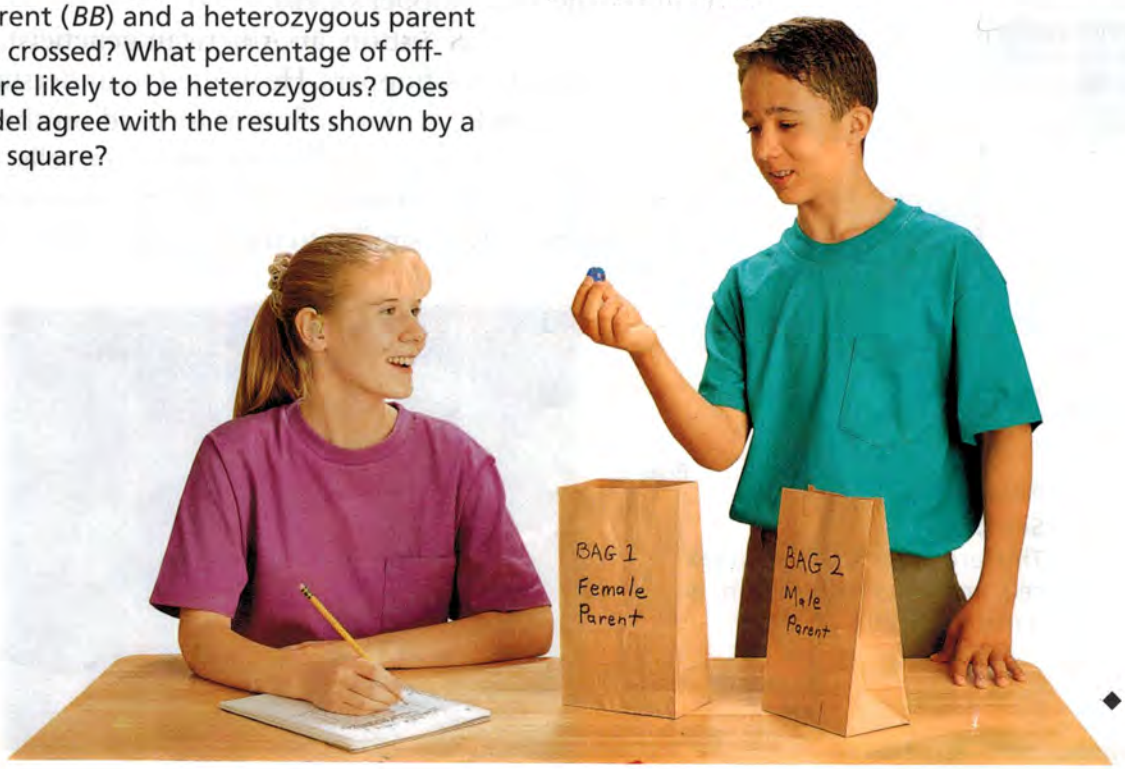
9. Place one blue marble and one white marble in Bag 1. Place one blue marble and one white marble in Bag 2. Copy the data table again and label it *Data Table 3*.
10. Repeat Steps 4 and 5 ten times.

Analyze and Conclude

1. **Making Models** Make a Punnett square for each of the crosses you modeled in Part 1, Part 2, and Part 3.
2. **Interpreting Data** According to your results in Part 1, how many different kinds of offspring are possible when the homozygous parents (*BB* and *bb*) are crossed? Do the results you obtained using the marble model agree with the results shown by a Punnett square?
3. **Predicting** According to your results in Part 2, what percentage of offspring are likely to be homozygous when a homozygous parent (*BB*) and a heterozygous parent (*Bb*) are crossed? What percentage of offspring are likely to be heterozygous? Does the model agree with the results shown by a Punnett square?
4. **Making Models** According to your results in Part 3, what different kinds of offspring are possible when two heterozygous parents (*Bb* × *Bb*) are crossed? What percentage of each type of offspring are likely to be produced? Does the model agree with the results of a Punnett square?
5. **Inferring** For Part 3, if you did 100 trials instead of 10 trials, would your results be closer to the results shown in a Punnett square? Explain.
6. **Communicating** In a paragraph, explain how the marble model compares with a Punnett square. How are the two methods alike? How are they different?

More to Explore

In peas, the allele for yellow seeds (*Y*) is dominant over the allele for green seeds (*y*). What possible crosses do you think could produce a heterozygous plant with yellow seeds (*Yy*)? Use the marble model and Punnett squares to test your predictions.



Section 3

The Cell and Inheritance

Reading Preview

Key Concepts

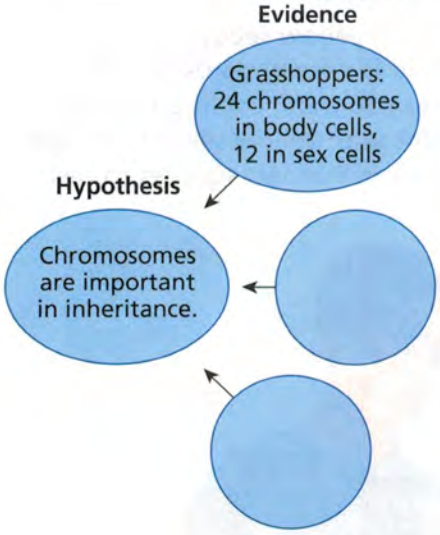
- What role do chromosomes play in inheritance?
- What events occur during meiosis?
- What is the relationship between chromosomes and genes?

Key Term

- meiosis

Target Reading Skill

Identifying Supporting Evidence As you read, identify the evidence that supports the hypothesis that chromosomes are important in inheritance. Write the evidence in a graphic organizer.



Lab zone Discover Activity

Which Chromosome Is Which?

Mendel did not know about chromosomes or their role in genetics. Today we know that genes are located on chromosomes.

1. Label two craft sticks with the letter *A*. The craft sticks represent a pair of chromosomes in the female parent. Turn the sticks face down on a piece of paper.
2. Label two more craft sticks with the letter *a*. These represent a pair of chromosomes in the male parent. Turn the sticks face down on another piece of paper.
3. Turn over one craft stick "chromosome" from each piece of paper. Move both sticks to a third piece of paper. These represent a pair of chromosomes in the offspring. Note the allele combination that the offspring received.

Think It Over

Making Models Use this model to explain how chromosomes are involved in the inheritance of alleles.

Mendel's work showed that genes exist. But scientists in the early twentieth century did not know what structures in cells contained genes. The search for the answer to this puzzle is something like a mystery story. The story could be called "The Clue in the Grasshopper's Cells."

In 1903, Walter Sutton, an American geneticist, was studying the cells of grasshoppers. He wanted to understand how sex cells (sperm and egg) form. Sutton focused on the movement of chromosomes during the formation of sex cells. He hypothesized that chromosomes were the key to understanding how offspring have traits similar to those of their parents.

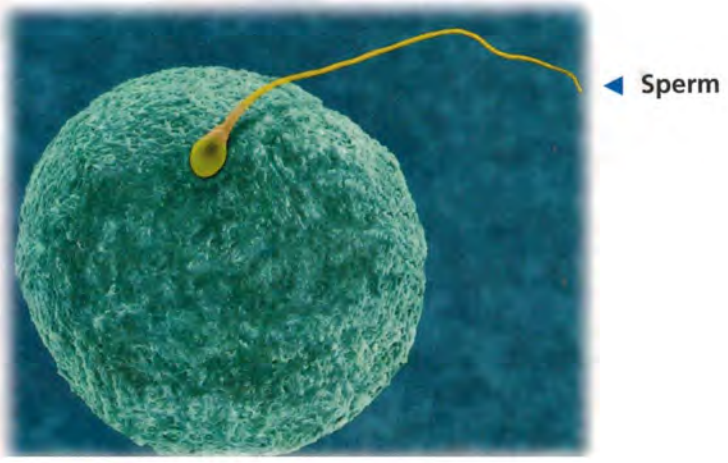


FIGURE 11
Sex Cells
The large egg is a female sex cell, and the smaller sperm is a male sex cell.

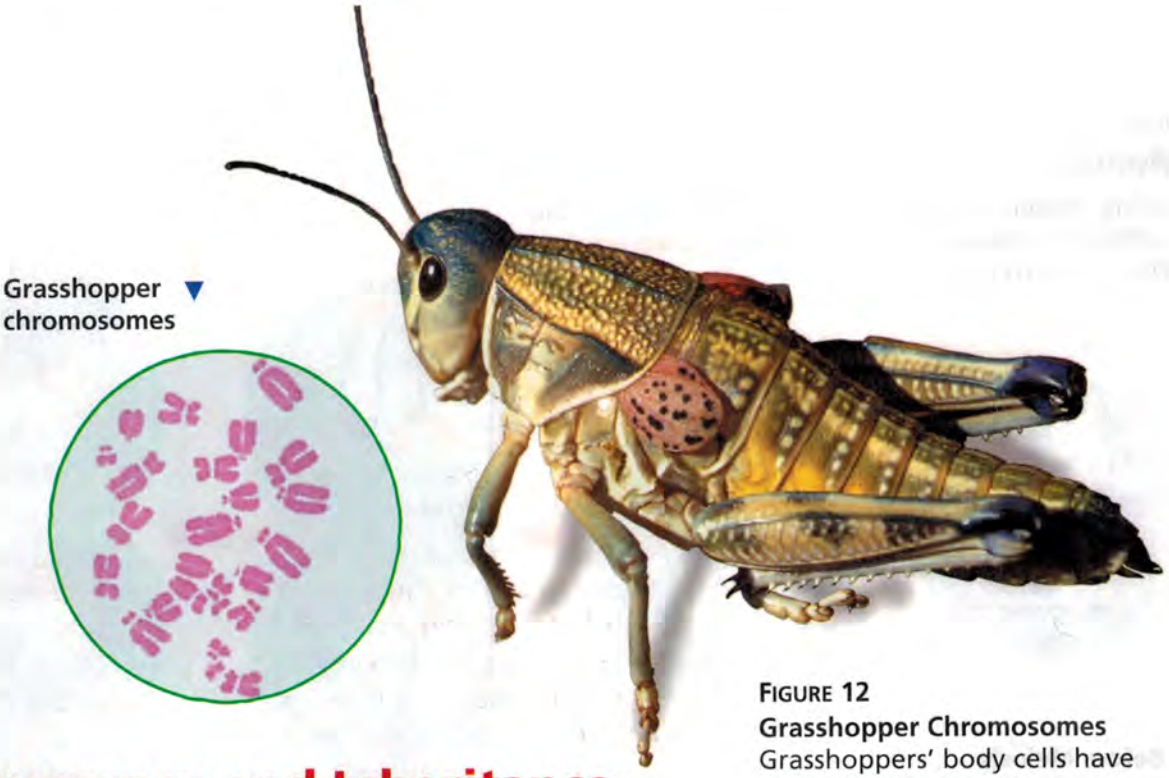


FIGURE 12
Grasshopper Chromosomes
Grasshoppers' body cells have twice the number of chromosomes as their sex cells.
Applying Concepts *What is the function of chromosomes?*

Chromosomes and Inheritance

Sutton needed evidence to support his hypothesis that chromosomes were important in the inheritance of traits. He found that evidence in grasshoppers' cells. The body cells of a grasshopper have 24 chromosomes. To his surprise, Sutton found that the grasshopper's sex cells have only 12 chromosomes. In other words, a grasshopper's sex cells have exactly half the number of chromosomes found in its body cells.

Chromosome Pairs Sutton observed what happened when a sperm cell and an egg cell joined during fertilization. The fertilized egg that formed had 24 chromosomes. As a result, the grasshopper offspring had exactly the same number of chromosomes in its cells as did each of its parents. The 24 chromosomes existed in 12 pairs. One chromosome in each pair came from the male parent, while the other chromosome came from the female parent.

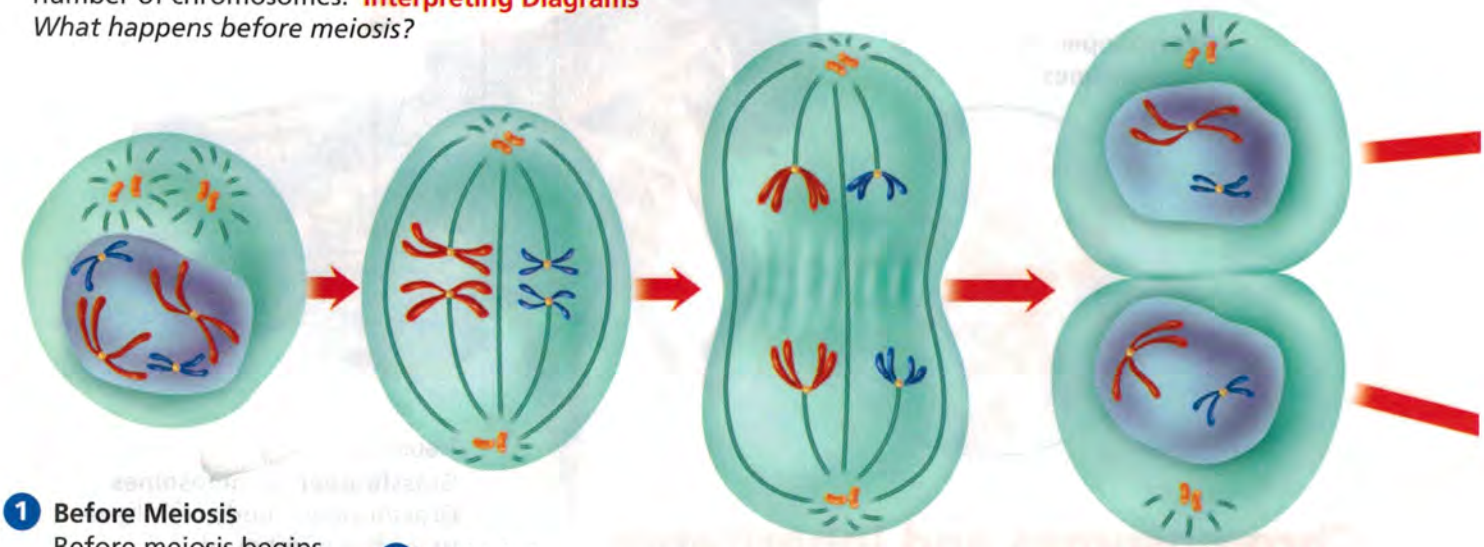
Genes on Chromosomes Recall that alleles are different forms of a gene. Because of Mendel's work, Sutton knew that alleles exist in pairs in an organism. One allele in a pair comes from the organism's female parent and the other allele comes from the male parent. Sutton realized that paired alleles were carried on paired chromosomes. Sutton's idea came to be known as the chromosome theory of inheritance. **According to the chromosome theory of inheritance, genes are carried from parents to their offspring on chromosomes.**

Reading Checkpoint **What is the relationship between alleles and chromosomes?**

FIGURE 13

Meiosis

During meiosis, a cell produces sex cells with half the number of chromosomes. **Interpreting Diagrams** *What happens before meiosis?*



1 Before Meiosis
Before meiosis begins, every chromosome in the parent cell is copied. Centromeres hold the two chromatids together.

2 Meiosis I

A The chromosome pairs line up in the center of the cell.

B The pairs separate and move to opposite ends of the cell.

C Two cells form, each with half the number of chromosomes. Each chromosome still has two chromatids.

Meiosis

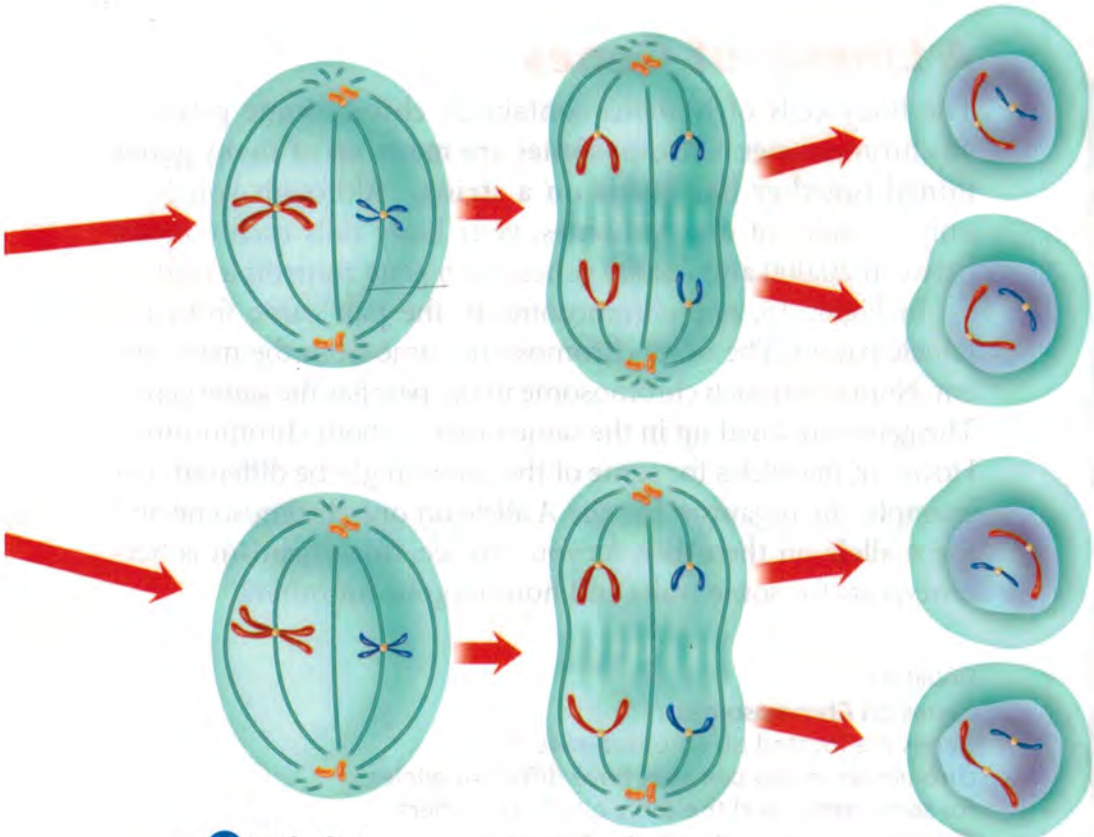
How do sex cells end up with half the number of chromosomes as body cells? To answer this question, you need to understand the events that occur during meiosis. **Meiosis** (my OH sis) is the process by which the number of chromosomes is reduced by half to form sex cells—sperm and eggs.

What Happens During Meiosis You can trace the events of meiosis in Figure 13. In this example, each parent cell has four chromosomes arranged in two pairs. **During meiosis, the chromosome pairs separate and are distributed to two different cells. The resulting sex cells have only half as many chromosomes as the other cells in the organism.** The sex cells end up with only two chromosomes each—half the number found in the parent cell. Each sex cell has one chromosome from each original pair.

When sex cells combine to form an organism, each sex cell contributes half the normal number of chromosomes. Thus, the offspring gets the normal number of chromosomes—half from each parent.

Go Online
NSTA SciLINKS

For: Links on meiosis
Visit: www.SciLinks.org
Web Code: scn-0333



3 Meiosis II

A The chromosomes with their two chromatids move to the center of the cell.

B The centromeres split, and the chromatids separate. Single chromosomes move to opposite ends of the cell.

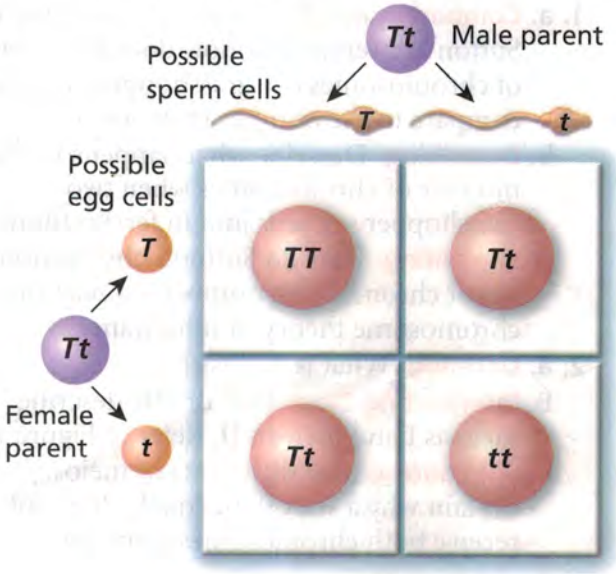
4 End of Meiosis
Four sex cells have been produced. Each cell has only half the number of chromosomes that the parent cell had at the beginning of meiosis. Each cell has only one chromosome from each original pair.

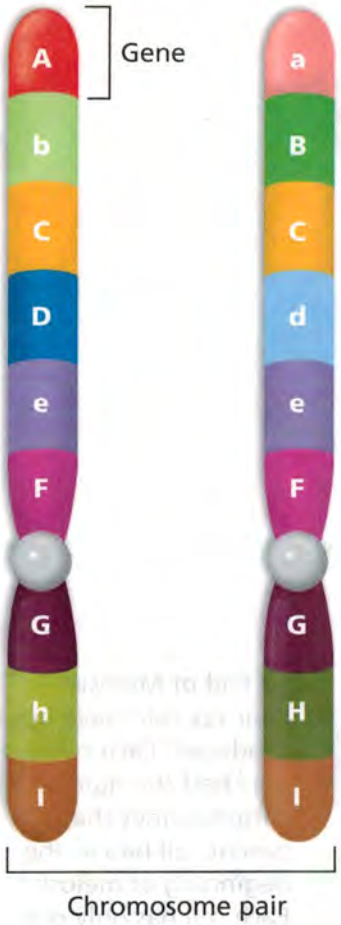
Meiosis and Punnett Squares

A Punnett square is actually a way to show the events that occur at meiosis. When the chromosome pairs separate and go into two different sex cells, so do the alleles carried on each chromosome. One allele from each pair goes to each sex cell.

In Figure 14, you can see how the Punnett square accounts for the separation of alleles during meiosis. As shown across the top of the Punnett square, half of the sperm cells from the male parent will receive the chromosome with the *T* allele. The other half of the sperm cells will receive the chromosome with the *t* allele. In this example, the same is true for the egg cells from the female parent, as shown down the left side of the Punnett square. Depending on which sperm cell combines with which egg cell, one of the allele combinations shown in the boxes will result.

FIGURE 14
Meiosis Punnett Square
Both parents are heterozygous for the trait of stem height. The Punnett square shows the possible allele combinations after fertilization.





A Lineup of Genes

The body cells of humans contain 23 chromosome pairs, or 46 chromosomes. **Chromosomes are made up of many genes joined together like beads on a string.** Although you have only 23 pairs of chromosomes, your body cells each contain between 20,000 and 25,000 genes. Each gene controls a trait.

In Figure 15, one chromosome in the pair came from the female parent. The other chromosome came from the male parent. Notice that each chromosome in the pair has the same genes. The genes are lined up in the same order on both chromosomes. However, the alleles for some of the genes might be different. For example, the organism has the *A* allele on one chromosome and the *a* allele on the other. As you can see, this organism is heterozygous for some traits and homozygous for others.

FIGURE 15
Genes on Chromosomes
Genes are located on chromosomes. The chromosomes in a pair may have different alleles for some genes and the same alleles for others.
Classifying *For which genes is this organism homozygous? For which genes is it heterozygous?*

Section 3 Assessment

Target Reading Skill **Identifying Supporting Evidence** Refer to your graphic organizer about the chromosome theory of inheritance as you answer Question 1 below.

Reviewing Key Concepts

1. a. **Comparing and Contrasting** According to Sutton's observations, how does the number of chromosomes in a grasshopper's body cells compare to the number in its sex cells?
   b. **Describing** Describe what happens to the number of chromosomes when two grasshopper sex cells join in fertilization.
   c. **Explaining** How do Sutton's observations about chromosome number support the chromosome theory of inheritance?
2. a. **Defining** What is meiosis?
   b. **Interpreting Diagrams** Briefly describe meiosis I and meiosis II. Refer to Figure 13.
   c. **Sequencing** Use the events of meiosis to explain why a sex cell normally does not receive both chromosomes from a pair.
3. a. **Describing** How are genes arranged on a chromosome?
   b. **Comparing and Contrasting** How does the order of genes in one member of a chromosome pair compare to the order of genes on the other chromosome?

Writing in Science

Newspaper Interview You are a newspaper reporter in the early 1900s. You want to interview Walter Sutton about his work with chromosomes. Write three questions you would like to ask Sutton. Then, for each question, write answers that Sutton might have given.

Section 4

The DNA Connection

Reading Preview

Key Concepts

- What forms the genetic code?
- How does a cell produce proteins?
- How can mutations affect an organism?

Key Terms

- messenger RNA
- transfer RNA
- mutation

Target Reading Skill

Sequencing A sequence is the order in which the steps in a process occur. As you read, make a flowchart that shows protein synthesis. Put the steps of the process in separate boxes in the flowchart in the order in which they occur.

Protein Synthesis

DNA provides code to form messenger RNA.

↓

Messenger RNA attaches to ribosome.

↓

Lab zone Discover Activity

Can You Crack the Code?

1. Use the Morse code in the chart to decode the question in the message below. The letters are separated by slash marks.

• – – / • • • • / • / • – • / • / • – / • – • / • / – – • / • / – • / • / • • • / • – • • / – – – / – • – • / • – / – / • / – • • /

2. Write your answer to the question in Morse code.
3. Exchange your coded answer with a partner. Then decode your partner's answer.

Think It Over

Forming Operational Definitions Based on your results from this activity, write a definition of the word *code*. Then compare your definition to one in a dictionary.

A • –	N – •
B – • • •	O – – –
C – • – •	P • – – •
D – • •	Q – – • –
E •	R • – •
F • • – •	S • • •
G – – •	T –
H • • • •	U • • –
I • •	V • • • –
J • – – –	W • – –
K – • –	X – • • –
L • – • •	Y – • – –
M – –	Z – – • •

The young, white, ring-tailed lemur in the photograph below was born in a forest in southern Madagascar. White lemurs are extremely rare. Why was this lemur born with such an uncommon phenotype? To answer this question, you need to know how the genes on a chromosome control an organism's traits.

A white lemur and its mother ▶

The Genetic Code

The main function of genes is to control the production of proteins in an organism's cells. Proteins help to determine the size, shape, color, and many other traits of an organism.

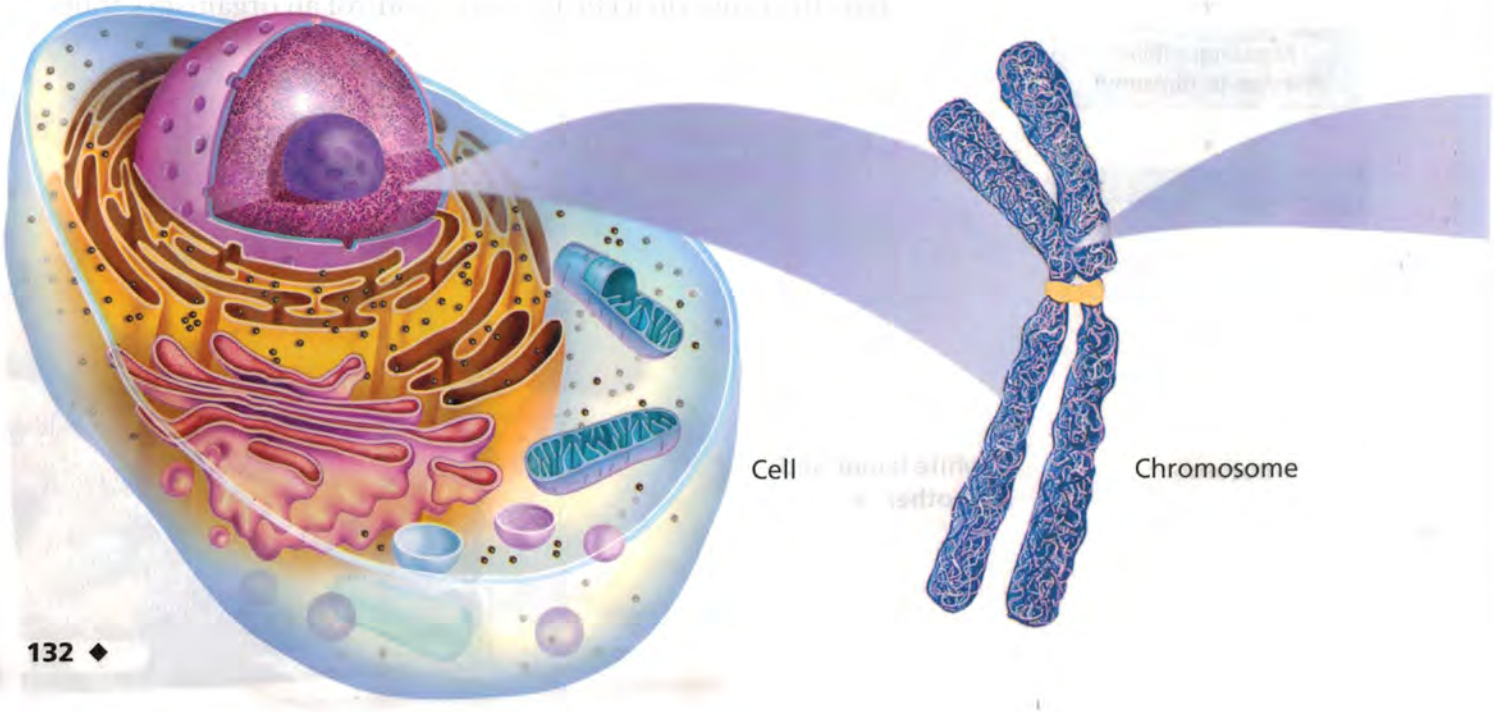
Genes and DNA Recall that chromosomes are composed mostly of DNA. In Figure 16, you can see the relationship between chromosomes and DNA. Notice that a DNA molecule is made up of four different nitrogen bases—adenine (A), thymine (T), guanine (G), and cytosine (C). These bases form the rungs of the DNA "ladder."

A gene is a section of a DNA molecule that contains the information to code for one specific protein. A gene is made up of a series of bases in a row. The bases in a gene are arranged in a specific order—for example, ATGACGTAC. A single gene on a chromosome may contain anywhere from several hundred to a million or more of these bases. Each gene is located at a specific place on a chromosome.

Order of the Bases A gene contains the code that determines the structure of a protein. **The order of the nitrogen bases along a gene forms a genetic code that specifies what type of protein will be produced.** Remember that proteins are long-chain molecules made of individual amino acids. In the genetic code, a group of three DNA bases codes for one specific amino acid. For example, the base sequence CGT (cytosine-guanine-thymine) always codes for the amino acid alanine. The order of the three-base code units determines the order in which amino acids are put together to form a protein.

FIGURE 16
The DNA Code

Chromosomes are made of DNA. Each chromosome contains thousands of genes. The sequence of bases in a gene forms a code that tells the cell what protein to produce. **Interpreting Diagrams** *Where in the cell are chromosomes located?*



How Cells Make Proteins

The production of proteins is called protein synthesis. **During protein synthesis, the cell uses information from a gene on a chromosome to produce a specific protein.** Protein synthesis takes place on the ribosomes in the cytoplasm of a cell. As you know, the cytoplasm is outside the nucleus. The chromosomes, however, are found inside the nucleus. How, then, does the information needed to produce proteins get out of the nucleus and into the cytoplasm?

The Role of RNA Before protein synthesis can take place, a "messenger" must first carry the genetic code from the DNA inside the nucleus into the cytoplasm. This genetic messenger is called ribonucleic acid, or RNA.

Although RNA is similar to DNA, the two molecules differ in some important ways. Unlike DNA, which has two strands, RNA has only one strand. RNA also contains a different sugar molecule from the sugar found in DNA. Another difference between DNA and RNA is in their nitrogen bases. Like DNA, RNA contains adenine, guanine, and cytosine. However, instead of thymine, RNA contains uracil (YOOR uh sil).

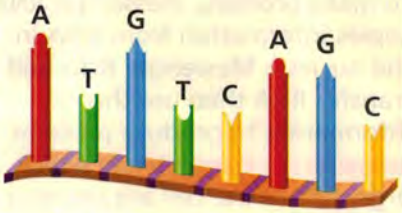
Types of RNA There are several types of RNA involved in protein synthesis. **Messenger RNA** copies the coded message from the DNA in the nucleus, and carries the message to the ribosome in the cytoplasm. Another type of RNA, called **transfer RNA,** carries amino acids to the ribosome and adds them to the growing protein.

Reading Checkpoint How is RNA different from DNA?

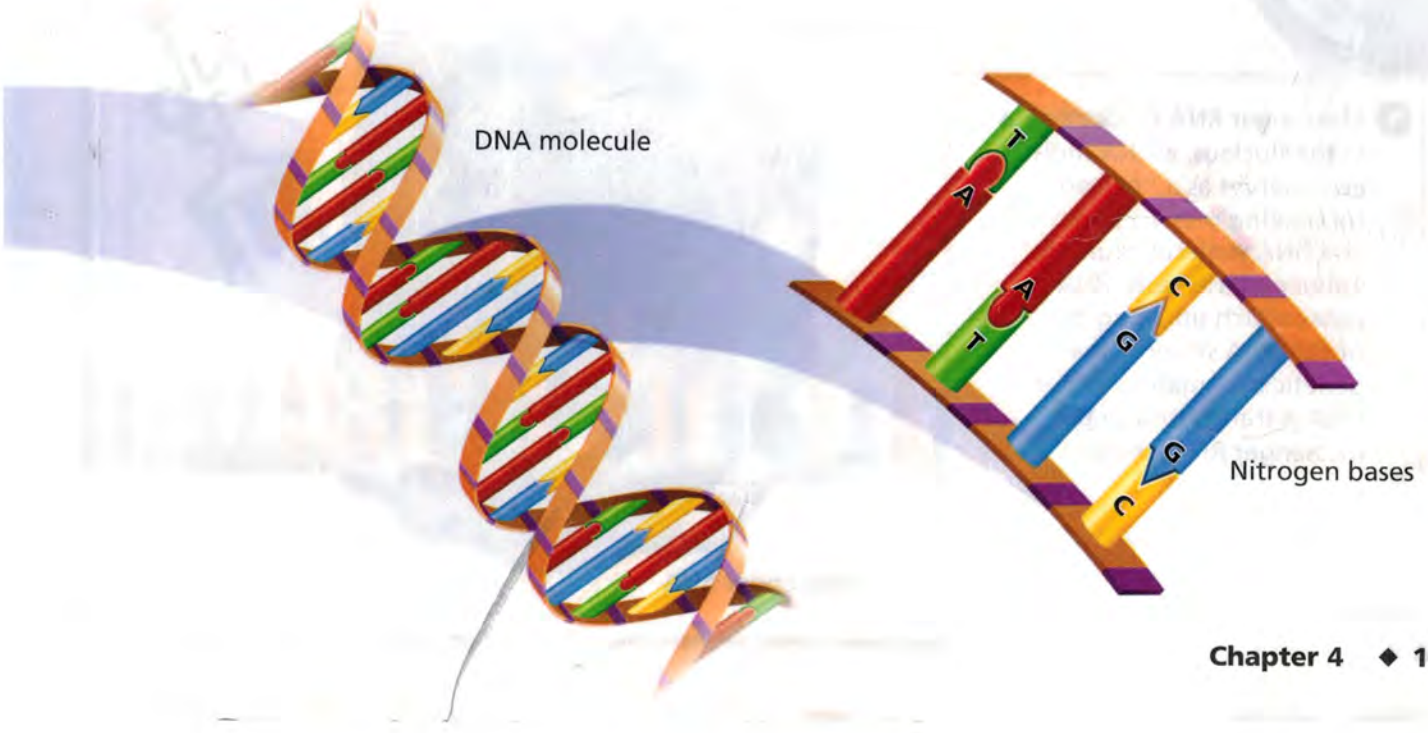
Lab zone Skills Activity

Drawing Conclusions

The following is a sequence of nitrogen bases on one strand of a nucleic acid molecule.



Does the strand come from DNA or RNA? Explain your answer.



Translating the Code The process of protein synthesis is shown in Figure 17. Look at the illustration as you read the following steps.

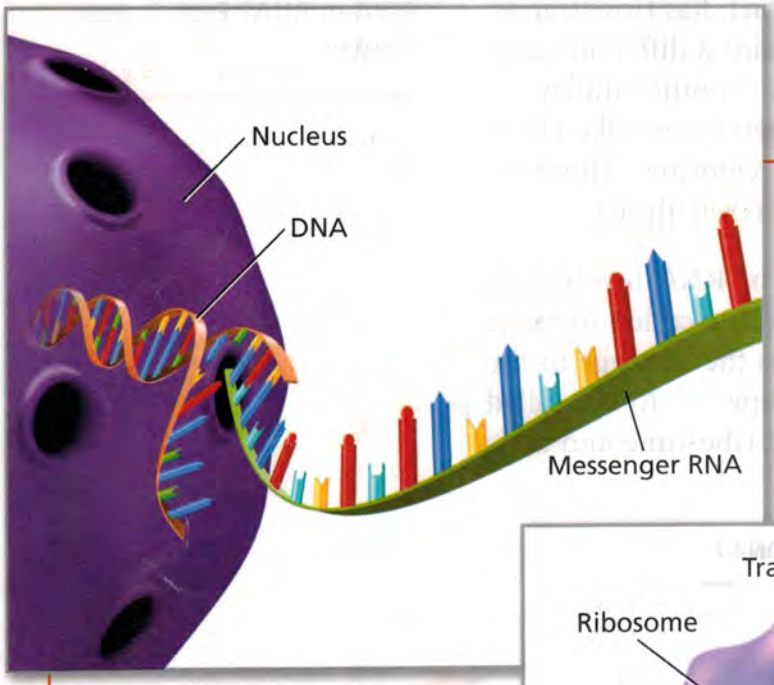
1 The first step is for a DNA molecule to "unzip" between its base pairs. Then one of the strands of DNA directs the production of a strand of messenger RNA. To form the RNA strand, RNA bases pair up with the DNA bases. The process is similar to the process in which DNA replicates. Cytosine always pairs with guanine. However, uracil—not thymine— pairs with adenine.

2 The messenger RNA then leaves the nucleus and enters the cytoplasm. In the cytoplasm, messenger RNA attaches to a ribosome. On the ribosome, the messenger RNA provides the code for the protein molecule that will form. During protein synthesis, the ribosome moves along the messenger RNA strand.

FIGURE 17

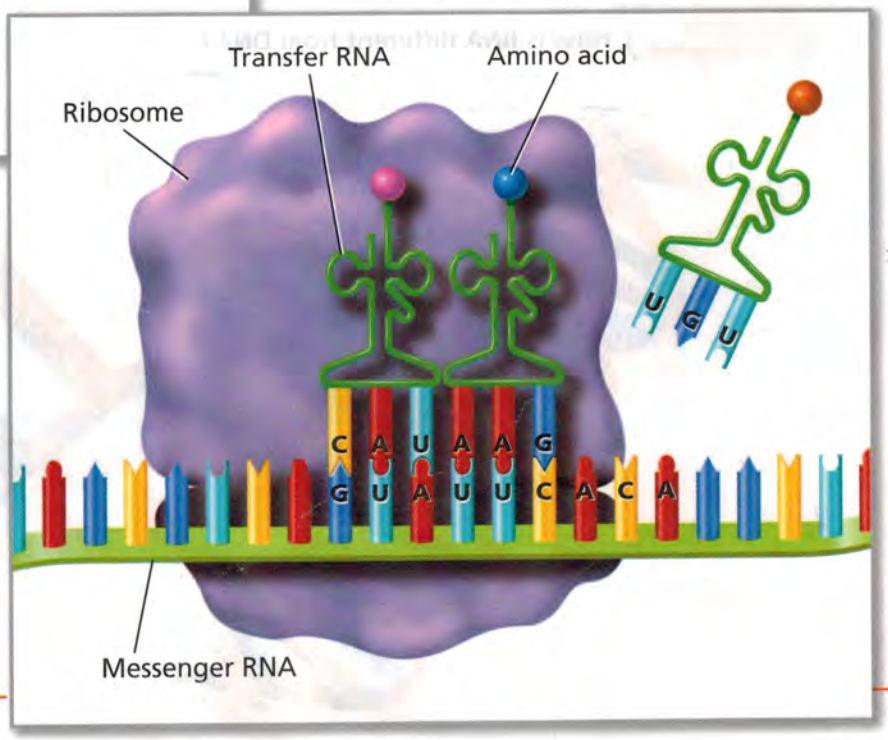
Protein Synthesis

To make proteins, messenger RNA copies information from DNA in the nucleus. Messenger RNA and transfer RNA then use this information to produce proteins.
Interpreting Diagrams *In which organelle of the cell are proteins manufactured?*



1 Messenger RNA Production ▲
In the nucleus, a DNA molecule serves as a "pattern" for making messenger RNA. The DNA molecule "unzips" between base pairs. RNA bases match up along one of the DNA strands. The genetic information in the DNA is transferred to the messenger RNA strand.

2 Messenger RNA Attaches to a Ribosome ▼
When the messenger RNA enters the cytoplasm, it attaches to a ribosome, where production of the protein chain begins. The ribosome moves along the messenger RNA strand.



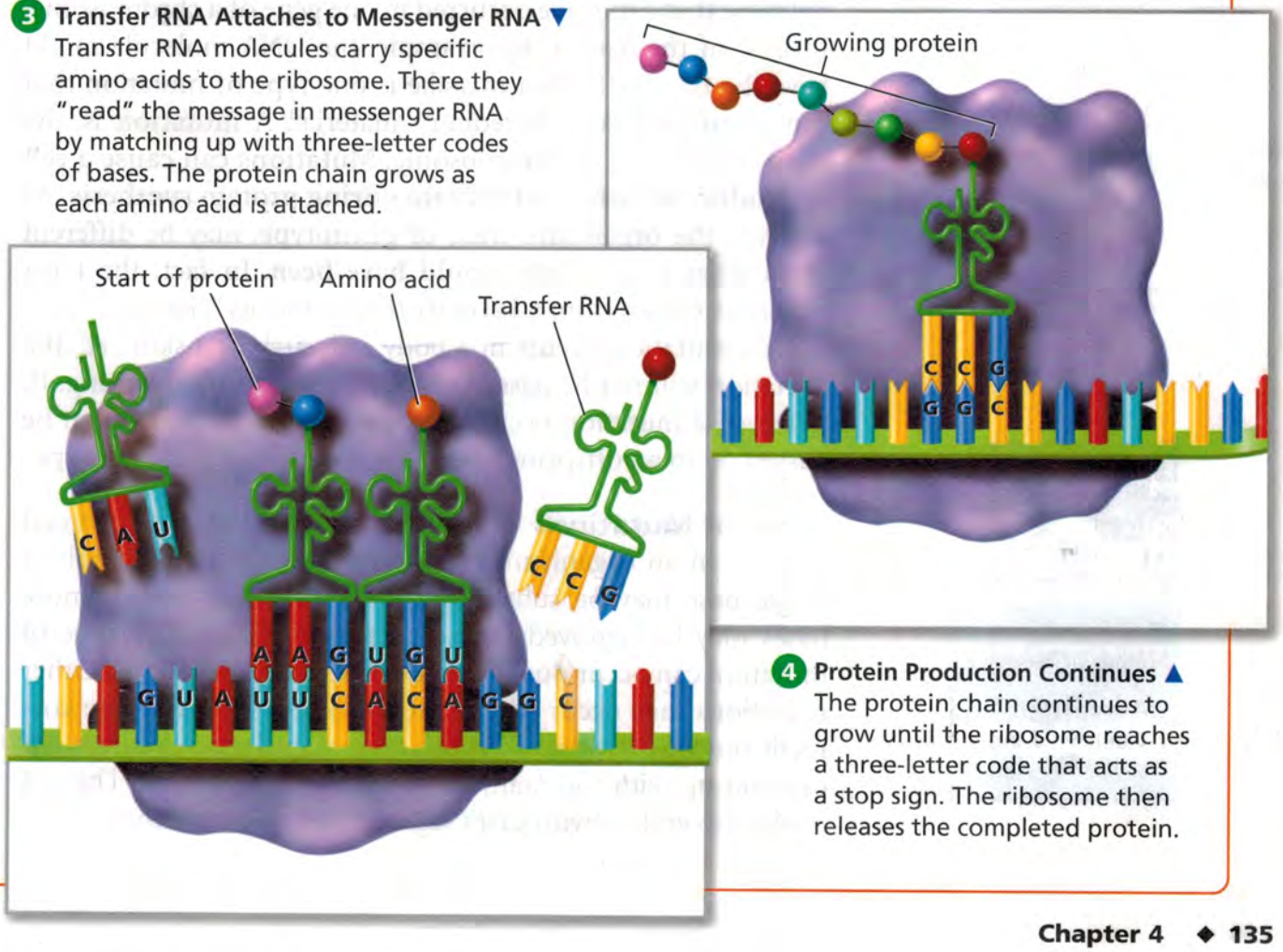
❸ Molecules of transfer RNA attach to the messenger RNA. The bases on the transfer RNA "read" the message by pairing up three-letter codes to bases on the messenger RNA. For example, you can see that a molecule of transfer RNA with the bases AAG pairs with the bases UUC on the messenger RNA. The molecules of transfer RNA carry specific amino acids. The amino acids link in a chain. The order of the amino acids in the chain is determined by the order of the three-letter codes on the messenger RNA.

❹ The protein molecule grows longer as each transfer RNA molecule puts the amino acid it is carrying along the growing protein chain. Once an amino acid is added to the protein chain, the transfer RNA is released into the cytoplasm and can pick up another amino acid. Each transfer RNA molecule always picks up the same kind of amino acid.

Reading Checkpoint **What is the function of transfer RNA?**

Go Online active art

For: Protein Synthesis activity
Visit: PHSchool.com
Web Code: cep-3034



❸ **Transfer RNA Attaches to Messenger RNA** ▼ Transfer RNA molecules carry specific amino acids to the ribosome. There they "read" the message in messenger RNA by matching up with three-letter codes of bases. The protein chain grows as each amino acid is attached.

❹ **Protein Production Continues** ▲ The protein chain continues to grow until the ribosome reaches a three-letter code that acts as a stop sign. The ribosome then releases the completed protein.

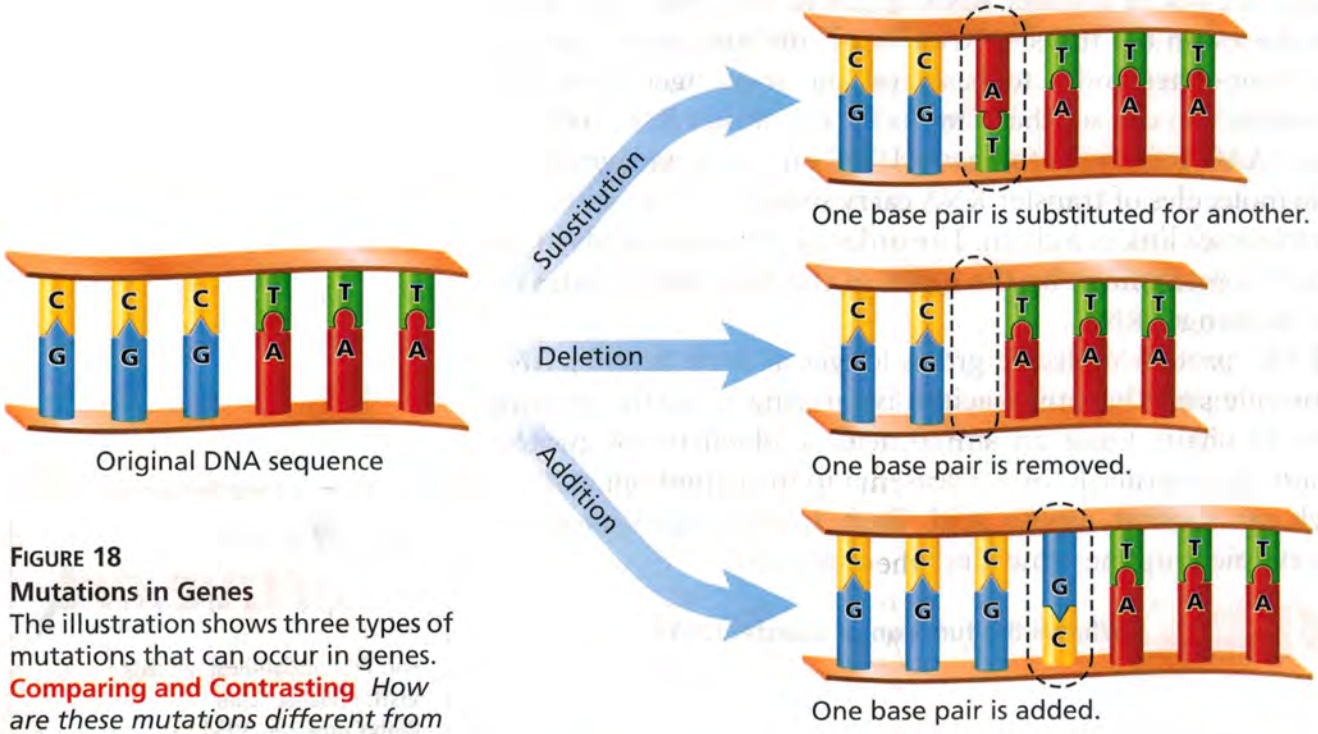


FIGURE 18
Mutations in Genes
The illustration shows three types of mutations that can occur in genes.
Comparing and Contrasting *How are these mutations different from the mutations that occur when chromosomes do not separate during meiosis?*

Mutations

Suppose that a mistake occurred in one gene of a chromosome. Instead of the base A, for example, the DNA molecule might have the base G. Such a mistake is one type of mutation that can occur in a cell's hereditary material. A **mutation** is any change in a gene or chromosome. **Mutations can cause a cell to produce an incorrect protein during protein synthesis. As a result, the organism's trait, or phenotype, may be different from what it normally would have been.** In fact, the term *mutation* comes from a Latin word that means "change."

If a mutation occurs in a body cell, such as a skin cell, the mutation will not be passed on to the organism's offspring. If, however, a mutation occurs in a sex cell, the mutation can be passed on to an offspring and affect the offspring's phenotype.

Types of Mutations Some mutations are the result of small changes in an organism's hereditary material. For example, a single base may be substituted for another, or one or more bases may be removed from a section of DNA. This type of mutation can occur during the DNA replication process. Other mutations may occur when chromosomes don't separate correctly during meiosis. When this type of mutation occurs, a cell can end up with too many or too few chromosomes. The cell could also end up with extra segments of chromosomes.

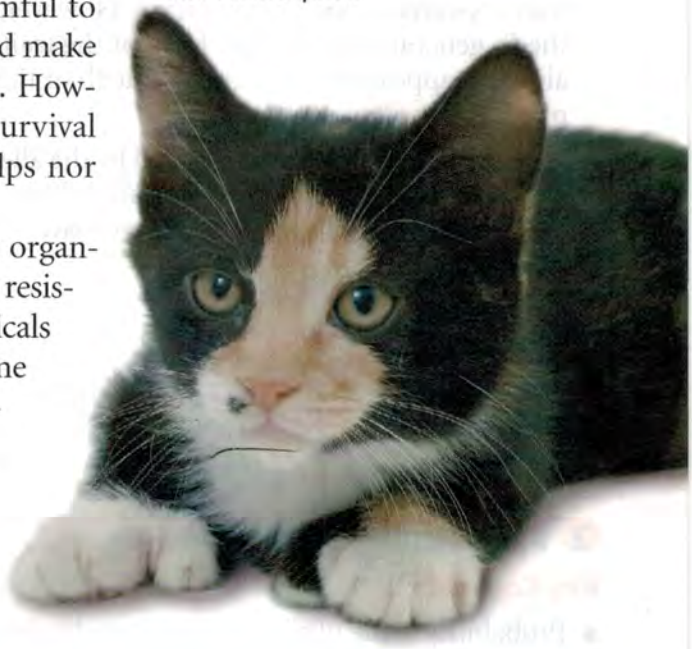
Effects of Mutations Because mutations can introduce changes in an organism, they can be a source of genetic variety. Some mutations are harmful to an organism. A few mutations, however, are helpful, and others are neither harmful nor helpful. A mutation is harmful to an organism if it reduces the organism's chance for survival and reproduction.

Whether a mutation is harmful or not depends partly on the organism's environment. The mutation that led to the production of a white lemur would probably be harmful to an organism in the wild. The lemur's white color would make it more visible, and thus easier for predators to find. However, a white lemur in a zoo has the same chance for survival as a brown lemur. In a zoo, the mutation neither helps nor harms the lemur.

Helpful mutations, on the other hand, improve an organism's chances for survival and reproduction. Antibiotic resistance in bacteria is an example. Antibiotics are chemicals that kill bacteria. Gene mutations have enabled some kinds of bacteria to become resistant to certain antibiotics—that is, the antibiotics do not kill the bacteria that have the mutations. The mutations have improved the bacteria's ability to survive and reproduce.

Reading Checkpoint **What are two types of mutations?**

FIGURE 19
Six-Toed Cat
Because of a mutation in one of its ancestors, this cat has six toes on each front paw.



Section 4 Assessment

Target Reading Skill **Sequencing** Refer to your flowchart as you answer Question 2.

Reviewing Key Concepts

1. a. **Explaining** What is the relationship between a gene, a DNA molecule, and a protein?
   b. **Relating Cause and Effect** How does a DNA molecule determine the structure of a specific protein?
   c. **Inferring** The DNA base sequence GGG codes for the amino acid proline. Could this same base sequence code for a different amino acid? Why or why not?
2. a. **Listing** List the sequence of events that happens during protein synthesis.
   b. **Describing** What is messenger RNA? Describe how it performs its function.
   c. **Inferring** Does transfer RNA perform its function in the nucleus or cytoplasm? Explain your answer.
3. a. **Reviewing** How does a mutation in a gene affect the order of DNA bases?
   b. **Relating Cause and Effect** How can a mutation in a gene cause a change in an organism's phenotype?

Writing in Science

Compare/Contrast Paragraph Write a paragraph comparing and contrasting gene mutations and chromosome mutations. In your paragraph, explain what the two types of mutations are, and how they are similar and different.

Chapter 4

Study Guide

The BIG Idea **Reproduction and Heredity** Organisms produced by sexual reproduction inherit half their DNA from each parent. The new combination of DNA determines an organism's traits.

1 Mendel's Work

Key Concepts

- In all of Mendel's crosses, only one form of the trait appeared in the F_1 generation. However, in the F_2 generation, the "lost" form of the trait always reappeared in about one fourth of the plants.
- An organism's traits are controlled by the alleles it inherits from its parents. Some alleles are dominant, while other alleles are recessive.

Key Terms

heredity
trait
genetics
fertilization
purebred
gene
alleles
dominant allele
recessive allele
hybrid

2 Probability and Heredity

Key Concepts

- Probability is the likelihood that a particular event will occur.
- In a genetic cross, the allele that each parent will pass on to its offspring is based on probability.
- An organism's phenotype is its physical appearance, or visible traits. An organism's genotype is its genetic makeup, or allele combinations.
- In codominance, the alleles are neither dominant nor recessive. As a result, both alleles are expressed in the offspring.

Key Terms

probability
Punnett square
phenotype
genotype
homozygous
heterozygous
codominance

3 The Cell and Inheritance

Key Concepts

- According to the chromosome theory of inheritance, genes are carried from parents to their offspring on chromosomes.
- During meiosis, the chromosome pairs separate and are distributed to two different cells. The resulting sex cells have only half as many chromosomes as the other cells in the organism.
- Chromosomes are made up of many genes joined together like beads on a string.

Key Term

meiosis

4 The DNA Connection

Key Concepts

- The order of the nitrogen bases along a gene forms a genetic code that specifies what type of protein will be produced.
- During protein synthesis, the cell uses information from a gene on a chromosome to produce a specific protein.
- Mutations can cause a cell to produce an incorrect protein during protein synthesis. As a result, the organism's trait, or phenotype, may be different from what it normally would have been.

Key Terms

messenger RNA
transfer RNA
mutation

Review and Assessment

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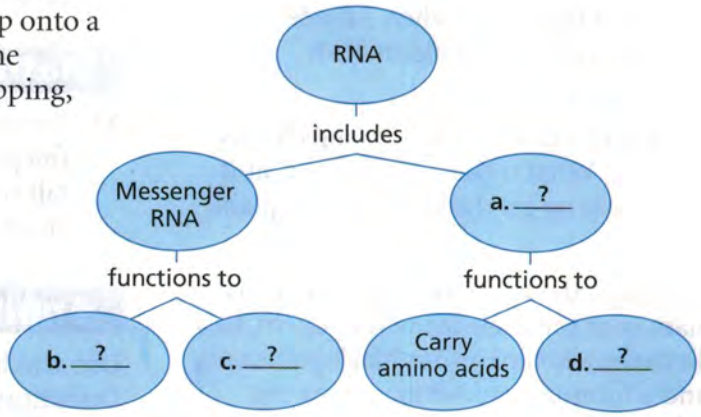
Organizing Information

Concept Mapping Copy the concept map onto a separate sheet of paper. Then complete the concept map. (For more on Concept Mapping, see the Skills Handbook.)



Reviewing Key Terms

Choose the letter of the best answer.

1. The different forms of a gene are called
   a. alleles. **b.** chromosomes.
   c. phenotypes. **d.** genotypes.
2. The likelihood that a particular event will occur is called
   a. chance.
   b. a Punnett square.
   c. probability.
   d. recessive.
3. An organism with two identical alleles for a trait is
   a. heterozygous.
   b. homozygous.
   c. recessive.
   d. dominant.
4. If the body cells of an organism have 10 chromosomes, then the sex cells produced during meiosis would have
   a. 5 chromosomes.
   b. 10 chromosomes.
   c. 15 chromosomes.
   d. 20 chromosomes.
5. During protein synthesis, messenger RNA
   a. links one amino acid to another.
   b. releases the completed protein chain.
   c. provides a code from DNA in the nucleus.
   d. carries amino acids to the ribosome.

If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.

6. The scientific study of heredity is called genetics.
7. An organism's physical appearance is its genotype.
8. In codominance, neither of the alleles is dominant or recessive.
9. Each transfer RNA molecule picks up one kind of protein.
10. Mutations in body cells are passed to offspring.

Writing in Science

Science Article You are a science reporter for a newspaper. Write an article about gene mutations. Explain what a mutation is and what determines whether it is helpful or harmful.

Discovery CHANNEL SCHOOL

Genetics: The Science of Heredity
Video Preview
Video Field Trip
▶ Video Assessment

Review and Assessment

Checking Concepts

11. Describe what happened when Mendel crossed purebred tall pea plants with purebred short pea plants.

12. You toss a coin five times and it lands heads up each time. What is the probability that it will land heads up on the sixth toss? Explain your answer.

13. In guinea pigs, the allele for black fur (*B*) is dominant over the allele for white fur (*b*). In a cross between a heterozygous black guinea pig (*Bb*) and a homozygous white guinea pig (*bb*), what is the probability that an offspring will have white fur? Use a Punnett square to answer the question.

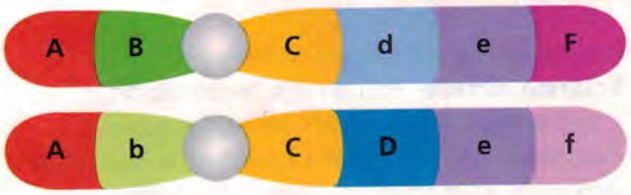
14. Describe the role of transfer RNA in protein synthesis.

15. How can mutations affect protein synthesis?

Thinking Critically

16. **Applying Concepts** In rabbits, the allele for a spotted coat is dominant over the allele for a solid-colored coat. A spotted rabbit was crossed with a solid-colored rabbit. The offspring all had spotted coats. What are the probable genotypes of the parents? Explain.

17. **Interpreting Diagrams** The diagram below shows a chromosome pair. For which genes is the organism heterozygous?



18. **Predicting** A new mutation in mice causes the coat to be twice as thick as normal. In what environments would this mutation be helpful? Why?

19. **Applying Concepts** If the body cells have 12 chromosomes, how many will the sex cells have?

20. **Relating Cause and Effect** Why are mutations that occur in an organism's body cells not passed on to its offspring?

Math Practice

21. **Percentage** A garden has 80 pea plants. Of the plants, 20 have short stems and 60 have tall stems. What percentage of the plants have short stems? What percentage have tall stems?

Applying Skills

Use the information in the table to answer Questions 22–24.

In peas, the allele for green pods (G) is dominant over the allele for yellow pods (g). The table shows the phenotypes of offspring produced from a cross of two plants with green pods.

Phenotype	Number of Offspring
Green pods	27
Yellow pods	9

22. **Calculating Percent** Calculate what percent of the offspring produce green pods. Calculate what percent have yellow pods.

23. **Inferring** What is the genotype of the offspring with yellow pods? What are the possible genotypes of the offspring with green pods?

24. **Drawing Conclusions** What are the genotypes of the parents? How do you know?

Lab zone Chapter Project

Performance Assessment Finalize your display of your pet's family. Be prepared to discuss the inheritance patterns in your pet's family. Examine your classmates' exhibits. See which offspring look most like, and least like, their parents. Can you find any offspring that "break the laws" of inheritance?

Chapter

5

Modern Genetics

The BIG Idea

Science and Technology

What applications of science and technology have advanced the study of genetics?

Chapter Preview

The members of this family resemble one another because they share some alleles. ▶

Discovery CHANNEL SCHOOL

Modern Genetics

- ▶ Video Preview
- Video Field Trip
- Video Assessment

Lab zone™ **Chapter Project**

Teach Others About a Trait

People inherit alleles for traits from their parents. Some traits, such as keen eyesight, are beneficial. Other traits, such as colorblindness, can present challenges. In this project you will design a display to help teach younger children about a genetically inherited trait. You and your group will need to research the inheritance pattern of your selected trait.

Your Goal To design and build an educational tool or display that can be used to educate young children

The display you create should

- illustrate how the trait is inherited and whom it can affect
- explain whether the trait is dominant, recessive, or codominant
- contain an interactive question and answer section that includes a way of predicting the probability that a person will inherit the trait
- stand by itself and be easy to set up

Plan It! Begin by choosing a trait and researching its inheritance pattern. Then determine how the display will look and the materials you need. Determine what is the best method to make the display interactive. Plan to test your display on a younger audience to assess their understanding and then revise your design.

Section 1

Human Inheritance

Reading Preview

Key Concepts

- What are some patterns of inheritance in humans?
- What are the functions of the sex chromosomes?
- What is the relationship between genes and the environment?

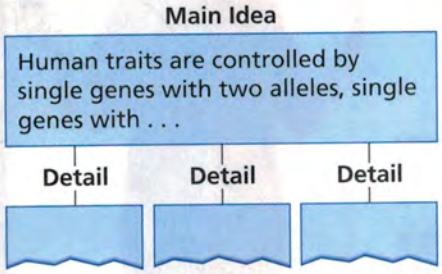
Key Terms

- multiple alleles
- sex chromosomes
- sex-linked gene
- carrier

Target Reading Skill

Identifying Main Ideas

As you read the Patterns of Human Inheritance section, write the main idea—the biggest or most important idea—in a graphic organizer like the one below. Then write three supporting details that further explain the main idea.



Lab zone Discover Activity

How Tall Is Tall?

1. Choose a partner. Measure each other's height to the nearest 5 centimeters. Record your measurements on the chalkboard.
2. Create a bar graph showing the number of students at each height. Plot the heights on the horizontal axis and the number of students on the vertical axis.

Think It Over

Inferring Do you think height in humans is controlled by a single gene, as it is in peas? Explain your answer.

The arrival of a baby is a happy event. Eagerly, the parents and grandparents gather around to admire the newborn baby. "Don't you think she looks like her father?" "Yes, but she has her mother's eyes."

When a baby is born, the parents, their families, and their friends try to determine whom the baby resembles. Chances are good that the baby will look a little bit like both parents. That is because both parents pass alleles for traits on to their offspring.

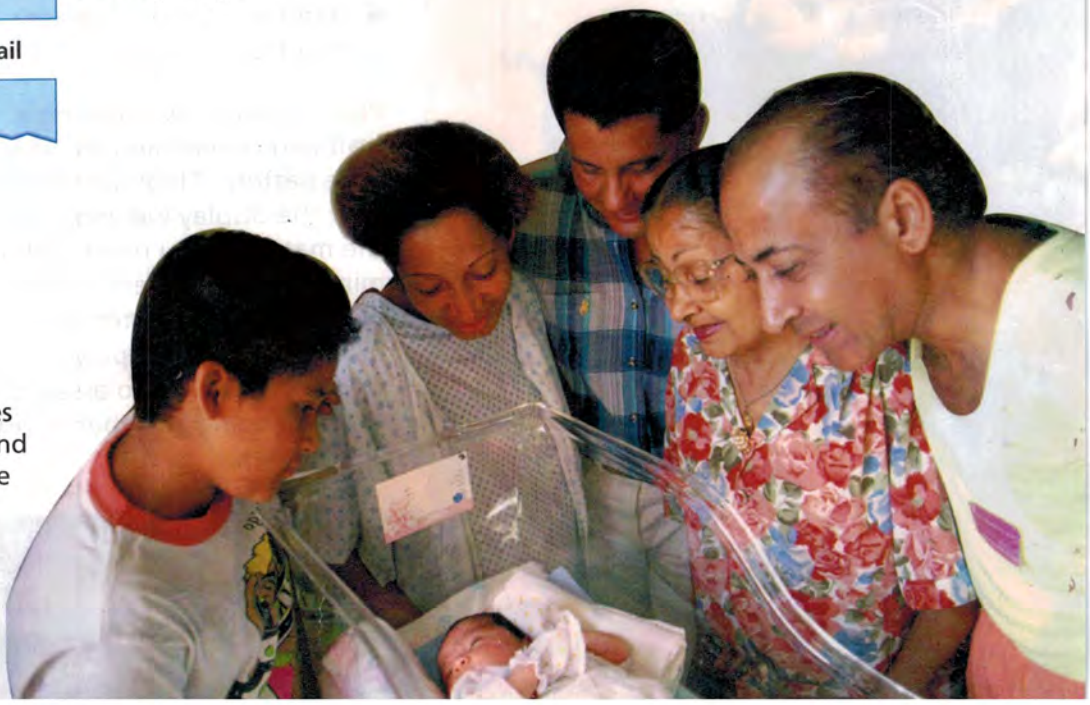


FIGURE 1
Family Resemblance
Because children inherit alleles for traits from their mother and father, children often look like their parents.

Patterns of Human Inheritance

Take a few seconds to look at the other students in your classroom. Some people have curly hair; others have straight hair. Some people are tall, some are short, and many others are in between. You'll probably see eyes of many different colors, ranging from pale blue to dark brown. The different traits you see are determined by a variety of inheritance patterns. **Some human traits are controlled by single genes with two alleles, and others by single genes with multiple alleles. Still other traits are controlled by many genes that act together.**

Single Genes With Two Alleles A number of human traits are controlled by a single gene with one dominant allele and one recessive allele. These human traits have two distinctly different phenotypes, or physical appearances.

For example, a widow's peak is a hairline that comes to a point in the middle of the forehead. The allele for a widow's peak is dominant over the allele for a straight hairline. The Punnett square in Figure 2 illustrates a cross between two parents who are heterozygous for a widow's peak. Trace the possible combinations of alleles that a child may inherit. Notice that each child has a 3 in 4, or 75 percent, probability of having a widow's peak. There is only a 1 in 4, or 25 percent, probability that a child will have a straight hairline. When Mendel crossed peas that were heterozygous for a trait, he obtained similar percentages in the offspring.

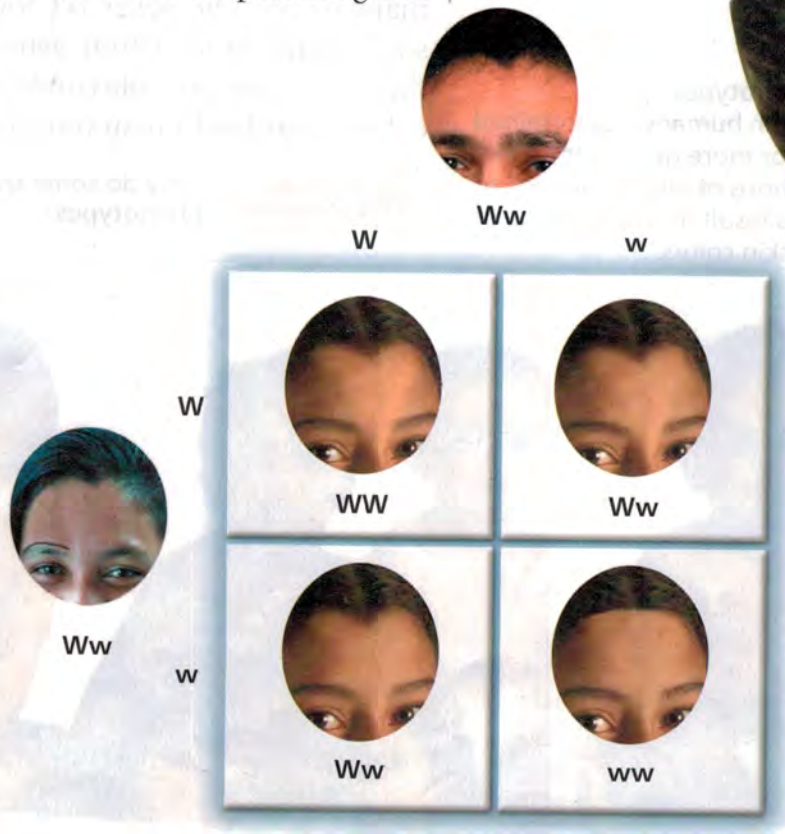


FIGURE 2
Widow's Peak Punnett Square
This Punnett square shows a cross between two parents with widow's peaks.
Interpreting Diagrams *What are the possible genotypes of the offspring? What percentage of the offspring will have each genotype?*

FIGURE 3
Inheritance of Blood Type
Blood type is determined by a single gene with three alleles. This chart shows which combinations of alleles result in each blood type.

Alleles of Blood Types	
Blood Type	**Combination of Alleles**
A	I^AI^A or I^Ai
B	I^BI^B or I^Bi
AB	I^AI^B
O	ii

Single Genes With Multiple Alleles

Some human traits are controlled by a single gene that has more than two alleles. Such a gene is said to have **multiple alleles**—three or more forms of a gene that code for a single trait. Even though a gene may have multiple alleles, a person can carry only two of those alleles. This is because chromosomes exist in pairs. Each chromosome in a pair carries only one allele for each gene.

Human blood type is controlled by a gene with multiple alleles. There are four main blood types—A, B, AB, and O. Three alleles control the inheritance of blood types. The allele for blood type A and the allele for blood type B are codominant. The allele for blood type A is written as I^A. The allele for blood type B is written I^B. The allele for blood type O—written i—is recessive. Recall that when two codominant alleles are inherited, neither allele is masked. A person who inherits an I^A allele from one parent and an I^B allele from the other parent will have type AB blood. Figure 3 shows the allele combinations that result in each blood type. Notice that only people who inherit two i alleles have type O blood.

Traits Controlled by Many Genes

If you completed the Discover activity, you saw that height in humans has more than two distinct phenotypes. In fact, there is an enormous variety of phenotypes for height. Some human traits show a large number of phenotypes because the traits are controlled by many genes. The genes act together as a group to produce a single trait. At least four genes control height in humans, so there are many possible combinations of genes and alleles. Skin color is another human trait that is controlled by many genes.

Reading Checkpoint **Why do some traits exhibit a large number of phenotypes?**

FIGURE 4
Many Phenotypes
Skin color in humans is determined by three or more genes. Different combinations of alleles for each of the genes result in a wide range of possible skin colors.

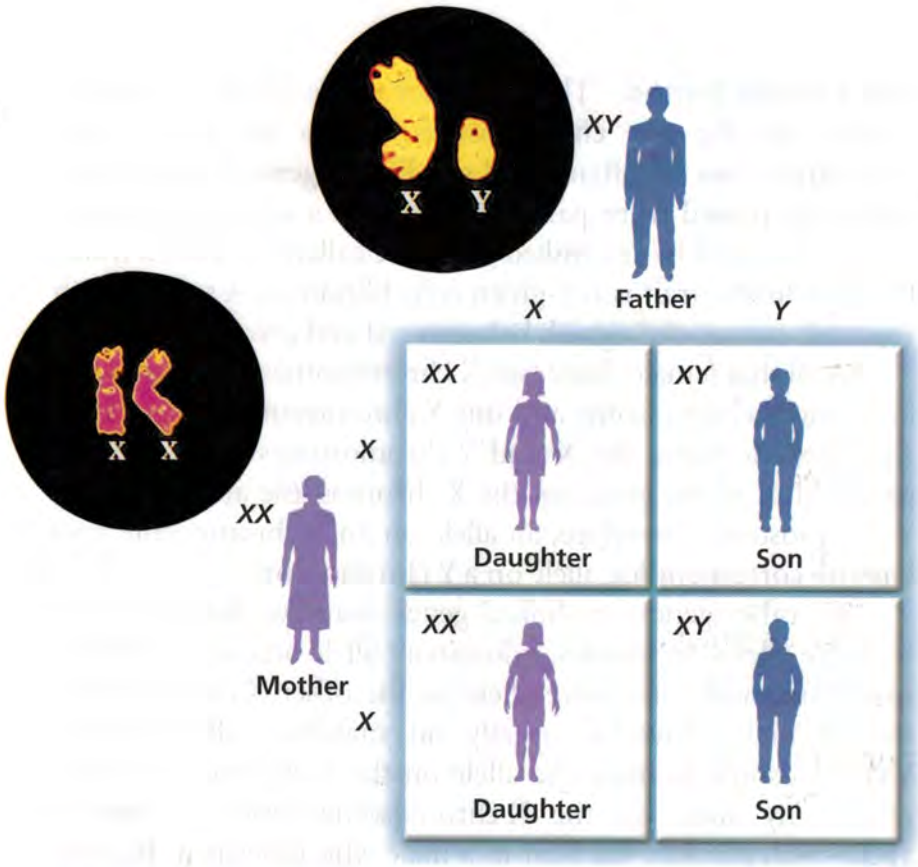


FIGURE 5
Male or Female?
As this Punnett square shows, there is a 50 percent probability that a child will be a girl and a 50 percent probability that a child will be a boy.
Interpreting Diagrams *What sex will the child be if a sperm with a Y chromosome fertilizes an egg?*

The Sex Chromosomes

The **sex chromosomes** are one of the 23 pairs of chromosomes in each body cell. **The sex chromosomes carry genes that determine whether a person is male or female. They also carry genes that determine other traits.**

Girl or Boy? The sex chromosomes are the only chromosome pair that do not always match. If you are a girl, your two sex chromosomes match. The two chromosomes are called X chromosomes. If you are a boy, your sex chromosomes do not match. One of them is an X chromosome, and the other is a Y chromosome. The Y chromosome is much smaller than the X chromosome.

Sex Chromosomes and Fertilization What happens to the sex chromosomes when egg and sperm cells form? Since both of a female's sex chromosomes are X chromosomes, all eggs carry one X chromosome. Males, however, have two different sex chromosomes. Therefore, half of a male's sperm cells carry an X chromosome, while half carry a Y chromosome.

When a sperm cell with an X chromosome fertilizes an egg, the egg has two X chromosomes. The fertilized egg will develop into a girl. When a sperm with a Y chromosome fertilizes an egg, the egg has one X chromosome and one Y chromosome. The fertilized egg will develop into a boy.

Lab zone **Try This Activity**

The Eyes Have It

One inherited trait is eye dominance—the tendency to use one eye more than the other. Here's how you can test yourself for this trait.

1. Hold your hand out in front of you at arm's length. Point your finger at an object across the room.
2. Close your right eye. With only your left eye open, observe how far your finger appears to move.
3. Repeat Step 2 with the right eye open. With which eye did your finger seem to remain closer to the object? That eye is dominant.

Designing Experiments
Is eye dominance related to hand dominance—whether a person is right-handed or left-handed? Design an experiment to find out. *Obtain your teacher's permission before carrying out your experiment.*

Sex-Linked Genes The genes for some human traits are carried on the sex chromosomes. Genes on the X and Y chromosomes are often called **sex-linked genes** because their alleles are passed from parent to child on a sex chromosome. Traits controlled by sex-linked genes are called sex-linked traits. One sex-linked trait is red-green colorblindness. A person with this trait cannot distinguish between red and green.

Recall that females have two X chromosomes, whereas males have one X chromosome and one Y chromosome. Unlike most chromosome pairs, the X and Y chromosomes have different genes. Most of the genes on the X chromosome are not on the Y chromosome. Therefore, an allele on an X chromosome may have no corresponding allele on a Y chromosome.

Like other genes, sex-linked genes can have dominant and recessive alleles. In females, a dominant allele on one X chromosome will mask a recessive allele on the other X chromosome. But in males, there is usually no matching allele on the Y chromosome to mask the allele on the X chromosome. As a result, any allele on the X chromosome—even a recessive allele—will produce the trait in a male who inherits it. Because males have only one X chromosome, males are more likely than females to have a sex-linked trait that is controlled by a recessive allele.

FIGURE 6
Colorblindness
The lower photo shows how a red barn and green fields look to a person with red-green colorblindness.

Normal vision

Red-green colorblind vision

FIGURE 8
Heredity and Environment
When a person plays a violin, genetically determined traits such as muscle coordination interact with environmental factors such as time spent in practice.

The Effect of Environment

In humans and other organisms, the effects of genes are often influenced by the environment—an organism's surroundings. **Many of a person's characteristics are determined by an interaction between genes and the environment.**

You have learned that several genes work together to help determine human height. However, people's heights are also influenced by their environments. People's diets can affect their height. A diet lacking in protein, certain minerals, or certain vitamins can prevent a person from growing as tall as might be possible.

Environmental factors can also affect human skills, such as playing a musical instrument. For example, physical traits such as muscle coordination and a good sense of hearing will help a musician play well. But the musician also needs instruction on how to play the instrument. Musical instruction is an environmental factor.

Reading Checkpoint **How can environmental factors affect a person's height?**

Section 1 Assessment

Target Reading Skill **Identifying Main Ideas**
Use your graphic organizer to help you answer Question 1 below.

Reviewing Key Concepts

1. a. **Identifying** Identify three patterns of inheritance in humans. Give an example of a trait that follows each pattern.
   b. **Summarizing** How many human blood types are there? Summarize how blood type is inherited.
   c. **Drawing Conclusions** Aaron has blood type O. Can either of his parents have blood type AB? Explain your answer.
2. a. **Reviewing** What are the functions of the sex chromosomes?
   b. **Comparing and Contrasting** Contrast the sex chromosomes found in human females and human males.
   c. **Relating Cause and Effect** Explain how red-green colorblindness is inherited. Why is the condition more common in males than in females?
3. a. **Reviewing** Are a person's characteristics determined only by genes? Explain.
   b. **Applying Concepts** Explain what factors might work together to enable a great soccer player to kick a ball a long distance.

Writing in Science

Heredity and Environment Think of an ability you admire, such as painting, dancing, snowboarding, or playing games skillfully. Write a paragraph explaining how genes and the environment might work together to enable a person to develop this ability.

Inheritance of Colorblindness Colorblindness is a trait controlled by a recessive allele on the X chromosome. Many more males than females have red-green colorblindness. You can understand why this is the case by examining the Punnett square in Figure 7. Both parents in this example have normal color vision. Notice, however, that the mother is a carrier of colorblindness. A **carrier** is a person who has one recessive allele for a trait and one dominant allele. A carrier of a trait controlled by a recessive allele does not have the trait. However, the carrier can pass the recessive allele on to his or her offspring. In the case of sex-linked traits, only females can be carriers.

As you can see in Figure 7, there is a 25 percent probability that this couple will have a colorblind child. Notice that none of the couple's daughters will be colorblind. On the other hand, the sons have a 50 percent probability of being colorblind. For a female to be colorblind, she must inherit two recessive alleles for colorblindness, one from each parent. A male needs to inherit only one recessive allele. This is because there is no gene for color vision on the Y chromosome. Thus, there is no allele that could mask the recessive allele on the X chromosome.

Reading Checkpoint **What is the sex of a person who is a carrier for colorblindness?**

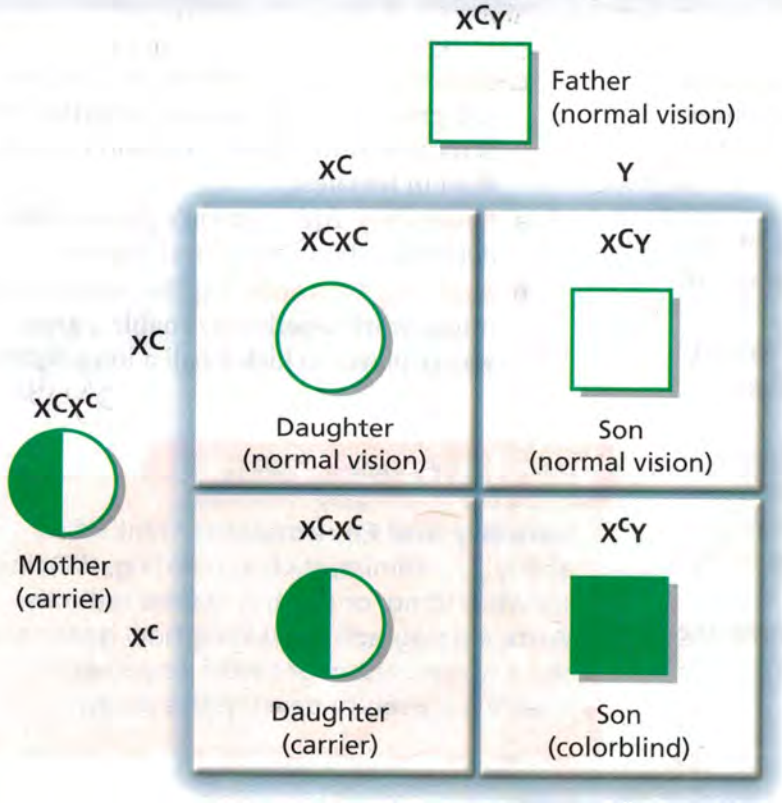


FIGURE 7
Colorblindness Punnett Square
Red-green colorblindness is a sex-linked trait. A girl who receives only one recessive allele (written X^c) for red-green colorblindness will not have the trait. However, a boy who receives one recessive allele will be colorblind.
Applying Concepts *What allele combination would a daughter need to inherit to be colorblind?*

Section 2

Human Genetic Disorders

Reading Preview

Key Concepts

- What are two major causes of genetic disorders in humans?
- How do geneticists trace the inheritance of traits?
- How are genetic disorders diagnosed and treated?

Key Terms

- genetic disorder
- pedigree
- karyotype

Target Reading Skill

Comparing and Contrasting

As you read, compare and contrast the types of genetic disorders by completing a table like the one below.

Disorder	Description	Cause
Cystic fibrosis	Abnormally thick mucus	Loss of three DNA bases

Lab zone

Discover Activity

How Many Chromosomes?

The photo at right shows the chromosomes from a cell of a person with Down syndrome, a genetic disorder. The chromosomes have been sorted into pairs.

1. Count the number of chromosomes in the photo.
2. How does the number of chromosomes compare to the usual number of chromosomes in human cells?

Think It Over

Inferring How do you think a cell could have ended up with this number of chromosomes? (*Hint:* Think about the events that occur during meiosis.)

The air inside the stadium was hot and still. The crowd cheered loudly as the runners approached the starting blocks. At the crack of the starter's gun, the runners leaped into motion and sprinted down the track. Seconds later, the race was over. The runners, bursting with pride, hugged each other and their coaches. These athletes were running in the Special Olympics, a competition for people with disabilities. Many of the athletes who compete in the Special Olympics have disabilities that result from genetic disorders.

◀ Runners in the Special Olympics

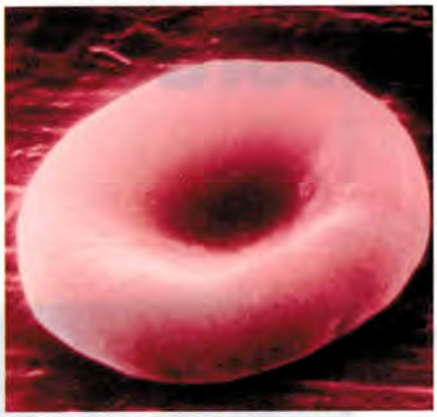


FIGURE 9
Sickle-Cell Disease
Normally, red blood cells are shaped like round disks (top). In a person with sickle-cell disease, red blood cells can become sickle-shaped (bottom).

Lab zone Skills Activity

Predicting

A man has sickle-cell disease. His wife does not have the disease, but is heterozygous for the sickle-cell trait. Predict the probability that their child will have sickle-cell disease. (*Hint:* Construct a Punnett square.)

Causes of Genetic Disorders

A **genetic disorder** is an abnormal condition that a person inherits through genes or chromosomes. **Some genetic disorders are caused by mutations in the DNA of genes. Other disorders are caused by changes in the overall structure or number of chromosomes.** In this section, you will learn about some common genetic disorders.

Cystic Fibrosis Cystic fibrosis is a genetic disorder in which the body produces abnormally thick mucus in the lungs and intestines. The thick mucus fills the lungs, making it hard for the affected person to breathe. Cystic fibrosis is caused by a recessive allele on one chromosome. The recessive allele is the result of a mutation in which three bases are removed from a DNA molecule.

Sickle-Cell Disease Sickle-cell disease affects hemoglobin, a protein in red blood cells that carries oxygen. When oxygen concentrations are low, the red blood cells of people with the disease have an unusual sickle shape. Sickle-shaped red blood cells clog blood vessels and cannot carry as much oxygen as normal cells. The allele for the sickle-cell trait is codominant with the normal allele. A person with two sickle-cell alleles will have the disease. A person with one sickle-cell allele will produce both normal hemoglobin and abnormal hemoglobin. This person usually will not have symptoms of the disease.

Hemophilia Hemophilia is a genetic disorder in which a person's blood clots very slowly or not at all. People with the disorder do not produce one of the proteins needed for normal blood clotting. The danger of internal bleeding from small bumps and bruises is very high. Hemophilia is caused by a recessive allele on the X chromosome. Because hemophilia is a sex-linked disorder, it occurs more frequently in males than in females.

Down Syndrome In Down syndrome, a person's cells have an extra copy of chromosome 21. In other words, instead of a pair of chromosomes, a person with Down syndrome has three of that chromosome. Down syndrome most often occurs when chromosomes fail to separate properly during meiosis. People with Down syndrome have some degree of mental retardation. Heart defects are also common, but can be treated.

Reading Checkpoint **How is the DNA in the sickle-cell allele different from the normal allele?**

Pedigrees

Imagine that you are a geneticist who is interested in tracing the occurrence of a genetic disorder through several generations of a family. What would you do? **One important tool that geneticists use to trace the inheritance of traits in humans is a pedigree.** A **pedigree** is a chart or "family tree" that tracks which members of a family have a particular trait.

The trait in a pedigree can be an ordinary trait, such as a widow's peak, or a genetic disorder, such as cystic fibrosis. Figure 10 shows a pedigree for albinism, a condition in which a person's skin, hair, and eyes lack normal coloring.

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FIGURE 10
A Pedigree

The father in the photograph has albinism. The pedigree shows the inheritance of the allele for albinism in three generations of a family. **Interpreting Diagrams** *Where is an albino male shown in the pedigree?*

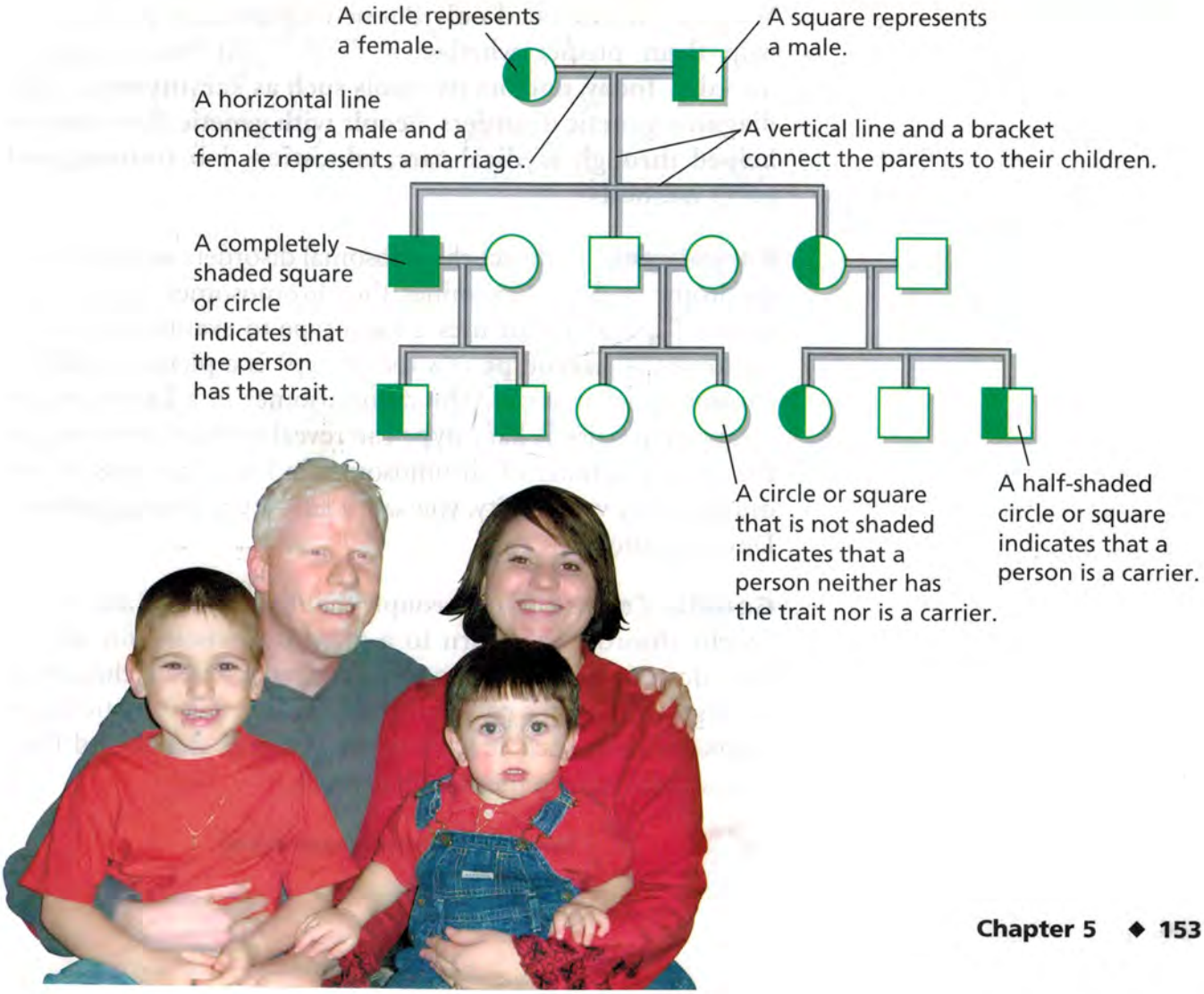
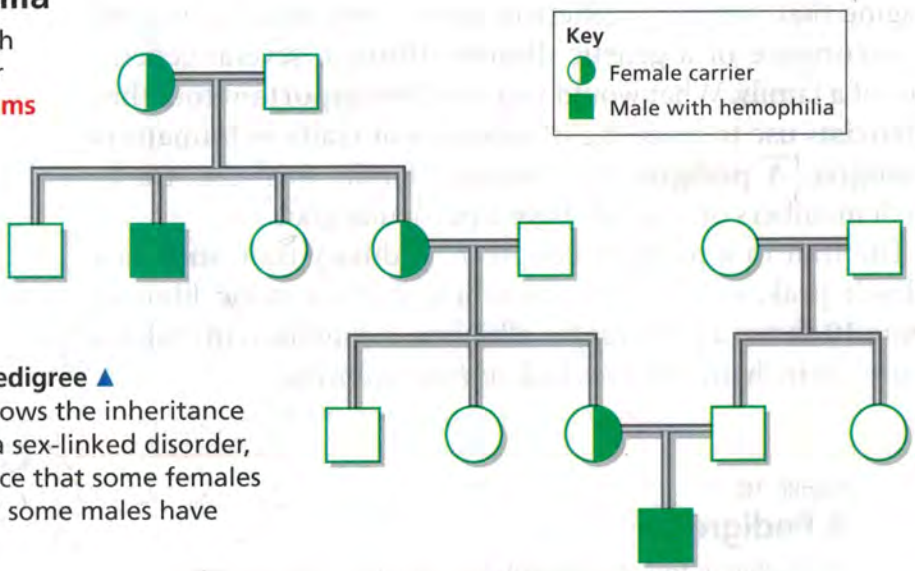


FIGURE 11

Living With Hemophilia

With proper care, people with hemophilia can manage their disorder. **Interpreting Diagrams** *In the pedigree, how many people have hemophilia?*



A Hemophilia Pedigree ▲
The pedigree shows the inheritance of hemophilia, a sex-linked disorder, in a family. Notice that some females are carriers, and some males have the disorder.

Managing Genetic Disorders

Years ago, doctors had only Punnett squares and pedigrees to help them predict whether a child might have a genetic disorder. **Today, doctors use tools such as karyotypes to help diagnose genetic disorders. People with genetic disorders are helped through medical care, education, job training, and other methods.**

Karyotypes To detect chromosomal disorders such as Down syndrome, a doctor examines the chromosomes from a person's cells. The doctor uses a karyotype to examine the chromosomes. A **karyotype** (KA ree uh typ) is a picture of all the chromosomes in a cell. The chromosomes in a karyotype are arranged in pairs. A karyotype can reveal whether a person has the correct number of chromosomes in his or her cells. If you did the Discover activity, you saw a karyotype from a girl with Down syndrome.

Genetic Counseling A couple that has a family history of a genetic disorder may turn to a genetic counselor for advice. Genetic counselors help couples understand their chances of having a child with a particular genetic disorder. Genetic counselors use tools such as karyotypes, pedigree charts, and Punnett squares to help them in their work.

Reading Checkpoint **What do genetic counselors do?**

Physical Therapy ▶ Trained medical workers help hemophilia patients cope with their disorder. Here, a boy receives physical therapy.

Sports ▶ A boy with hemophilia learns how to play golf. The disorder does not stop people from living active lives.

Dealing With Genetic Disorders People with genetic disorders face serious challenges, but help is available. Medical treatments help people with some disorders. For example, physical therapy helps remove mucus from the lungs of people with cystic fibrosis. People with sickle-cell disease take folic acid, a vitamin, to help their bodies manufacture red blood cells. Because of education and job training, adults with Down syndrome can find work in hotels, banks, restaurants, and other places of employment. Fortunately, most genetic disorders do not prevent people from living active, productive lives.

Section 2 Assessment

Target Reading Skill

Comparing and Contrasting Use the information in your table to help you answer Question 1 below.

Reviewing Key Concepts

1. a. **Identifying** Identify the two major causes of genetic disorders in humans.
   b. **Explaining** Which of those two major causes is responsible for Down syndrome?
   c. **Describing** How are the cells of a person with Down syndrome different from those of a person without the disorder?
2. a. **Defining** What is a pedigree?
   b. **Inferring** Why are pedigrees helpful in understanding genetic disorders?
   c. **Applying Concepts** Sam has hemophilia. Sam's brother, mother, and father do not have hemophilia. Draw a pedigree showing who has the disorder and who is a carrier.
3. a. **Reviewing** What is a karyotype?
   b. **Inferring** Would a karyotype reveal the presence of sickle-cell disease? Why or why not?

Writing in Science

Creating a Web Site Create an imaginary Web site to inform the public about genetic disorders. Write a description of one disorder for the Web site.

Lab zone **Skills Lab**

Family Puzzle

Problem

A husband and wife want to understand the probability that their children might inherit cystic fibrosis. How can you use the information in the box labeled Case Study to predict the probability?

Skills Focus

interpreting data, predicting

Materials

• 12 index cards • scissors • marker

Procedure

1. Read the Case Study. In your notebook, draw a pedigree that shows all the family members. Use circles to represent the females, and squares to represent the males. Shade in the circles or squares representing the individuals who have cystic fibrosis.
2. You know that cystic fibrosis is controlled by a recessive allele. To help you figure out Joshua and Bella's family pattern, create a set of cards to represent the alleles. Cut each of six index cards into four smaller cards. On 12 of the small cards, write *N* to represent the dominant normal allele. On the other 12 small cards, write *n* for the recessive allele.

Case Study: Joshua and Bella

- Joshua and Bella have a son named Ian. Ian has been diagnosed with cystic fibrosis.
- Joshua and Bella are both healthy.
- Bella's parents are both healthy.
- Joshua's parents are both healthy.
- Joshua's sister, Sara, has cystic fibrosis.

3. Begin by using the cards to represent Ian's alleles. Since he has cystic fibrosis, what alleles must he have? Write in this genotype next to the pedigree symbol for Ian.
4. Joshua's sister, Sara, also has cystic fibrosis. What alleles does she have? Write in this genotype next to the pedigree symbol that represents Sara.
5. Now use the cards to figure out what genotypes Joshua and Bella must have. Write their genotypes next to their symbols in the pedigree.
6. Work with the cards to figure out the genotypes of all other family members. Fill in each person's genotype next to his or her symbol in the pedigree. If more than one genotype is possible, write in both genotypes.

Analyze and Conclude

1. **Interpreting Data** What were the possible genotypes of Joshua's parents? What were the genotypes of Bella's parents?
2. **Predicting** Joshua also has a brother. What is the probability that he has cystic fibrosis? Explain.
3. **Communicating** Imagine that you are a genetic counselor. A couple asks why you need information about many generations of their families to draw conclusions about a hereditary condition. Write an explanation you can give to them.

More to Explore

Review the pedigree that you just studied. What data suggest that the traits are not sex-linked? Explain.

Section 3

Tech & Design

Advances in Genetics

Reading Preview

Key Concepts

- What are three ways of producing organisms with desired traits?
- What is the goal of the Human Genome Project?

Key Terms

- selective breeding
- inbreeding • hybridization
- clone • genetic engineering
- gene therapy • genome

Target Reading Skill

Asking Questions Before you read, preview the red headings. In a graphic organizer like the one below, ask a question for each heading. As you read, write answers to your questions.

Advances in Genetics

Question	Answer
What is selective breeding?	Selective breeding is . . .

Lab zone Discover Activity

What Do Fingerprints Reveal?

1. Label a sheet of paper with your name. Then roll one of your fingers from side to side on an ink pad. Make a fingerprint by carefully rolling your inked finger on the paper.
2. Divide into groups. Each group should choose one member to use the same finger to make a second fingerprint on a sheet of paper. Leave the paper unlabeled.
3. Exchange your group's fingerprints with those from another group. Compare each labeled fingerprint with the fingerprint on the unlabeled paper. Decide whose fingerprint it is.
4. Wash your hands after completing this activity.

Think It Over

Observing Why are fingerprints used to identify people?

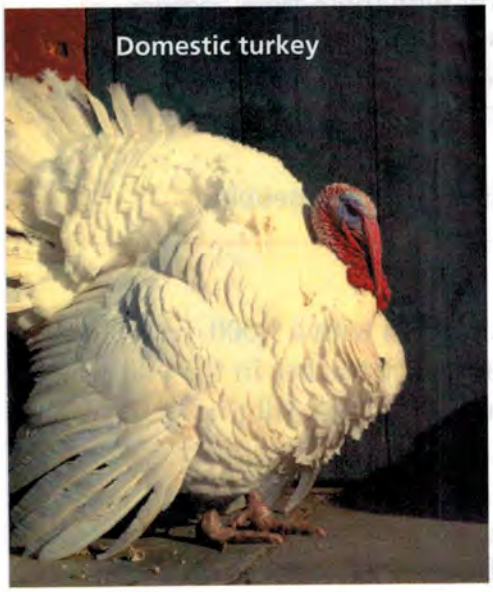
Would you like to have your picture taken with a 9,000-year-old family member? Adrian Targett, a history teacher in the village of Cheddar in England, has actually done that. All that's left of his ancient relative, known as "Cheddar Man," is a skeleton. The skeleton was discovered in a cave near the village. DNA analysis indicates that Targett and Cheddar Man are relatives.

Like your fingerprints, your DNA is different from everyone else's. Because of advances in genetics, DNA evidence can show many things, such as family relationships.

FIGURE 12
Distant Relatives
Adrian Targett visits his distant relative, Cheddar Man. Unfortunately, Cheddar Man cannot respond to questions about life 9,000 years ago.

FIGURE 13
Inbreeding
Turkeys such as the one with white feathers were developed by inbreeding. Breeders started with wild turkeys.

Wild turkey



Selective Breeding

Genetic techniques have enabled people to produce organisms with desirable traits. **Selective breeding, cloning, and genetic engineering are three methods for developing organisms with desirable traits.**

The process of selecting organisms with desired traits to be parents of the next generation is called **selective breeding.** Thousands of years ago, in what is now Mexico, the food that we call corn was developed in this way. Every year, farmers saved seeds from the healthiest plants that produced the best food. In the spring, they planted those seeds. By repeating this process over and over, farmers developed plants that produced better corn. People have used selective breeding with many different plants and animals. Two selective breeding techniques are inbreeding and hybridization.

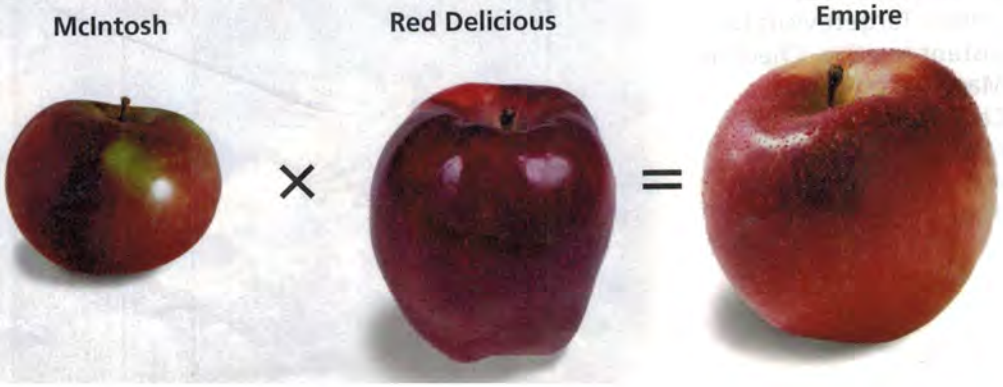
Inbreeding The technique of **inbreeding** involves crossing two individuals that have similar characteristics. For example, suppose a male and a female turkey are both plump and grow quickly. Their offspring will probably also have those desirable qualities. Inbred organisms have alleles that are very similar to those of their parents.

Inbred organisms are genetically very similar. Therefore, inbreeding increases the probability that organisms may inherit alleles that lead to genetic disorders. For example, inherited hip problems are common in many breeds of dogs.

Hybridization In **hybridization** (hy brid ih ZAY shun), breeders cross two genetically different individuals. The hybrid organism that results is bred to have the best traits from both parents. For example, a farmer might cross corn that produces many kernels with corn that is resistant to disease. The result might be a hybrid corn plant with both of the desired traits.

Reading Checkpoint **What is the goal of hybridization?**

FIGURE 14
Hybridization
McIntosh and Red Delicious apples were crossed to produce Empire apples.
Applying Concepts *What desirable traits might breeders have been trying to produce?*



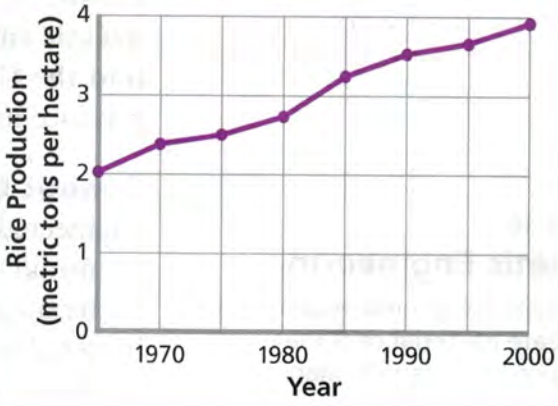
Math Analyzing Data

Changing Rice Production

The graph shows how worldwide rice production changed between 1965 and 2000. New, hybrid varieties of rice plants are one factor that has affected the amount of rice produced.

1. **Reading Graphs** According to the graph, how did rice production change between 1965 and 2000?
2. **Reading Graphs** How many metric tons of rice per hectare were produced in 1965? How many were produced in 2000?
3. **Calculating** Calculate the approximate difference between rice production in 1965 and 2000.

Worldwide Rice Production



4. **Developing Hypotheses** What factors besides new varieties of plants might help account for the difference in rice production between 1965 and 2000?

Cloning

For some organisms, a technique called cloning can be used to produce offspring with desired traits. A **clone** is an organism that has exactly the same genes as the organism from which it was produced. It isn't hard to clone some kinds of plants, such as an African violet. Just cut a stem from one plant, and put the stem in soil. Water it, and soon you will have a whole new plant. The new plant is genetically identical to the plant from which the stem was cut.

Researchers have also cloned animals such as sheep and pigs. The methods for cloning these animals are complex. They involve taking the nucleus of an animal's body cell and using that nucleus to produce a new animal.

Reading Checkpoint **How can a clone of a plant be produced?**

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Modern Genetics

Video Preview
▶ Video Field Trip
Video Assessment

FIGURE 15
Cloned Goats
These goats were produced by cloning.

Genetic Engineering

Geneticists have developed another powerful technique for producing organisms with desired traits. In this process, called **genetic engineering**, genes from one organism are transferred into the DNA of another organism. Genetic engineering can produce medicines and improve food crops.

Genetic Engineering in Bacteria One type of genetically engineered bacteria produces a protein called insulin. Injections of insulin are needed by many people with diabetes. Recall that bacteria have a single DNA molecule in the cytoplasm. Some bacterial cells also contain small circular pieces of DNA called plasmids. In Figure 16, you can see how scientists insert the DNA for a human gene into the plasmid of a bacterium.

FIGURE 16
Genetic Engineering
Scientists use genetic engineering to create bacterial cells that produce important human proteins such as insulin.
Interpreting Diagrams *How does a human insulin gene become part of a plasmid?*

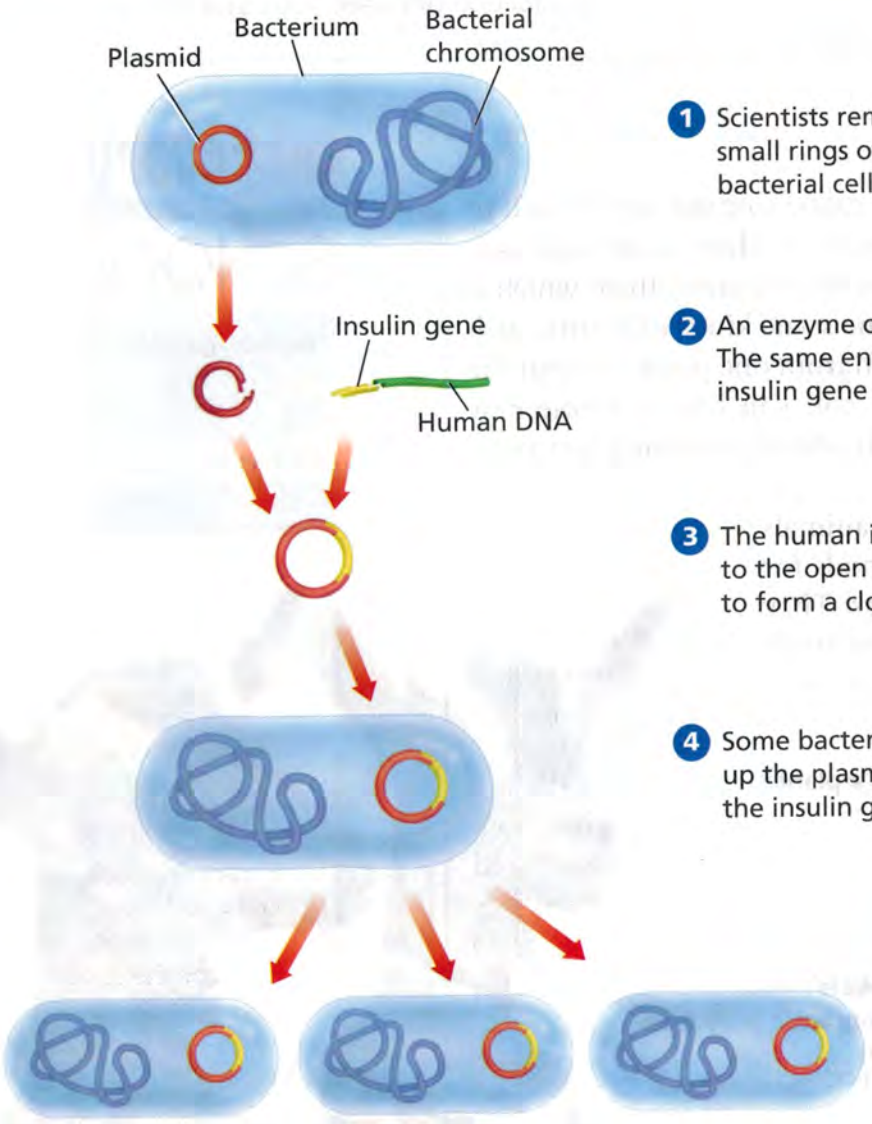


FIGURE 17
Genetically Engineered Fish
The bright red zebra danios are the result of genetic engineering.

Once the gene is inserted into the plasmid, the bacterial cell and all its offspring will contain this human gene. As a result, the bacteria produce the protein that the human gene codes for—in this case, insulin. Because bacteria reproduce quickly, large amounts of insulin can be produced in a short time.

Genetic Engineering in Other Organisms Scientists can also use genetic engineering techniques to insert genes into animals. For example, human genes can be inserted into the cells of cows. The cows then produce the human protein for which the gene codes in their milk. Scientists have used this technique to produce the blood clotting protein needed by people with hemophilia.

Genes have also been inserted into the cells of plants, such as tomatoes and rice. Some of the genes enable the plants to survive in cold temperatures or in poor soil. Other genetically engineered crops can resist insect pests.

Gene Therapy Someday it may be possible to use genetic engineering to correct some genetic disorders in humans. This process, called **gene therapy**, will involve inserting copies of a gene directly into a person's cells. For example, doctors may be able to treat hemophilia by replacing the defective allele on the X chromosome. The person's blood would then clot normally.

Concerns About Genetic Engineering Some people are concerned about the long-term effects of genetic engineering. For example, some people think that genetically engineered crops may not be entirely safe. People fear that these crops may harm the environment or cause health problems in humans. To address such concerns, scientists are trying to learn more about the effects of genetic engineering.

Reading Checkpoint **How do genetic engineering techniques enable scientists to produce clotting proteins?**

Go Online
SCILINKS NSTA
For: Links on genetic engineering
Visit: www.SciLinks.org
Web Code: scn-0343

Lab zone Skills Activity

Communicating

Suppose you work for a drug company that uses genetically engineered bacteria to produce insulin. Write an advertisement for the drug that includes a simplified explanation of how the drug is produced.

Learning About Human Genetics

Recent advances have enabled scientists to learn a great deal about human genetics. The Human Genome Project and DNA fingerprinting are two applications of this new knowledge.

The Human Genome Project Imagine trying to crack a code that is 6 billion letters long. That's exactly what the scientists working on the Human Genome Project did. A **genome** is all the DNA in one cell of an organism. **The main goal of the Human Genome Project was to identify the DNA sequence of every gene in the human genome.** In May 2006, the last chromosome in the human genome, chromosome 1, was sequenced. Scientists estimate that human DNA has between 20,000 and 25,000 genes. Analysis of the human genome, such as determining the exact location and function of each gene, could take several decades to complete.

DNA Fingerprinting DNA technology used in the Human Genome Project can also identify people and show whether people are related. DNA from a person's cells is broken down into small pieces, or fragments. Selected fragments are used to produce a pattern called a DNA fingerprint. Except for identical twins, no two people have exactly the same DNA fingerprint. You will learn more about DNA fingerprinting in Technology and Society.

Reading Checkpoint **About how many genes are in the human genome?**

FIGURE 18
The Human Genome Project
Scientists on the Human Genome Project continue to study human DNA.

Section 3 Assessment

Target Reading Skill **Asking Questions** Work with a partner to check your answers in your graphic organizer.

Reviewing Key Concepts

1. a. **Listing** List three methods that scientists can use to develop organisms with desirable traits.
   b. **Describing** Briefly describe each method.
   c. **Applying Concepts** Lupita has a houseplant. Which method would be the best way of producing a similar plant for a friend? Explain your answer.
2. a. **Defining** What is a genome?
   b. **Explaining** What is the Human Genome Project?
   c. **Relating Cause and Effect** How might knowledge gained from the Human Genome Project be used in gene therapy?

Lab zone At-Home Activity

Food and Selective Breeding Go to a grocery store with a parent or other family member. Discuss how fruits and vegetables have been produced by selective breeding. Choose a fruit or vegetable, and identify the traits that make it valuable.

Lab zone Skills Lab

Guilty or Innocent?

Problem

A crime scene may contain hair, skin, or blood from a criminal. These materials all contain DNA that can be used to make a DNA fingerprint. A DNA fingerprint, which consists of a series of bands, is something like a bar code. How can a DNA fingerprint identify individuals?

Skills Focus

drawing conclusions, inferring

Materials

- 4–6 bar codes
- hand lens

Procedure

1. Look at the photograph of DNA band patterns shown at right. Each person's DNA produces a unique pattern of these bands.
2. Now look at the Universal Product Code, also called a bar code, shown below the DNA bands. A bar code can be used as a model of a DNA band pattern. Compare the bar code with the DNA bands to see what they have in common. Record your observations.
3. Suppose that a burglary has taken place, and you're the detective leading the investigation. Your teacher will give you a bar code that represents DNA from blood found at the crime scene. You arrange to have DNA samples taken from several suspects. Write a sentence describing what you will look for as you try to match each suspect's DNA to the DNA sample from the crime scene.
4. You will now be given bar codes representing DNA samples taken from the suspects. Compare those bar codes with the bar code that represents DNA from the crime scene.
5. Use your comparisons to determine whether any of the suspects was present at the crime scene.

Analyze and Conclude

1. **Drawing Conclusions** Based on your findings, were any of the suspects present at the crime scene? Support your conclusion with specific evidence.
2. **Inferring** Why do people's DNA patterns differ so greatly?
3. **Drawing Conclusions** How would your conclusions be affected if you learned that the suspect whose DNA matched the evidence had an identical twin?
4. **Communicating** Suppose you are a defense lawyer. DNA evidence indicates that the bloodstain at the scene of a crime belongs to your client. Do you think this DNA evidence should be enough to convict your client? Write a speech you might give to the jury in defense of your client.

More to Explore

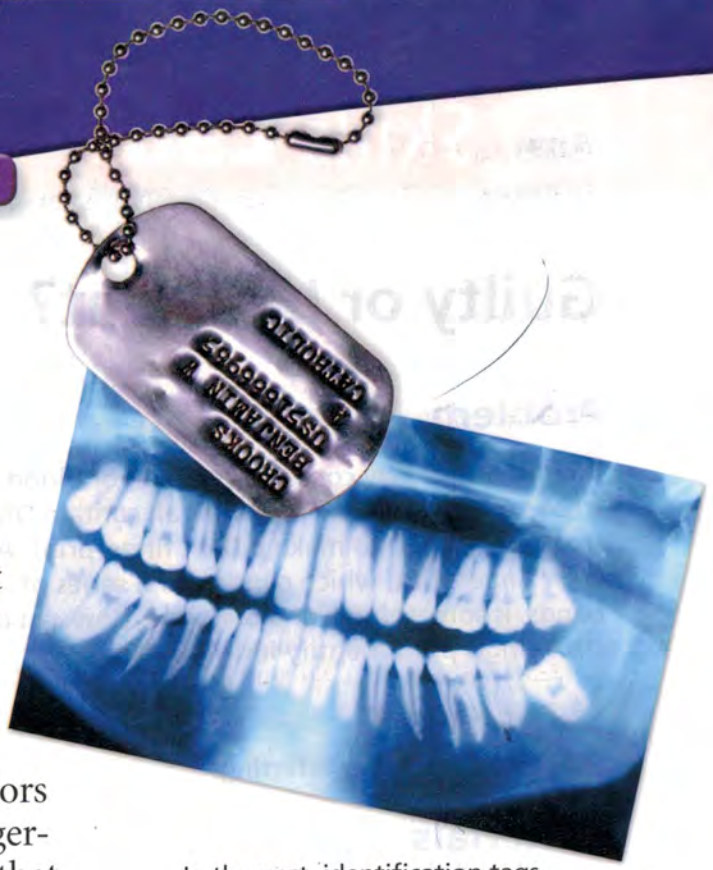
Do you think the DNA fingerprints of a parent and a child would show any similarities? Explain your thinking.

Technology and Society

• Tech & Design •

DNA Fingerprinting

What do you have that no one else has? Unless you are an identical twin, your DNA is unique. Because one person's DNA is like no one else's, it can be used to produce genetic "fingerprints." These fingerprints can tie a person to the scene of a crime. They can prevent the wrong person from going to jail. They can also be used to identify skeletal remains. Today, soldiers and sailors give blood and saliva samples so their DNA fingerprints can be saved. Like the identification tags that soldiers wear, DNA records can be used to identify the bodies of unknown soldiers or civilians.



In the past, identification tags and dental records were the main methods for identifying skeletal remains.

TTCGAATTCGAATTCTGAATTCTAGAATTCGAA

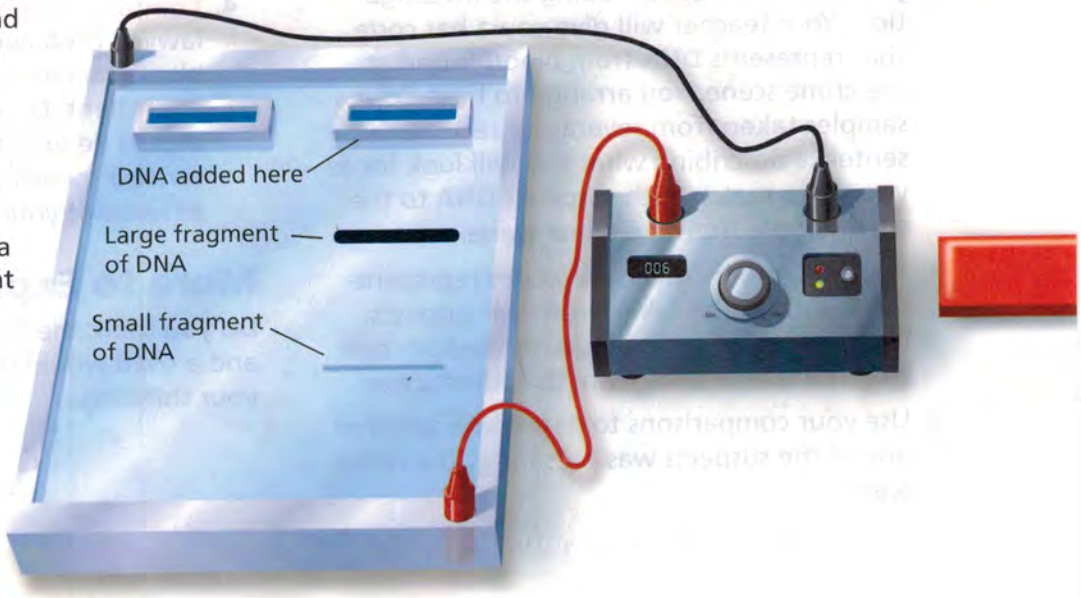
TTCG | AATTCG | AATTCTG | AATTCTAG | AATTCGAA

4 bases | 6 bases | 7 bases | 8 bases | 8 bases

This enzyme cuts the DNA every time it encounters the DNA sequence GAATTC.

1 After a sample of DNA is extracted from the body, an enzyme cuts the DNA strand into several smaller pieces.

2 The cut-up DNA fragments are loaded into a gel that uses electric current to separate fragments. Larger fragments of DNA move through the gel more slowly than the smaller fragments.



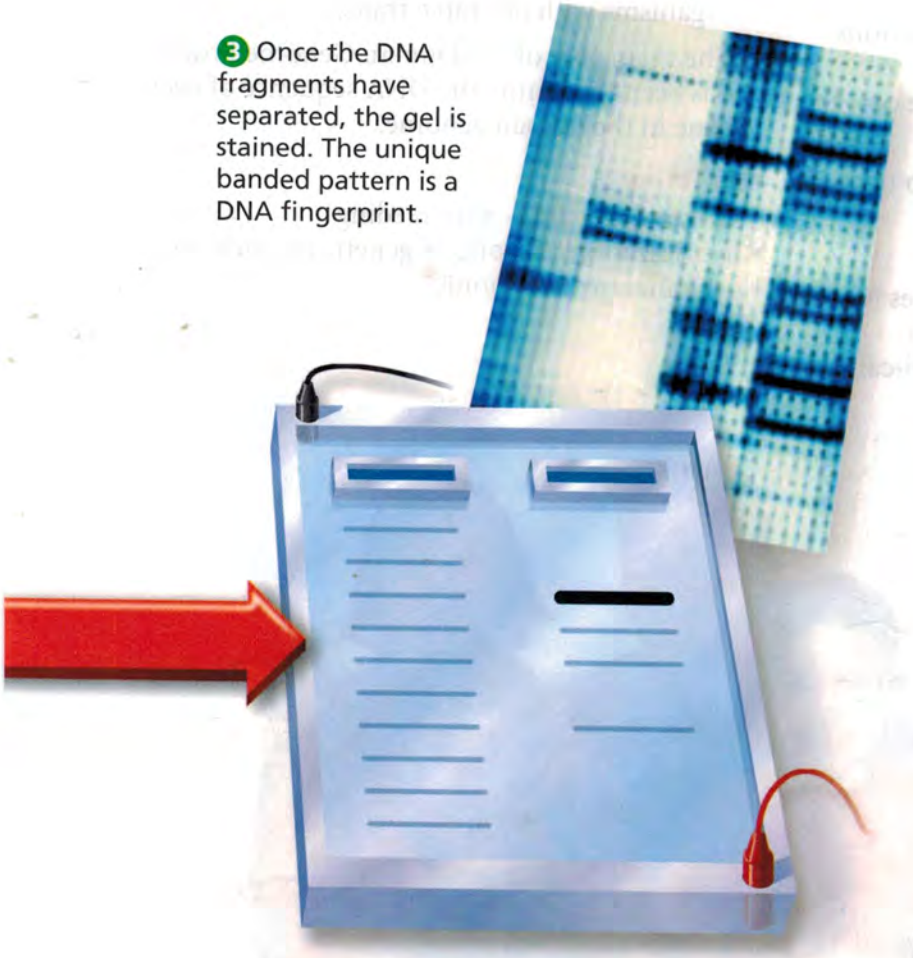
Analyzing DNA

In one method of DNA analysis, DNA from saliva, blood, bones, teeth, or other fluids or tissues is taken from cells. Special enzymes are added to cut the DNA into small pieces. Selected pieces are put into a machine that runs an electric current through the DNA and sorts the pieces by size. The DNA then gets stained and photographed. When developed, a unique banded pattern, similar to a product bar code, is revealed. The pattern can be compared to other samples of DNA to determine a match.

Limitations of DNA Fingerprinting

Like all technology, DNA fingerprinting has its limitations. DNA is very fragile and the films produced can be difficult to read if the DNA samples are old. In rare instances, DNA from the people testing the samples can become mixed in with the test samples and produce inaccurate results. DNA testing is also time consuming and expensive.

▲ Scientist reading a DNA fingerprint



3 Once the DNA fragments have separated, the gel is stained. The unique banded pattern is a DNA fingerprint.

Weigh the Impact

1. Identify the Need

Make a list of at least five situations in which DNA fingerprinting could be useful.

2. Research

Research the situations you listed in Question 1 to find out if DNA analysis is or can be used in each.

3. Write

Choose one application of DNA analysis and write one or two paragraphs to explain when the application can be used.

Go Online
PHSchool.com

For: More on DNA fingerprinting
Visit: PHSchool.com
Web Code: ceh-3040

Chapter 5

Study Guide

The BIG Idea **Science and Technology** Karyotyping, hybridization, cloning, genetic engineering, the Human Genome Project, and DNA fingerprinting are all science and technology applications that have advanced the study of genetics.

1 Human Inheritance

Key Concepts

- Some human traits are controlled by single genes with two alleles, and others by single genes with multiple alleles. Still other traits are controlled by many genes that act together.
- The sex chromosomes carry genes that determine whether a person is male or female. They also carry genes that determine other traits.
- Many of a person's characteristics are determined by an interaction between genes and the environment.

Key Terms

multiple alleles
sex chromosomes
sex-linked gene
carrier

2 Human Genetic Disorders

Key Concepts

- Some genetic disorders are caused by mutations in the DNA of genes. Other disorders are caused by changes in the overall structure or number of chromosomes.
- One important tool that geneticists use to trace the inheritance of traits in humans is a pedigree.
- Today doctors use tools such as karyotypes to help detect genetic disorders. People with genetic disorders are helped through medical care, education, job training, and other methods.

Key Terms

genetic disorder
pedigree
karyotype

3 Advances in Genetics

Key Concepts

- Selective breeding, cloning, and genetic engineering are three methods for developing organisms with desirable traits.
- The main goal of the Human Genome Project has been to identify the DNA sequence of every gene in the human genome.

Key Terms

• selective breeding • inbreeding
• hybridization • clone • genetic engineering
• gene therapy • genome

Review and Assessment

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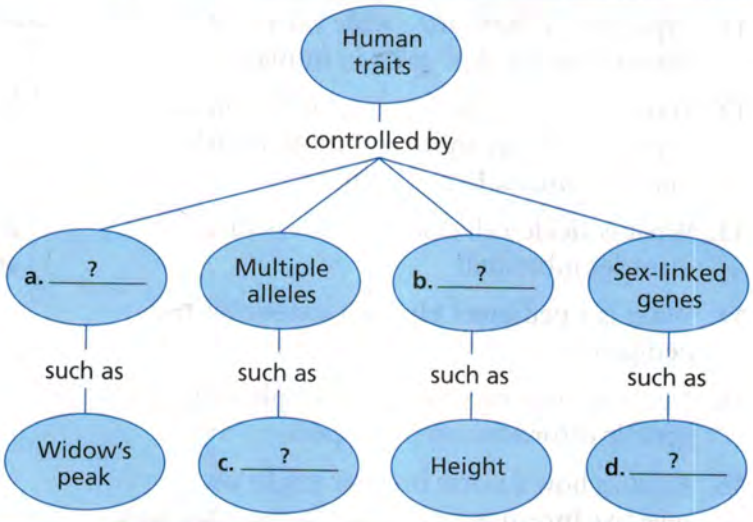
Visit: PHSchool.com
Web Code: cea-3040

Organizing Information

Concept Mapping Copy the concept map about human traits onto a separate sheet of paper. Then complete it and add a title. (For more on Concept Mapping, see the Skills Handbook.)



Reviewing Key Terms

Choose the letter of the best answer.

1. A human trait that is controlled by a single gene with multiple alleles is
   a. dimples. **b.** blood type.
   c. height. **d.** skin color.
2. A sex-linked disorder is
   a. cystic fibrosis.
   b. sickle-cell disease.
   c. hemophilia.
   d. Down syndrome.
3. Which of the following would most likely be used to diagnose Down syndrome?
   a. a karyotype
   b. a pedigree
   c. a blood-clotting test
   d. a Punnett square
4. Inserting a human gene into a bacterial plasmid is an example of
   a. inbreeding.
   b. selective breeding.
   c. DNA fingerprinting.
   d. genetic engineering.
5. An organism that has the same genes as the organism from which it was produced is called a
   a. clone. **b.** hybrid.
   c. genome. **d.** pedigree.

If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.

6. A widow's peak is a human trait that is controlled by a single gene.
7. A male inherits two X chromosomes.
8. A karyotype tracks which members of a family have a trait.
9. Hybridization is the crossing of two genetically similar organisms.
10. A genome is all the DNA in one cell of an organism.

Writing in Science

Fact Sheet You are a scientist in a cloning lab. Write a fact sheet that explains what the process of cloning involves. Describe at least one example.

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▶ Video Assessment

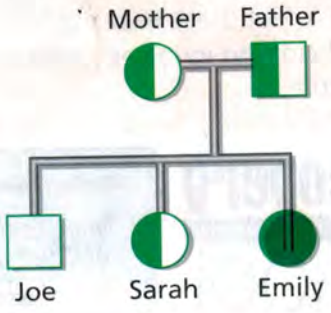
Review and Assessment

Checking Concepts

11. Explain why there are a wide variety of phenotypes for skin color in humans.
12. Traits controlled by recessive alleles on the X chromosome are more common in males than in females. Explain why.
13. What is sickle-cell disease? How is this disorder inherited?
14. What is a pedigree? How do geneticists use pedigrees?
15. Describe two ways in which people with genetic disorders can be helped.
16. Explain how a horse breeder might use selective breeding to produce horses that have golden coats.
17. Describe how gene therapy might be used in the future to treat a person with hemophilia.
18. What is the Human Genome Project?

Thinking Critically

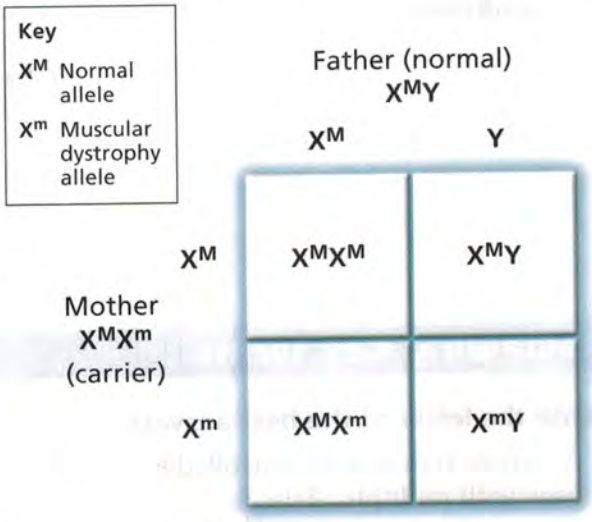
19. **Problem Solving** A woman with normal color vision has a colorblind daughter. What are the genotypes and phenotypes of both parents?
20. **Calculating** If a mother is a carrier of hemophilia and the father does not have hemophilia, what is the probability that their son will have the trait? Explain your answer.
21. **Interpreting Diagrams** The allele for cystic fibrosis is recessive. Identify which members of the family in the pedigree have cystic fibrosis and which are carriers.



Applying Skills

Use the Punnett square to answer Questions 22–24.

The Punnett square below shows how muscular dystrophy, a sex-linked recessive disorder, is inherited.



22. **Interpreting Data** What is the probability that a daughter of these parents will have muscular dystrophy? Explain your answer.
23. **Interpreting Data** What is the probability that a son of these parents will have muscular dystrophy? Explain your answer.
24. **Inferring** Is it possible for a woman to have muscular dystrophy? Why or why not?

Lab zone Chapter Project

Performance Assessment Present your display board to your class. Highlight important facts about the genetic trait you selected. Discuss the innovative designs you incorporated into the display board. In your presentation, highlight the interactive part of your project.