chapter 5

Heredity

The BIG Idea

Inherited genes determine an organism's traits.

Section 1
Genetics

Main Idea Using scientific methods, Gregor Mendel discovered the basic principles of genetics.

Section 2
Genetics Since Mendel

Main Idea It is now known that interactions among alleles, genes, and the environment determine an organism's traits.

Section 3
Advances in Genetics

Main Idea Through genetic engineering, scientists can change the DNA of organisms to improve them, increase resistance to insects and diseases, or produce medicines.

Why do people look different?

People have different skin colors, different kinds of hair, and different heights. Knowing how these differences are determined will help you predict when certain traits might appear. This will help you understand what causes hereditary disorders and how these are passed from generation to generation.

Science Journal Write three traits that you have and how you would determine how those traits were passed to you.

Ron Chapple/Getty Images

Start-Up Activities

Launch LAB

Who around you has dimples?

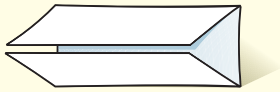
You and your best friend enjoy the same sports, like the same food, and even have similar haircuts. But, there are noticeable differences between your appearances. Most of these differences are controlled by the genes you inherited from your parents. In the following lab, you will observe one of these differences.

1. Notice the two students in the photographs. One student has dimples when she smiles, and the other student doesn't have dimples.
2. Ask your classmates to smile naturally. In your Science Journal, record the name of each classmate and whether each one has dimples.
3. **Think Critically** In your Science Journal, calculate the percentage of students who have dimples. Are facial dimples a common feature among your classmates?

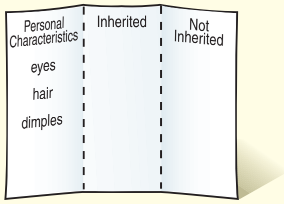
FOLDABLES™ Study Organizer

Classify Characteristics As you read this chapter about heredity, you can use the following Foldable to help you classify characteristics as inherited or not inherited.

STEP 1 **Fold** the top of a vertical piece of paper down and the bottom up to divide the paper into thirds.



STEP 2 **Turn** the paper horizontally; **unfold and label** the three columns as shown.



Read for Main Ideas Before you read the chapter, list personal characteristics and predict which are inherited or not inherited. As you read the chapter, check and change your list.

Science Online — Preview this chapter's content and activities at booka.msscience.com

Get Ready to Read

Visualize

1 Learn It! Visualize by forming mental images of the text as you read. Imagine how the text descriptions look, sound, feel, smell, or taste. Look for any pictures or diagrams on the page that may help you add to your understanding.

2 Practice It! Read the following paragraph. As you read, use the underlined details to form a picture in your mind.

> In a Punnett square for predicting one trait, the letters representing the two alleles from one parent are written along the top of the grid, one letter per section. Those of the second parent are placed down the side of the grid, one letter per section. Each square of the grid is filled in with one allele donated by each parent. The letters that you use to fill in each of the squares represent the genotypes of possible offspring that the parents could produce.
>
> —*from page 133*

Based on the description above, try to visualize a Punnett square. Now look at the *Applying Math* feature on page 133.

- How closely do these Punnett squares match your mental picture?
- Reread the passage and look at the picture again. Did your ideas change?
- Compare your image with what others in your class visualized.

3 Apply It! Read the chapter and list three subjects you were able to visualize. Make a rough sketch showing what you visualized.

Reading Tip

Forming your own mental images will help you remember what you read.

Target Your Reading

Use this to focus on the main ideas as you read the chapter.

1. **Before you read** the chapter, respond to the statements below on your worksheet or on a numbered sheet of paper.
   - Write an **A** if you **agree** with the statement.
   - Write a **D** if you **disagree** with the statement.

2. **After you read** the chapter, look back to this page to see if you've changed your mind about any of the statements.
   - If any of your answers changed, explain why.
   - Change any false statements into true statements.
   - Use your revised statements as a study guide.

Before You Read A or D		Statement	After You Read A or D
	1	The two alleles of a gene can be the same or different.	
	2	Alleles are either dominant or recessive.	
	3	An organism's phenotype determines its genotype.	
	4	A Punnett square shows the actual genetics of offspring from two parents.	
	5	Traits are determined by more than one gene.	
	6	Some organisms inherit extra chromosomes.	
	7	A pedigrees chart can show the inheritance of a trait within a family.	
	8	The female parent determines whether an offspring will be male or female.	
	9	Genetically engineered organisms can produce medicines.	
	10	Sex-linked disorders are more common in females than in males.	

Science Online

Print out a worksheet of this page at booka.msscience.com

section 1

Genetics

as you read

What You'll Learn

- **Explain** how traits are inherited.
- **Identify** Mendel's role in the history of genetics.
- **Use** a Punnett square to predict the results of crosses.
- **Compare and contrast** the difference between an individual's genotype and phenotype.

Why It's Important

Heredity and genetics help explain why people are different.

Review Vocabulary
meiosis: reproductive process that produces four haploid sex cells from one diploid cell

New Vocabulary
- heredity
- allele
- genetics
- hybrid
- dominant
- recessive
- Punnett square
- genotype
- phenotype
- homozygous
- heterozygous

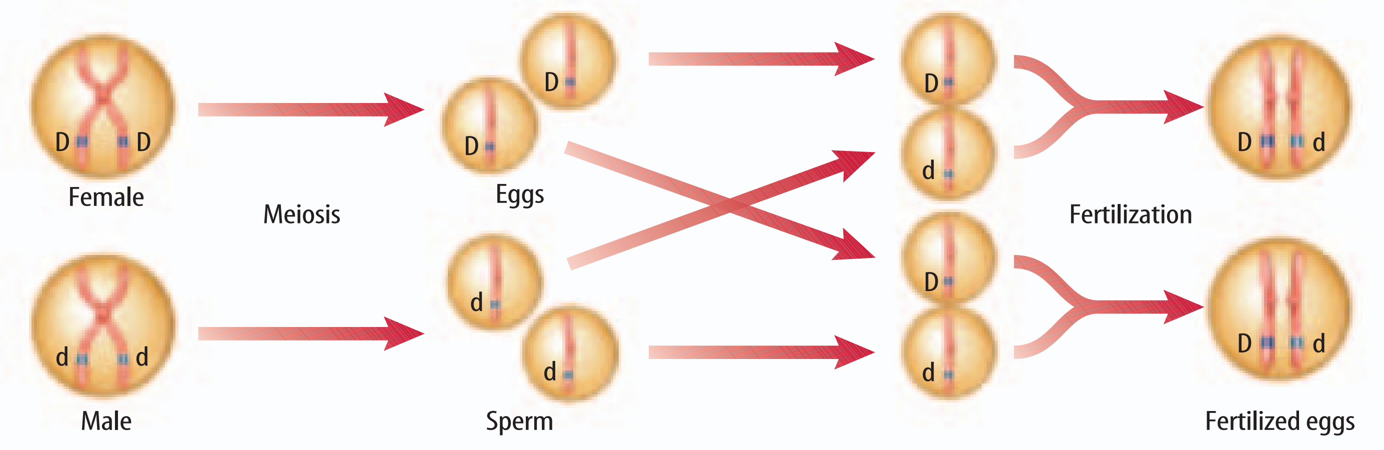
Inheriting Traits

Do you look more like one parent or grandparent? Do you have your father's eyes? What about Aunt Isabella's cheekbones? Eye color, nose shape, and many other physical features are some of the traits that are inherited from parents, as **Figure 1** shows. An organism is a collection of traits, all inherited from its parents. **Heredity** (huh REH duh tee) is the passing of traits from parent to offspring. What controls these traits?

What is genetics? Generally, genes on chromosomes control an organism's form and function or traits. The different forms of a trait that make up a gene pair are called **alleles** (uh LEELZ). When a pair of chromosomes separates during meiosis (mi OH sus), alleles for each trait also separate into different sex cells. As a result, every sex cell has one allele for each trait. In **Figure 2,** the allele in one sex cell controls one form of the trait for having facial dimples. The allele in the other sex cell controls a different form of the trait—not having dimples. The study of how traits are inherited through the interactions of alleles is the science of **genetics** (juh NE tihks).

Figure 1 Note the strong family resemblance among these four generations.

Figure 2 An allele is one form of a gene. Alleles separate into separate sex cells during meiosis. In this example, the alleles that control the trait for dimples include *D,* the presence of dimples, and *d,* the absence of dimples.



The alleles that control a trait are located on each duplicated chromosome.

During meiosis, duplicated chromosomes separate.

During fertilization, each parent donates one chromosome. This results in two alleles for the trait of dimples in the new individual formed.

Mendel—The Father of Genetics

Did you know that an experiment with pea plants helped scientists understand why your eyes are the color that they are? Gregor Mendel was an Austrian monk who studied mathematics and science but became a gardener in a monastery. His interest in plants began as a boy in his father's orchard where he could predict the possible types of flowers and fruits that would result from crossbreeding two plants. Curiosity about the connection between the color of a pea flower and the type of seed that same plant produced inspired him to begin experimenting with garden peas in 1856. Mendel made careful use of scientific methods, which resulted in the first recorded study of how traits pass from one generation to the next. After eight years, Mendel presented his results with pea plants to scientists.

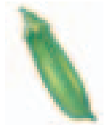
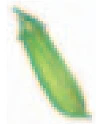
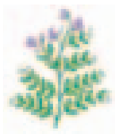
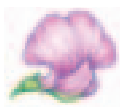
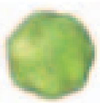
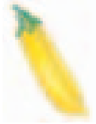
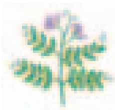
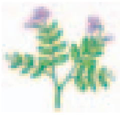
Before Mendel, scientists mostly relied on observation and description, and often studied many traits at one time. Mendel was the first to trace one trait through several generations. He was also the first to use the mathematics of probability to explain heredity. The use of math in plant science was a new concept and not widely accepted then. Mendel's work was forgotten for a long time. In 1900, three plant scientists, working separately, reached the same conclusions as Mendel. Each plant scientist had discovered Mendel's writings while doing his own research. Since then, Mendel has been known as the father of genetics.

Science Online

Topic: Genetics
Visit booka.msscience.com for Web links to information about early genetics experiments.

Activity List two other scientists who studied genetics, and what organism they used in their research.

Table 1 Traits Compared by Mendel

Traits	Shape of Seeds	Color of Seeds	Color of Pods	Shape of Pods	Plant Height	Position of Flowers	Flower Color
Dominant trait	Round 	Yellow	Green 	Full 	Tall 	At leaf junctions 	Purple 
Recessive trait	Wrinkled 	Green 	Yellow 	Flat, constricted 	short 	At tips of branches 	White 

Genetics in a Garden

Each time Mendel studied a trait, he crossed two plants with different expressions of the trait and found that the new plants all looked like one of the two parents. He called these new plants **hybrids** (HI brudz) because they received different genetic information, or different alleles, for a trait from each parent. The results of these studies made Mendel even more curious about how traits are inherited.

Garden peas are easy to breed for pure traits. An organism that always produces the same traits generation after generation is called a purebred. For example, tall plants that always produce seeds that produce tall plants are purebred for the trait of tall height. **Table 1** shows other pea plant traits that Mendel studied.

Reading Check *Why might farmers plant purebred crop seeds?*

Dominant and Recessive Factors In nature, insects randomly pollinate plants as they move from flower to flower. In his experiments, Mendel used pollen from the flowers of purebred tall plants to pollinate by hand the flowers of purebred short plants. This process is called cross-pollination. He found that tall plants crossed with short plants produced seeds that produced all tall plants. Whatever caused the plants to be short had disappeared. Mendel called the tall form the **dominant** (DAH muh nunt) factor because it dominated, or covered up, the short form. He called the form that seemed to disappear the **recessive** (rih SE sihv) factor. Today, these are called dominant alleles and recessive alleles. What happened to the recessive form? **Figure 3** answers this question.

Mini LAB

Comparing Common Traits

Procedure

1. Safely survey as many **dogs** in your neighborhood as you can for the presence of a solid color or spotted coat, short or long hair, and floppy or upright ears.
2. Make a data table that lists each of the traits. Record your data in the data table.

Analysis

1. Compare the number of dogs that have one form of a trait with those that have the other form.
2. What can you conclude about the variations you noticed in the dogs?

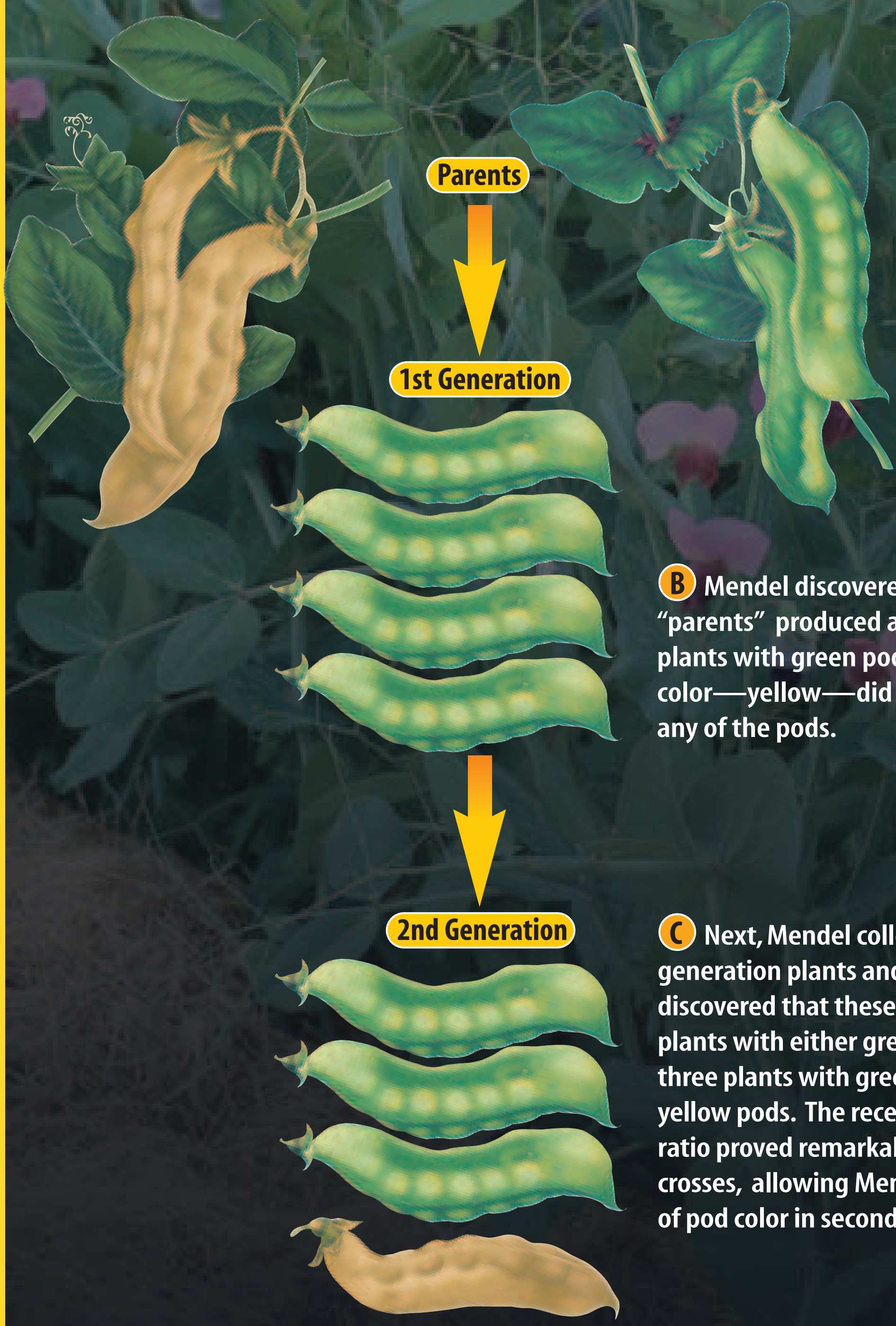
Try at Home

NATIONAL GEOGRAPHIC

VISUALIZING MENDEL'S EXPERIMENTS

Figure 3

Gregor Mendel discovered that the experiments he carried out on garden plants provided an understanding of heredity. For eight years he crossed plants that had different characteristics and recorded how those characteristics were passed from generation to generation. One such characteristic, or trait, was the color of pea pods. The results of Mendel's experiment on pea pod color are shown below.



A One of the so-called "parent plants" in Mendel's experiment had pods that were green, a dominant trait. The other parent plant had pods that were yellow, a recessive trait.

B Mendel discovered that the two "parents" produced a generation of plants with green pods. The recessive color—yellow—did not appear in any of the pods.

C Next, Mendel collected seeds from the first-generation plants and raised a second generation. He discovered that these second-generation plants produced plants with either green or yellow pods in a ratio of about three plants with green pods for every one plant with yellow pods. The recessive trait had reappeared. This 3:1 ratio proved remarkably consistent in hundreds of similar crosses, allowing Mendel to accurately predict the ratio of pod color in second-generation plants.

Using Probability to Make Predictions If you and your sister can't agree on what movie to see, you could solve the problem by tossing a coin. When you toss a coin, you're dealing with probabilities. Probability is a branch of mathematics that helps you predict the chance that something will happen. If your sister chooses tails while the coin is in the air, what is the probability that the coin will land tail-side up? Because a coin has two sides, there are two possible outcomes, heads or tails. Therefore, the probability of tails is one out of two, or 50 percent.

Mendel also dealt with probabilities. One of the things that made his predictions accurate was that he worked with large numbers of plants. He studied almost 30,000 pea plants over a period of eight years. By doing so, Mendel increased his chances of seeing a repeatable pattern. Valid scientific conclusions need to be based on results that can be duplicated.

Figure 4 This snapdragon's phenotype is red.
Determine *Can you tell what the flower's genotype for color is? Explain your answer.*

Barry L. Runk From Grant Heilman

Punnett Squares Suppose you wanted to know what colors of pea plant flowers you would get if you pollinated white flowers on one pea plant with pollen from purple flowers on a different plant. How could you predict what the offspring would look like without making the cross? A handy tool used to predict results in Mendelian genetics is the **Punnett** (PUH nut) **square.** In a Punnett square, letters represent dominant and recessive alleles. An uppercase letter stands for a dominant allele. A lowercase letter stands for a recessive allele. The letters are a form of code. They show the **genotype** (JEE nuh tipe), or genetic makeup, of an organism. Once you understand what the letters mean, you can tell a lot about the inheritance of a trait in an organism.

The way an organism looks and behaves as a result of its genotype is its **phenotype** (FEE nuh tipe), as shown in **Figure 4.** If you have brown hair, then the phenotype for your hair color is brown.

Alleles Determine Traits Most cells in your body have at least two alleles for every trait. These alleles are located on similar pairs of chromosomes within the nucleus of cells. An organism with two alleles that are the same is called **homozygous** (hoh muh ZI gus) for that trait. For Mendel's peas, this would be written as *TT* (homozygous for the tall-dominant trait) or *tt* (homozygous for the short-recessive trait). An organism that has two different alleles is called **heterozygous** (he tuh roh ZI gus) for that trait. The hybrid plants Mendel produced were all heterozygous for height, *Tt.*

Reading Check *What is the difference between homozygous and heterozygous organisms?*

Making a Punnett Square In a Punnett square for predicting one trait, the letters representing the two alleles from one parent are written along the top of the grid, one letter per section. Those of the second parent are placed down the side of the grid, one letter per section. Each square of the grid is filled in with one allele donated by each parent. The letters that you use to fill in each of the squares represent the genotypes of possible offspring that the parents could produce.

Applying Math — Calculate Percentages

PUNNET SQUARE One dog carries heterozygous, black-fur traits (*Bb*), and its mate carries homogeneous, blond-fur traits (*bb*). Use a Punnett square to determine the probability of one of their puppies having black fur.

Solution

1. *This is what you know:*
   - dominant allele is represented by *B*
   - recessive allele is represented by *b*
2. *This is what you need to find out:* What is the probability of a puppy's fur color being black?
3. *This is the procedure you need to use:*
   - Complete the Punnett square.
   - There are two *Bb* genotypes and four possible outcomes.
   - %(black fur) = $\frac{\text{number of ways to get black fur}}{\text{number of possible outcomes}}$

     $= \frac{2}{4} = \frac{1}{2} = 50\%$

Black dog

Blond dog	B	b
b	Bb	bb
b	Bb	bb

Genotypes of offspring: 2Bb, 2bb
Phenotypes of offspring: 2 black, 2 blond

4. *Check your answer:* $\frac{1}{2}$ of 4 is 2, which is the number of black dogs.

Practice Problems

1. In peas, the color yellow (*Y*) is dominant to the color green (*y*). According to the Punnett square, what is the probability of an offspring being yellow?
2. What is the probability of an offspring having the *yy* genotype?

Parent (Yy)

Parent (Yy)	Y	y
Y	YY	Yy
y	Yy	yy

For more practice, visit booka.msscience.com/math_practice

Principles of Heredity Even though Gregor Mendel didn't know anything about DNA, genes, or chromosomes, he succeeded in beginning to describe and mathematically represent how inherited traits are passed from parents to offspring. He realized that some factor in the pea plant produced certain traits. Mendel also concluded that these factors separated when the pea plant reproduced. Mendel arrived at his conclusions after years of detailed observation, careful analysis, and repeated experimentation. **Table 2** summarizes Mendel's principles of heredity.

Table 2 Principles of Heredity

1	Traits are controlled by alleles on chromosomes.
2	An allele's effect is dominant or recessive.
3	When a pair of chromosomes separates during meiosis, the different alleles for a trait move into separate sex cells.

section 1 review

Summary

Inheriting Traits

- Heredity is the passing of traits from parent to offspring.
- Genetics is the study of how traits are inherited through the interactions of alleles.

Mendel—The Father of Genetics

- In 1856, Mendel began experimenting with garden peas, using careful scientific methods.
- Mendel was the first to trace one trait through several generations.
- In 1900, three plant scientists separately reached the same conclusions as Mendel.

Genetics in a Garden

- Hybrids receive different genetic information for a trait from each parent.
- Genetics involves dominant and recessive factors.
- Punnett squares can be used to predict the results of a cross.
- Mendel's conclusions led to the principles of heredity.

Self Check

1. **Contrast** Alleles are described as being dominant or recessive. What is the difference between a dominant and a recessive allele?
2. **Describe** how dominant and recessive alleles are represented in a Punnett square.
3. **Explain** the difference between genotype and phenotype. Give examples.
4. **Infer** Gregor Mendel, an Austrian monk who lived in the 1800s, is known as the father of genetics. Explain why Mendel has been given this title.
5. **Think Critically** If an organism expresses a recessive phenotype, can you tell the genotype? Explain your answer by giving an example.

Applying Math

6. **Use Percentages** One fruit fly is heterozygous for long wings, and another fruit fly is homozygous for short wings. Long wings are dominant to short wings. Use a Punnett square to find the expected percent of offspring with short wings.

Science Online booka.msscience.com/self_check_quiz

Predicting Results

Could you predict how many brown rabbits would result from crossing two heterozygous black rabbits? Try this investigation to find out. Brown color is a recessive trait for hair color in rabbits.

Real-World Question

How does chance affect combinations of genes?

Goals

- **Model** chance events in heredity.
- **Compare and contrast** predicted and actual results.

Materials

paper bags (2)
red beans (100)
white beans (100)

Safety Precautions

WARNING: *Do not taste, eat, or drink any materials used in the lab.*

Procedure

1. Make a Punnett square for a cross between two heterozygous black rabbits, (*Bb* ⊆ *Bb*). *B* represents the black allele and b represents the brown allele.
2. Model the above cross by placing 50 red beans and 50 white beans in one paper bag and 50 red beans and 50 white beans in a second bag. Red beans represent black alleles and white beans represent brown alleles.
3. Label one of the bags *Female* for the female parent. Label the other bag *Male* for the male parent.
4. Use a data table to record the combination each time you remove two beans. Your table will need to accommodate 50 picks.
5. Without looking, remove one bean from each bag and record the results on your data table. Return the beans to their bags.
6. Repeat step five 49 more times.
7. **Count and record** the total numbers for each of the three combinations in your data table.
8. **Compile and record** the class totals.

Conclude and Apply

1. **Name** the combination that occurred most often.
2. **Calculate** the ratio of red/red to red/white to white/white. What hair color in rabbits do these combinations represent?
3. **Compare** your predicted (expected) results with your observed (actual) results.
4. **Hypothesize** how you could get predicted results to be closer to actual results.

Gene Combinations

Rabbits	Red/Red	Red/White	White/White
Your total	Do not write in this book.		
Class total			

Communicating Your Data

Write a paragraph that clearly describes your results. Have another student read your paragraph. Ask if he or she could understand what happened. If not, rewrite your paragraph and have the other student read it again. **For more help, refer to the Science Skill Handbook.**

section 2

Genetics Since Mendel

as you read

What You'll Learn

- **Explain** how traits are inherited by incomplete dominance.
- **Compare** multiple alleles and polygenic inheritance, and give examples of each.
- **Describe** two human genetic disorders and how they are inherited.
- **Explain** how sex-linked traits are passed to offspring.

Why It's Important

Most of your inherited traits involve more complex patterns of inheritance than Mendel discovered.

Review Vocabulary

gene: section of DNA on a chromosome that contains instructions for making specific proteins

New Vocabulary

- incomplete dominance
- polygenic inheritance
- sex-linked gene

Incomplete Dominance

Not even in science do things remain the same. After Mendel's work was rediscovered in 1900, scientists repeated his experiments. For some plants, such as peas, Mendel's results proved true. However, when different plants were crossed, the results were sometimes different. One scientist crossed purebred red-flowered four-o'clock plants with purebred white-flowered four-o'clock plants. He expected to get all red flowers, but they were pink. Neither allele for flower color seemed dominant. Had the colors become blended like paint colors? He crossed the pink-flowered plants with each other, and red, pink, and white flowers were produced. The red and white alleles had not become blended. Instead, when the allele for white flowers and the allele for red flowers combined, the result was an intermediate phenotype—a pink flower.

When the offspring of two homozygous parents show an intermediate phenotype, this inheritance is called **incomplete dominance.** Other examples of incomplete dominance include the flower color of some plant breeds and the coat color of some horse breeds, as shown in **Figure 5.**

Chestnut horse

Cremello horse

Figure 5 When a chestnut horse is bred with a cremello horse, all offspring will be palomino. The Punnett square shown on the opposite page can be used to predict this result. **Explain** *how the color of the palomino horse shows that the coat color of horses may be inherited by incomplete dominance.*

Multiple Alleles Mendel studied traits in peas that were controlled by just two alleles. However, many traits are controlled by more than two alleles. A trait that is controlled by more than two alleles is said to be controlled by multiple alleles. Traits controlled by multiple alleles produce more than three phenotypes of that trait.

Imagine that only three types of coins are made—nickels, dimes, and quarters. If every person can have only two coins, six different combinations are possible. In this problem, the coins represent alleles of a trait. The sum of each two-coin combination represents the phenotype. Can you name the six different phenotypes possible with two coins?

Blood type in humans is an example of multiple alleles that produce only four phenotypes. The alleles for blood types are called A, B, and O. The O allele is recessive to both the A and B alleles. When a person inherits one A allele and one B allele for blood type, both are expressed—phenotype AB. A person with phenotype A blood has the genetic makeup, or genotype—AA or AO. Someone with phenotype B blood has the genotype BB or BO. Finally, a person with phenotype O blood has the genotype OO.

Reading Check ***What are the six different blood type genotypes?***

Science Online

Topic: Blood Types

Visit booka.msscience.com for Web links to information about the importance of blood types in blood transfusions.

Activity Make a chart showing which blood types can be used for transfusions into people with A, B, AB, or O blood phenotypes.

Palomino horse

Punnett square

Cremello horse (C'C') / Chestnut horse (CC)	C	C
C'	CC'	CC'
C'	CC'	CC'

Genotypes: All CC'
Phenotypes: All palomino horses

Mini LAB

Interpreting Polygenic Inheritance

Procedure

1. Measure the hand spans of your classmates.
2. Using a **ruler,** measure from the tip of the thumb to the tip of the little finger when the hand is stretched out. Read the measurement to the nearest centimeter.
3. Record the name and hand-span measurement of each person in a data table.

Analysis

1. What range of hand spans did you find?
2. What are the mean, median, and mode for your class's data?
3. Are hand spans inherited as a simple Mendelian pattern or as a polygenic or incomplete dominance pattern? Explain.

Polygenic Inheritance

Eye color is an example of a trait that is produced by a combination of many genes. **Polygenic** (pah lih JEH nihk) **inheritance** occurs when a group of gene pairs acts together to produce a trait. The effects of many alleles produces a wide variety of phenotypes. For this reason, it may be hard to classify all the different shades of eye color.

Your height and the color of your eyes and skin are just some of the many human traits controlled by polygenic inheritance. It is estimated that three to six gene pairs control your skin color. Even more gene pairs might control the color of your hair and eyes. The environment also plays an important role in the expression of traits controlled by polygenic inheritance. Polygenic inheritance is common and includes such traits as grain color in wheat and milk production in cows. Egg production in chickens is also a polygenic trait.

Impact of the Environment Your environment plays a role in how some of your genes are expressed or whether they are expressed at all, as shown in **Figure 6.** Environmental influences can be internal or external. For example, most male birds are more brightly colored than females. Chemicals in their bodies determine whether the gene for brightly colored feathers is expressed.

Although genes determine many of your traits, you might be able to influence their expression by the decisions you make. Some people have genes that make them at risk for developing certain cancers. Whether they get cancer might depend on external environmental factors. For instance, if some people at risk for skin cancer limit their exposure to the Sun and take care of their skin, they might never develop cancer.

Reading Check *What environmental factors might affect the size of leaves on a tree?*

Figure 6 Himalayan rabbits have alleles for dark-colored fur. However, this allele is able to express itself only at lower temperatures. Only the areas located farthest from the rabbit's main body heat (ears, nose, feet, tail) have dark-colored fur.

Human Genes and Mutations

Sometimes a gene undergoes a change that results in a trait that is expressed differently. Occasionally errors occur in the DNA when it is copied inside of a cell. Such changes and errors are called mutations. Not all mutations are harmful. They might be helpful or have no effect on an organism.

Certain chemicals are known to produce mutations in plants or animals, including humans. X rays and radioactive substances are other causes of some mutations. Mutations are changes in genes.

Chromosome Disorders In addition to individual mutations, problems can occur if the incorrect number of chromosomes is inherited. Every organism has a specific number of chromosomes. However, mistakes in the process of meiosis can result in a new organism with more or fewer chromosomes than normal. A change in the total number of human chromosomes is usually fatal to the unborn embryo or fetus, or the baby may die soon after birth.

Look at the photo of human chromosome 21 in **Figure 7.** If three copies of this chromosome are in the fertilized human egg, Down syndrome results. Individuals with Down syndrome can be short, exhibit learning disabilities, and have heart problems. Such individuals can lead normal lives if they have no severe health complications.

INTEGRATE Career

Genetic Counselor Testing for genetic disorders may allow many affected individuals to seek treatment and cope with their diseases. Genetic counselors are trained to analyze a family's history to determine a person's health risk. Research what a genetic counselor does and how to become a genetic counselor. Record what you learn in your Science Journal.

Figure 7 Humans usually have 46 chromosomes arranged as 23 pairs. If a person inherits three copies of chromosome 21 instead of the usual two, Down syndrome results. Chris Burke, a well-known actor, has Down syndrome.

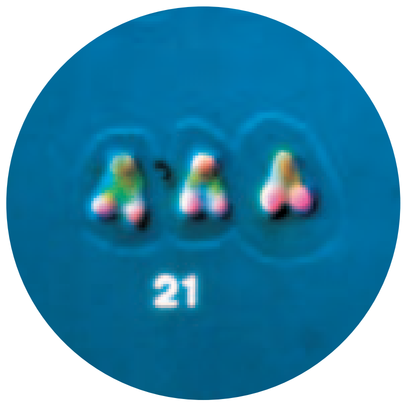


Figure 8 Sex in many organisms is determined by X and Y chromosomes.
Observe *How do the X (left) and Y (right) chromosomes differ from one another in shape and size?*

Recessive Genetic Disorders

Many human genetic disorders, such as cystic fibrosis, are caused by recessive genes. Some recessive genes are the result of a mutation within the gene. Many of these alleles are rare. Such genetic disorders occur when both parents have a recessive allele for this disorder. Because the parents are heterozygous, they don't show any symptoms. However, if each parent passes the recessive allele to the child, the child inherits both recessive alleles and will have a recessive genetic disorder.

Reading Check *How is cystic fibrosis inherited?*

Cystic fibrosis is a homozygous recessive disorder. It is the most common genetic disorder that can lead to death among Caucasian Americans. In most people, a thin fluid is produced that lubricates the lungs and intestinal tract. People with cystic fibrosis produce thick mucus instead of this thin fluid. The thick mucus builds up in the lungs and makes it hard to breathe. This buildup often results in repeated bacterial respiratory infections. The thick mucus also reduces or prevents the flow of substances necessary for digesting food. Physical therapy, special diets, and new drug therapies have increased the life spans of patients with cystic fibrosis.

Gender Determination

What determines the gender or sex of an individual? Much information on gender inheritance came from studies of fruit flies. Fruit flies have only four pairs of chromosomes. Because the chromosomes are large and few in number, they are easy to study. Scientists identified one pair that contains genes that determine the sex of the organism. They labeled the pair XX in females and XY in males. Geneticists use these labels when studying organisms, including humans. You can see human X and Y chromosomes in **Figure 8.**

Each egg produced by a female normally contains one X chromosome. Males produce sperm that normally have either an X or a Y chromosome. When a sperm with an X chromosome fertilizes an egg, the offspring is a female, XX. A male offspring, XY, is the result of a Y-containing sperm fertilizing an egg. What pair of sex chromosomes is in each of your cells? Sometimes chromosomes do not separate during meiosis. When this occurs, an individual can inherit an abnormal number of sex chromosomes.

Sex-Linked Disorders

A **sex-linked gene** is an allele on a sex chromosome. Some conditions that result from inheriting a sex-linked gene are called sex-linked disorders. Red-green color blindness in humans is a sex-linked disorder because the related genes are on the X chromosome. People who inherit this disorder have difficulty seeing the difference between green and red, and sometimes, yellow. This condition is a recessive sex-linked disorder. A female is color-blind when each of her X chromosomes has the recessive allele. A male has only one X chromosome and, if it has the recessive allele, he will be color-blind.

Dominant sex-linked disorders are rare and result when a person inherits at least one dominant sex-linked allele. Vitamin D-resistant rickets is an X-linked dominant disorder. The kidneys of an affected person cannot absorb adequate amounts of phosphorus. The person might have low blood-phosphorus levels, soft bones, and poor teeth formation.

Pedigrees Trace Traits

How can you trace a trait through a family? A pedigree is a visual tool for following a trait through generations of a family. Males are represented by squares and females by circles. A completely filled circle or square shows that the trait is seen in that person. Half-colored circles or squares indicate carriers. A carrier is heterozygous for the trait, and it is not seen. People represented by empty circles or squares do not have the trait and are not carriers. The pedigree in **Figure 9** shows how the trait for color blindness is carried through a family.

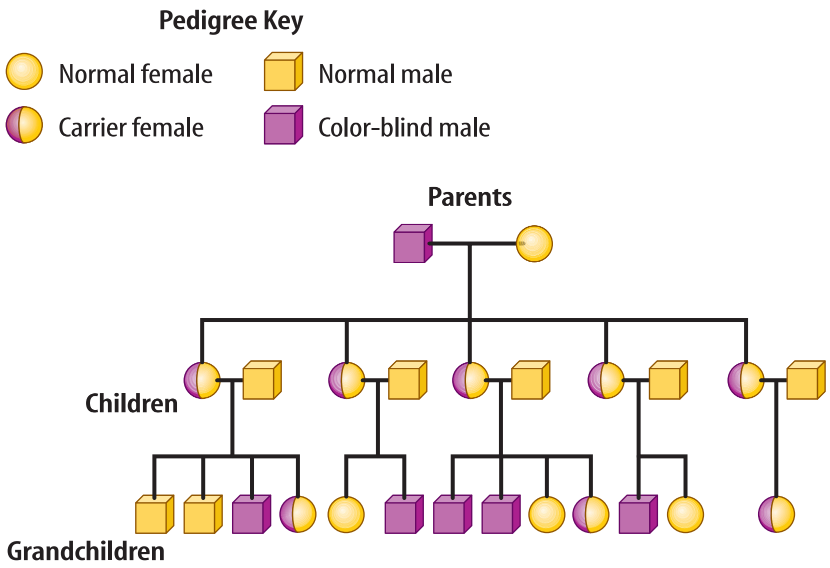
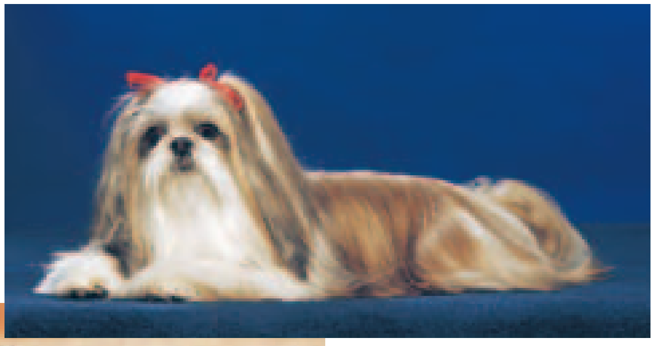
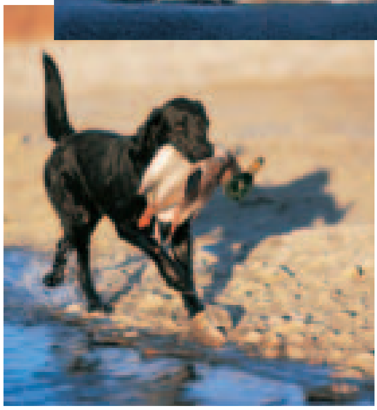


Figure 9 The symbols in this pedigree's key mean the same thing on all pedigree charts. The grandfather in this family was color-blind and married to a woman who was not a carrier of the color-blind allele.
Infer *why no women in this family are color-blind.*



Shih Tzu



Black Labrador

Figure 10
A variety of traits are considered when breeding dogs.

Using Pedigrees A pedigree is a useful tool for a geneticist. Sometimes a geneticist needs to understand who has had a trait in a family over several generations to determine its pattern of inheritance. A geneticist determines if a trait is recessive, dominant, sex-linked, or has some other pattern of inheritance. When geneticists understand how a trait is inherited, they can predict the probability that a baby will be born with a specific trait.

Pedigrees also are important in breeding animals or plants. Because livestock and plant crops are used as sources of food, these organisms are bred to increase their yield and nutritional content. Breeders of pets and show animals, like the dogs pictured in **Figure 10,** also examine pedigrees carefully for possible desirable physical and ability traits. Issues concerning health also are considered when researching pedigrees.

section 2 review

Summary

Incomplete Dominance

- Incomplete dominance is when a dominant and recessive allele for a trait show an intermediate phenotype.
- Many traits are controlled by more than two alleles.
- A wide variety of phenotypes is produced by polygenic inheritance.

Human Genes and Mutations

- Errors can occur when DNA is copied.
- Mistakes in meiosis can result in an unequal number of chromosomes in sex cells.
- Recessive genes control many human genetic disorders.

Sex Determination

- An allele inherited on a sex chromosome is called a sex-linked gene.
- Pedigrees are visual tools to trace a trait through generations of a family.

Self Check

1. **Compare** how inheritance by multiple alleles and polygenic inheritance are similar.
2. **Explain** why a trait inherited by incomplete dominance is not a blend of two alleles.
3. **Discuss** Choose two genetic disorders and discuss how they are inherited.
4. **Apply** Using a Punnett square, explain why males are affected more often than females by sex-linked genetic disorders.
5. **Think Critically** Why wouldn't a horse breeder mate male and female palominos to get palomino colts?

Applying Skills

6. **Predict** A man with blood type B marries a woman with blood type A. Their first child has blood type O. Use a Punnett square to predict what other blood types are possible for their offspring.
7. **Communicate** In your Science Journal, explain why offspring may or may not resemble either parent.

Science Online booka.msscience.com/self_check_quiz

section 3

Advances in Genetics

Why is genetics important?

If Mendel were to pick up a daily newspaper in any country today, he'd probably be surprised. News articles about developments in genetic research appear almost daily. The term *gene* has become a common word. The principles of heredity are being used to change the world.

Genetic Engineering

You might recall that chromosomes are made of DNA and are in the nucleus of a cell. Sections of DNA in chromosomes that direct cell activities are called genes. Through **genetic engineering,** scientists are experimenting with biological and chemical methods to change the arrangement of DNA that makes up a gene. Genetic engineering already is used to help produce large volumes of medicine. Genes also can be inserted into cells to change how those cells perform their normal functions, as shown in **Figure 11.** Other research is being done to find new ways to improve crop production and quality, including the development of plants that are resistant to disease.

as you read

What You'll Learn

- **Evaluate** the importance of advances in genetics.
- **Sequence** the steps in making genetically engineered organisms.

Why It's Important

Advances in genetics can affect your health, the foods that you eat, and your environment.

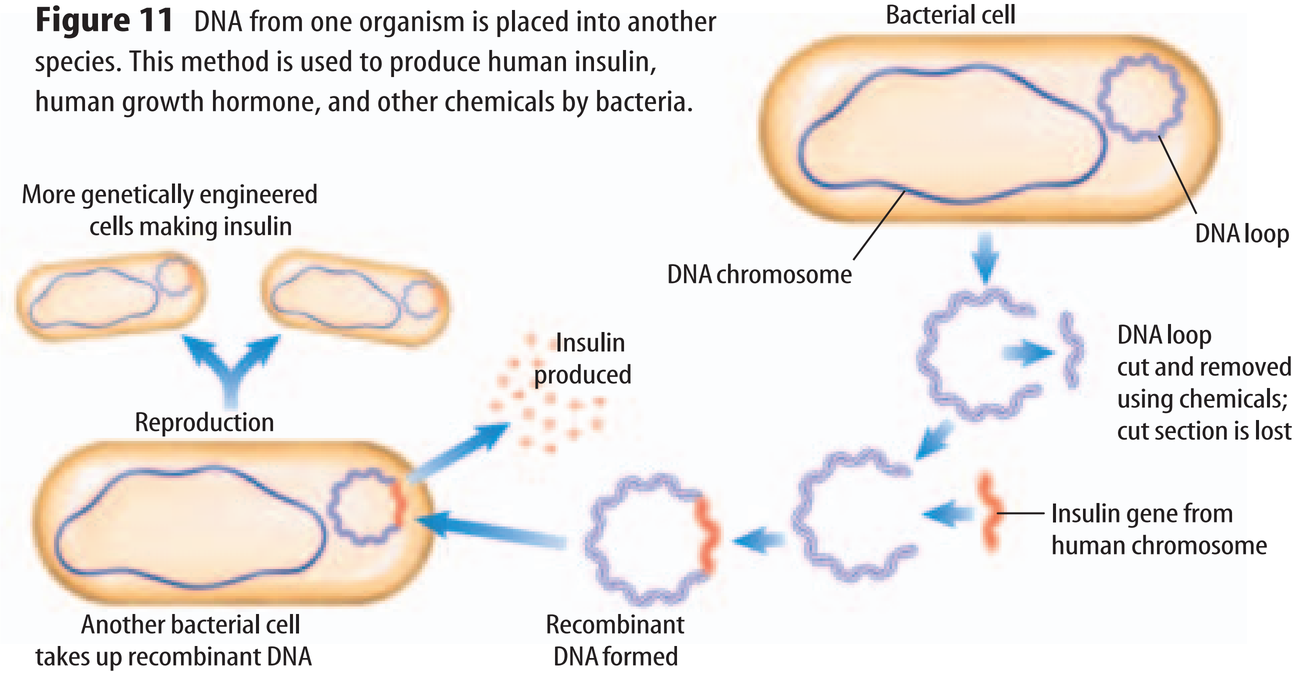
Review Vocabulary

DNA: deoxyribonucleic acid; the genetic material of all organisms

New Vocabulary

- genetic engineering

Figure 11 DNA from one organism is placed into another species. This method is used to produce human insulin, human growth hormone, and other chemicals by bacteria.



INTEGRATE Environment

Genetically Engineered Crops Crop plants are now being genetically engineered to produce chemicals that kill specific pests that feed on them. Some of the pollen from pesticide-resistant canola crops is capable of spreading up to 8 km from the plant, while corn and potato pollen can spread up to 1 km. What might be the effects of pollen landing on other plants?

Recombinant DNA Making recombinant DNA is one method of genetic engineering. Recombinant DNA is made by inserting a useful segment of DNA from one organism into a bacterium, as illustrated in **Figure 11.** Large quantities of human insulin are made by some genetically engineered organisms. People with Type 1 diabetes need this insulin because their pancreases produce too little or no insulin. Other uses include the production of growth hormone to treat dwarfism and chemicals to treat cancer.

Gene Transfer Another application of genetic-engineering is gene transfer. A goal of this experimental procedure is to replace abnormal genetic material with normal genetic material. First, normal DNA or RNA is placed in a virus. Then the virus delivers the normal DNA or RNA to target cells, as shown in **Figure 12.** Gene transfer, also known as gene therapy, might help correct genetic disorders such as cystic fibrosis. It also is being studied as a possible treatment for cancer, heart disease, and certain infectious diseases.

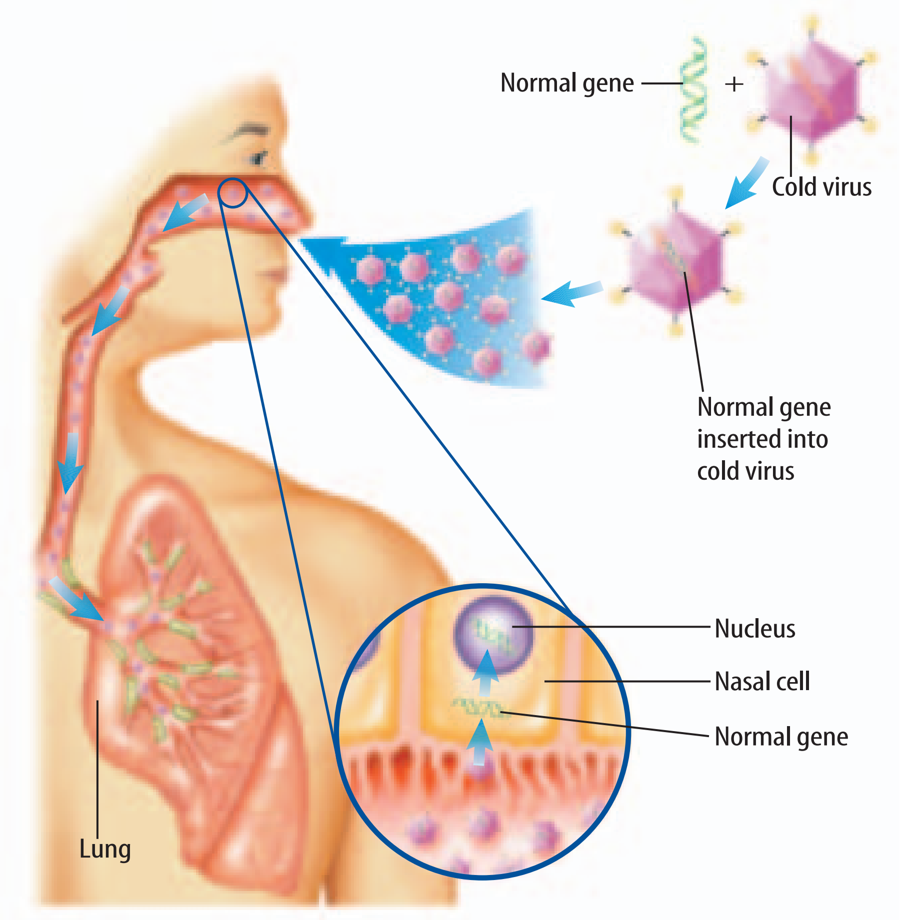


Figure 12 Gene transfer involves placing normal genetic material into a cell with abnormal genetic material. When the normal genetic material begins to function, the abnormal condition is corrected.

Genetically Engineered Plants For thousands of years people have improved the plants they use for food and clothing even without the knowledge of genotypes. Until recently, these improvements were the results of selecting plants with the most desired traits to breed for the next generation. This process is called selective breeding. Recent advances in genetics have not replaced selective breeding. Although a plant can be bred for a particular phenotype, the genotype and pedigree of the plants also are considered.

Genetic engineering can produce improvements in crop plants, such as corn, wheat, and rice. One type of genetic engineering involves finding the genes that produce desired traits in one plant and then inserting those genes into a different plant. Scientists recently have made genetically engineered tomatoes with a gene that allows tomatoes to be picked green and transported great distances before they ripen completely. Ripe, firm tomatoes are then available in the local market. In the future, additional food crops may be genetically engineered so that they are not desirable food for insects.

Reading Check ***What other types of traits would be considered desirable in plants?***

Because some people might prefer foods that are not changed genetically, some stores label such produce, as shown in **Figure 13.** The long-term effects of consuming genetically engineered plants are unknown.

Figure 13 Genetically engineered produce is sometimes labeled. This allows consumers to make informed choices about their foods.

section 3 review

Summary

Why is genetics important?

- Developments in genetic research appear in newspapers almost daily.
- The world is being changed by the principles of heredity.

Genetic Engineering

- Scientists work with biological and chemical methods to change the arrangement of DNA that makes up a gene.
- One method of genetic engineering is making recombinant DNA.
- A normal allele is replaced in a virus and then delivers the normal allele when it infects its target cell.

Self Check

1. **Apply** Give examples of areas in which advances in genetics are important.
2. **Compare and contrast** the technologies of using recombinant DNA and gene therapy.
3. **Infer** What are some benefits of genetically engineered crops?
4. **Describe** how selective breeding differs from genetic engineering.
5. **Think Critically** Why might some people be opposed to genetically engineered plants?

Applying Skills

6. **Concept Map** Make an events-chain concept map of the steps used in making recombinant DNA.

LAB

Design Your Own

Tests for Color Blindness

Goals

- **Design** an experiment that tests for a specific type of color blindness in males and females.
- **Calculate** the percentage of males and females with the disorder.

Possible Materials

white paper or poster board
colored markers: red, orange, yellow, bright green, dark green, blue
**computer and color printer*

**Alternate materials*

Real-World Question

What colors do color-blind people see? That depends on the type of color blindness that they inherit. The most common type is red-green color blindness in which people have difficulty seeing any difference between red and green. People with another inherited type cannot distinguish between blue and yellow. In rare instances, a person can inherit a type of color blindness where the only colors seen are shades of gray. What percentages of males and females in your school are color-blind?

Form a Hypothesis

Based on your reading and your own experiences, form a hypothesis about how common color blindness is among males and females.

Test Your Hypothesis

Make a Plan

1. Decide what type of color blindness you will test for—the common green-red color blindness or the more rare green-blue color blindness.
2. **List** the materials you will need and describe how you will create test pictures. Tests for color blindness use many circles of red, orange, and yellow as a background, with circles of dark and light green to make a picture or number. List the steps you will take to test your hypothesis.
3. Prepare a data table in your Science Journal to record your test results.

4. **Examine** your experiment to make sure all steps are in logical order.
5. **Identify** which pictures you will use as a control and which pictures you will use as variables.

Follow Your Plan

1. Make sure your teacher approves your plan before you start.
2. **Draw** the pictures that you will use to test for color blindness.
3. Carry out your experiment as planned and record your results in your data table.

Analyze Your Data

1. **Calculate** the percentage of males and females that tested positive for color blindness.
2. **Compare** the frequency of color blindness in males with the frequency of color blindness in females.

Conclude and Apply

1. **Explain** whether or not the results supported your hypothesis.
2. **Explain** why color blindness is called a sex-linked disorder.
3. **Infer** how common the color-blind disorder is in the general population.
4. **Predict** your results if you were to test a larger number of people.

Richard Hutchings

Communicating Your Data

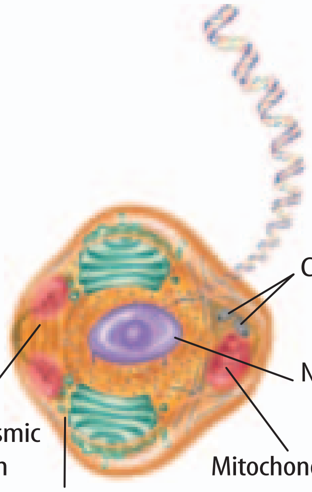
Using a word processor, write a short article for the advice column of a fashion magazine about how a color-blind person can avoid wearing outfits with clashing colors. **For more help, refer to the Science Skill Handbook.**

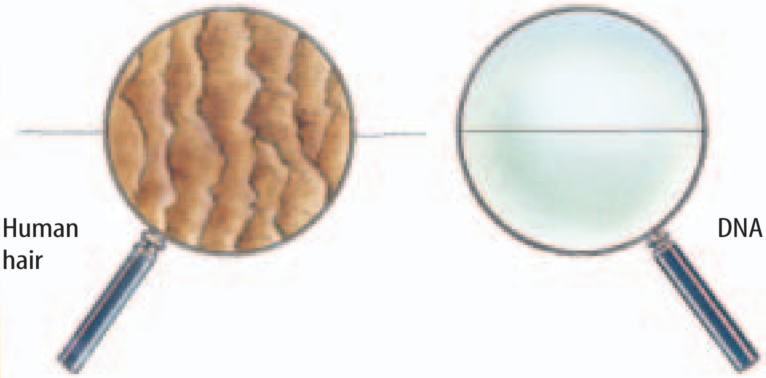
SCIENCE Stats

The Human Genome

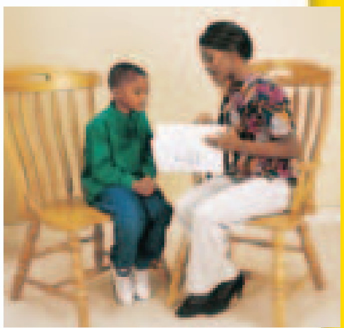
Did you know...

. . . The biggest advance in genetics in years took place in February 2001. Scientists successfully mapped the human genome. There are 30,000 to 40,000 genes in the human genome. Genes are in the nucleus of each of the several trillion cells in your body.





. . . The strands of DNA in the human genome, if unwound and connected end to end, would be more than 1.5 m long—but only about 130 trillionths of a centimeter wide. Even an average human hair is as much as 200,000 times wider than that.



. . . It would take about nine and one-half years to read aloud without stopping the 3 billion bits of instructions (called base pairs) in your genome.

Applying Math If one million base pairs of DNA take up 1 megabyte of storage space on a computer, how many gigabytes (1,024 megabytes) would the whole genome fill?

Find Out About It

Human genome scientists hope to identify the location of disease-causing genes. Visit booka.msscience.com/science_stats to research a genetic disease and share your results with your class.

KS Studios

Reviewing Main Ideas

Section 1 Genetics

1. Genetics is the study of how traits are inherited. Gregor Mendel determined the basic laws of genetics.
2. Traits are controlled by alleles on chromosomes.
3. Some alleles can be dominant or recessive.
4. When a pair of chromosomes separates during meiosis, the different alleles move into separate sex cells. Mendel found that he could predict the outcome of genetic crosses.

Section 2 Genetics Since Mendel

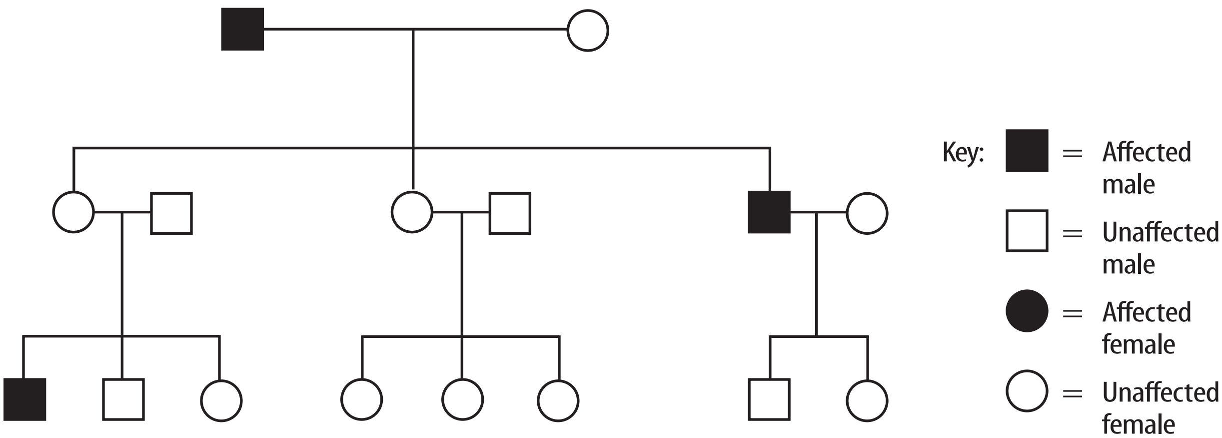
1. Inheritance patterns studied since Mendel include incomplete dominance, multiple alleles, and polygenic inheritance.
2. These inheritance patterns allow a variety of phenotypes to be produced.
3. Some disorders are the results of inheritance and can be harmful and even deadly.
4. Pedigree charts help reveal patterns of the inheritance of a trait in a family. Pedigrees show that sex-linked traits are expressed more often in males than in females.

Section 3 Advances in Genetics

1. Genetic engineering uses biological and chemical methods to change genes.
2. Recombinant DNA is one method of genetic engineering to make useful chemicals, including hormones.
3. Gene transfer shows promise for correcting many human genetic disorders, cancer, and other diseases.
4. Breakthroughs in the field of genetic engineering are allowing scientists to do many things, such as producing plants that are resistant to disease.

Visualizing Main Ideas

Examine the following pedigree for diabetes and explain the inheritance pattern.



chapter 5 Review

Using Vocabulary

Fill in the blanks with the correct word.

1. Alternate forms of a gene are called __________.
2. The outward appearance of a trait is a(n) __________.
3. Human height, eye color, and skin color are all traits controlled by __________.
4. An allele that produces a trait in the heterozygous condition is __________.
5. __________ is the science that deals with the study of heredity.
6. The actual combination of alleles of an organism is its __________.
7. __________ is moving fragments of DNA from one organism and inserting them into another organism.
8. A(n) __________ is a helpful device for predicting the probabilities of possible genotypes.
9. __________ is the passing of traits from parents to offspring.
10. Red-green color blindness is a human genetic disorder caused by a(n) __________.

Checking Concepts

Choose the word or phrase that best answers the question.

11. Which describes the allele that causes color blindness?
    - **A)** dominant
    - **B)** carried on the Y chromosome
    - **C)** carried on the X chromosome
    - **D)** present only in males
12. What is it called when the presence of two different alleles results in an intermediate phenotype?
    - **A)** incomplete dominance
    - **B)** polygenic inheritance
    - **C)** multiple alleles
    - **D)** sex-linked genes
13. What separates during meiosis?
    - **A)** proteins
    - **B)** phenotypes
    - **C)** alleles
    - **D)** pedigrees
14. What controls traits in organisms?
    - **A)** cell membrane
    - **B)** cell wall
    - **C)** genes
    - **D)** Punnett squares
15. What term describes the inheritance of cystic fibrosis?
    - **A)** polygenic inheritance
    - **B)** multiple alleles
    - **C)** incomplete dominance
    - **D)** recessive genes
16. What phenotype will the offspring represented in the Punnett square have?
    - **A)** all recessive
    - **B)** all dominant
    - **C)** half recessive, half dominant
    - **D)** Each will have a different phenotype.

	F	f
F	FF	Ff
F	FF	Ff

Science Online booka.msscience.com/vocabulary_puzzlemaker

Thinking Critically

17. Explain the relationship between DNA, genes, alleles, and chromosomes.

18. Classify these inheritance patterns:

a. many different phenotypes produced by one pair of alleles

b. many phenotypes produced by more than one pair of alleles; two phenotypes from two alleles; three phenotypes from two alleles.

Use the illustration below to answer question 19.

Tt	Tt
Tt	Tt

19. Interpret Scientific Illustrations What were the genotypes of the parents that produced the Punnett Square shown above?

20. Explain why two rabbits with the same genes might not be colored the same if one is raised in northern Maine and one is raised in southern Texas.

21. Apply Can a person with a genetic disorder that has been corrected by gene transfer pass the corrected condition to his or her children? Explain.

22. Predict Two organisms were found to have different genotypes but the same phenotype. Predict what these phenotypes might be. Explain.

23. Compare and contrast Mendelian inheritance with incomplete dominance.

Performance Activities

24. Newspaper Article Write a newspaper article to announce a new, genetically engineered plant. Include the method of developing the plant, the characteristic changed, and the terms that you would expect to see. Read your article to the class.

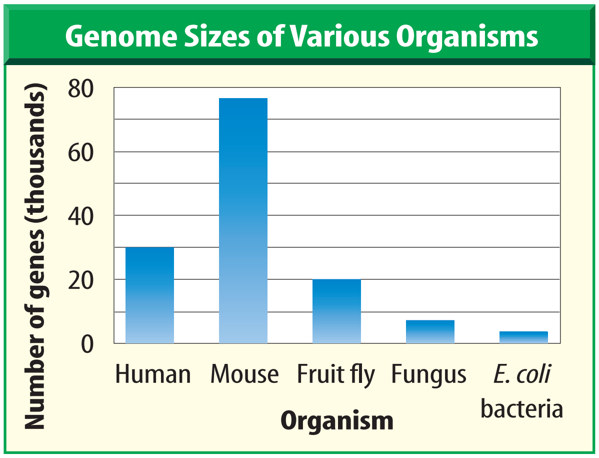
25. Predict In humans, the widow's peak allele is dominant, and the straight hairline allele is recessive. Predict how both parents with widow's peaks could have a child without a widow's peak hairline.

26. Use a word processor or program to write predictions about how advances in genetics might affect your life in the next ten years.

Applying Math

27. Human Genome If you wrote the genetic information for each gene in the human genome on a separate sheet of 0.2-mm-thick paper and stacked the sheets, how tall would the stack be?

Use the table below to answer question 28.



28. Genes Consult the graph above. How many more genes are in the human genome than the genome of the fruit fly?

Part 1 Multiple Choice

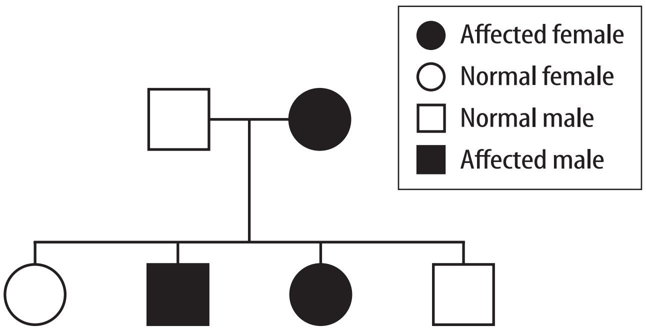
Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

1. Heredity includes all of the following except
   A. traits. **C.** nutrients.
   B. chromosomes. **D.** phenotype.

2. What is a mutation?
   A. A change in a gene which is harmful, beneficial, or has no effect at all.
   B. A change in a gene which is only beneficial.
   C. A change in a gene which is only harmful.
   D. No change in a gene.

3. Sex of the offspring is determined by
   A. only the mother, because she has two X chromosomes.
   B. only the father, because he has one X and one Y chromosome.
   C. an X chromosome from the mother and either an X or Y chromosome from the father.
   D. mutations.

Use the pedigree below to answer questions 4–6.



Huntington disease has a dominant (DD or Dd) inheritance pattern.

4. What is the genotype of the father?
   A. DD **C.** dd
   B. Dd **D.** D

5. What is the genotype of the mother?
   A. DD **C.** dd
   B. Dd **D.** D

6. The genotype of the unaffected children is
   A. DD. **C.** dd.
   B. Dd. **D.** D.

7. Manipulating the arrangement of DNA that makes up a gene is called
   A. genetic engineering.
   B. chromosomal migration.
   C. viral reproduction.
   D. cross breeding.

Use the Punnett square below to answer question 8.

	A	O
A	AA	AO
B	AB	BO

8. How many phenotypes would result from the following Punnett square?
   A. 1 **C.** 3
   B. 2 **D.** 4

9. Down syndrome is an example of
   A. incomplete dominance.
   B. genetic engineering.
   C. a chromosome disorder.
   D. a sex linked disorder.

Test-Taking Tip

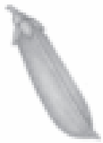
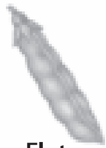
Complete Charts Write directly on complex charts such as a Punnett square.

Question 10 Draw a Punnett square to answer all parts of the question.

Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the table below to answer questions 10–11.

Some Traits Compared by Mendel			
Traits	**Shape of Seeds**	**Shape of Pods**	**Flower Color**
Dominant Trait	Round	 Full	 Purple
Recessive Trait	 Wrinkled	 Flat, constricted	 White

10. Create a Punnett square using the *Shape of Pods* trait crossing heterozygous parents. What percentage of the offspring will be heterozygous? What percentage of the offspring will be homozygous? What percentage of the offspring will have the same phenotype as the parents?

11. Gregor Mendel studied traits in pea plants that were controlled by single genes. Explain what would have happened if the alleles for flower color were an example of incomplete dominance. What phenotypes would he have observed?

12. Why are heterozygous individuals called carriers for non-sex-linked and X-linked recessive patterns of inheritance?

13. How many alleles does a body cell have for each trait? What happens to the alleles during meiosis?

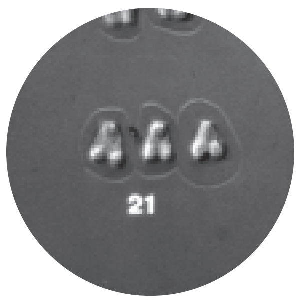
Part 3 Open Ended

Record your answers on a sheet of paper.

14. Genetic counseling helps individuals determine the genetic risk or probability a disorder will be passed to offspring. Why would a pedigree be a very important tool for the counselors? Which patterns of inheritance (dominant, recessive, x-linked) would be the easiest to detect?

15. Explain the process of gene transfer. What types of disorders would this be best suited? How might gene transfer help patients with cystic fibrosis?

Refer to the figure below to answer question 16.



16. What is the disorder associated with the karyotype shown above? How does this condition occur? What are the characteristics of someone with this disorder?

17. Explain why the parents of someone with cystic fibrosis do not show any symptoms. How are the alleles for cystic fibrosis passed from parents to offspring?

18. What is recombinant DNA and how is it used to help someone with Type I diabetes?

19. If each kernel on an ear of corn represents a separate genetic cross, would corn be a good plant to use to study genetics? Why or why not? What process could be used to control pollination?