

5

Heredity

The Big Idea

Heredity is the passage of traits from one generation to the next.

SECTION

- | | |
|-------------------------------|-----|
| 1 Mendel and His Peas..... | 114 |
| 2 Traits and Inheritance..... | 120 |
| 3 Meiosis..... | 126 |

About the



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



PRE-READING ACTIVITY



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





START-UP Activity

Clothing Combos

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

Procedure

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

Analysis

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

SECTION

1

What You Will Learn

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

Vocabulary

heredity
dominant trait
recessive trait

READING STRATEGY

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

heredity the passing of genetic traits from parent to offspring

Mendel and His Peas

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

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

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

Who Was Gregor Mendel?

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

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

Unraveling the Mystery

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

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



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

Self-Pollinating Peas

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

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

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

SCHOOL to HOME

Describing Traits

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

ACTIVITY

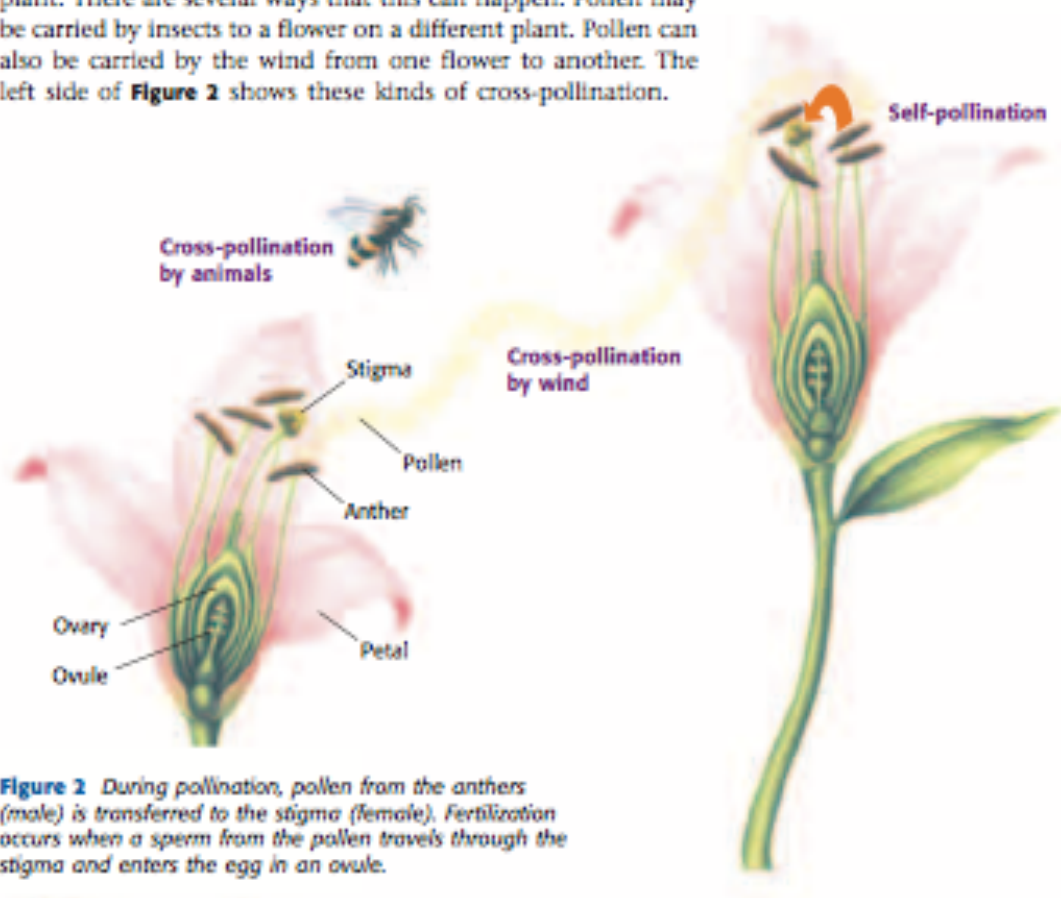


Figure 2 During pollination, pollen from the anthers (male) is transferred to the stigma (female). Fertilization occurs when a sperm from the pollen travels through the stigma and enters the egg in an ovule.

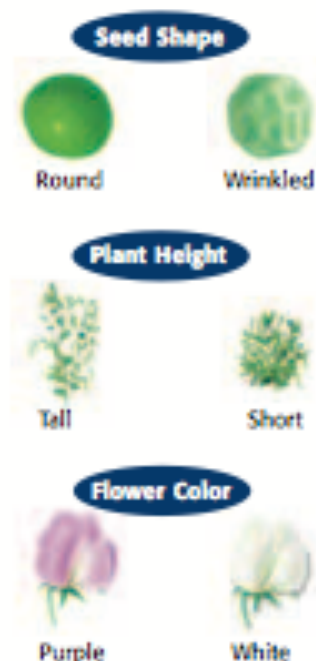


Figure 3 These are some of the plant characteristics that Mendel studied.

Characteristics

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

Mix and Match

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

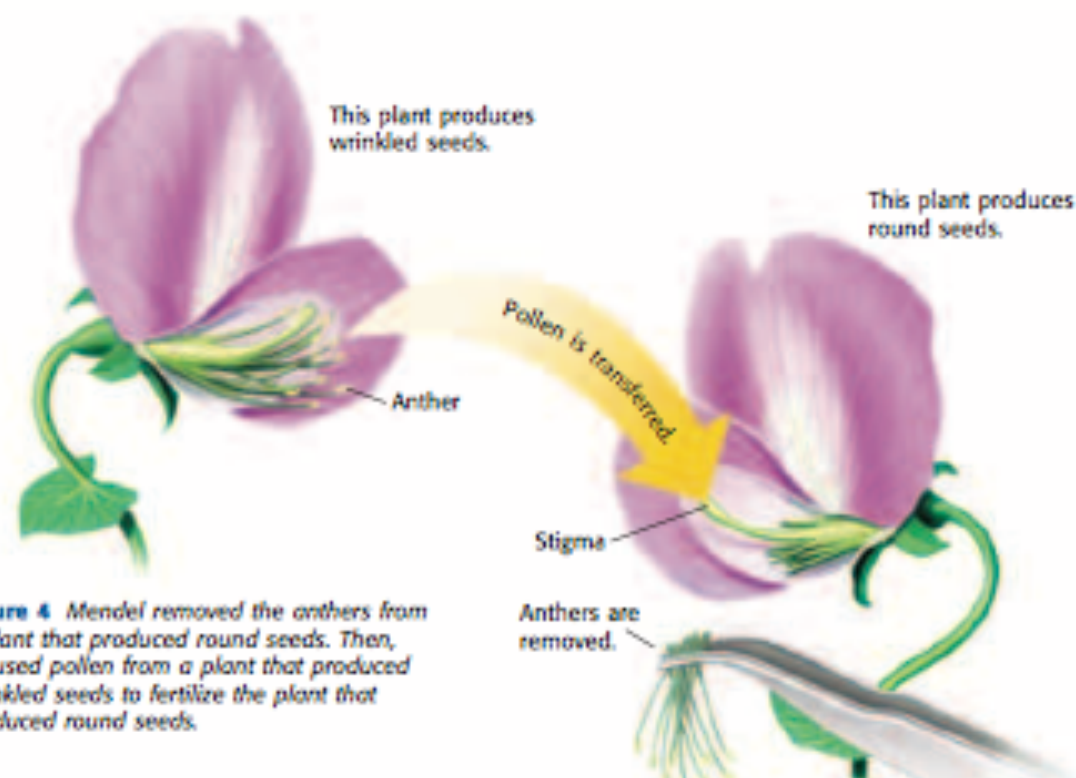


Figure 4 Mendel removed the anthers from a plant that produced round seeds. Then, he used pollen from a plant that produced wrinkled seeds to fertilize the plant that produced round seeds.

Mendel's First Experiments

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

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

Mendel's Second Experiments

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

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

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

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

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

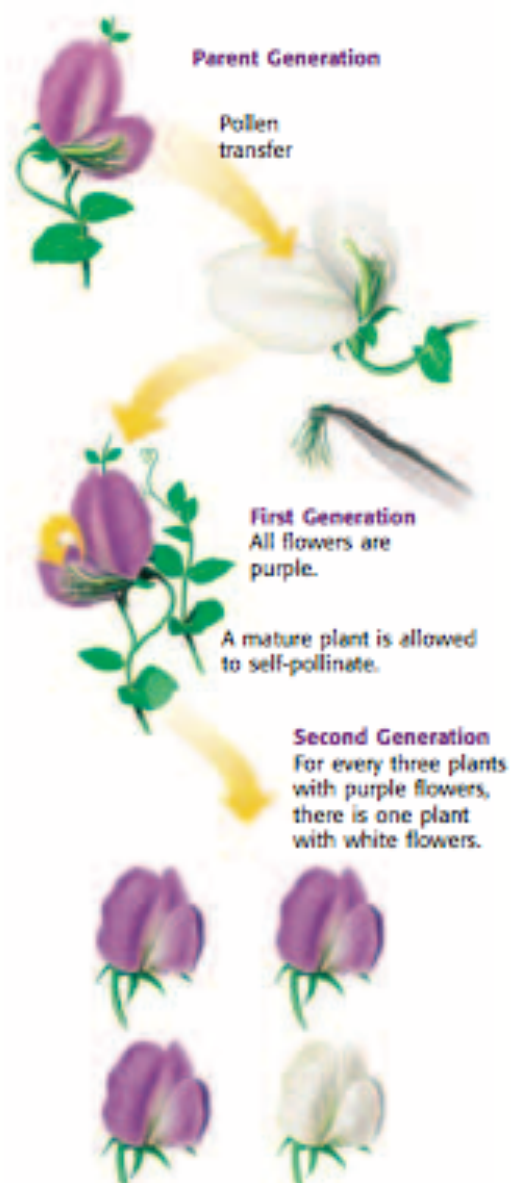


Figure 5 Mendel used the pollen from a plant with purple flowers to fertilize a plant with white flowers. Then, he allowed the offspring to self-pollinate.

MATH PRACTICE

Understanding Ratios

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

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

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

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

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















Ratios in Mendel's Experiments

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

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

 **Reading Check** What is a ratio?

Table 1 Mendel's Results

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

Gregor Mendel—Gone but Not Forgotten

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



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

SECTION Review

Summary

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

Using Key Terms

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

Understanding Key Ideas

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

Math Skills

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

Critical Thinking

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

SCILINKS

NSTA

Developed and maintained by the
National Science Teachers Association

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

Topic: Heredity; Dominant and Recessive Traits

SciLinks code: HSM0738; HSM0423

SECTION

2

Traits and Inheritance

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

What You Will Learn

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

Vocabulary

gene	genotype
allele	probability
phenotype	

READING STRATEGY

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

gene one set of instructions for an inherited trait

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

phenotype an organism's appearance or other detectable characteristic

A Great Idea

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

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

Phenotype

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

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

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



Genotype

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

Punnett Squares

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

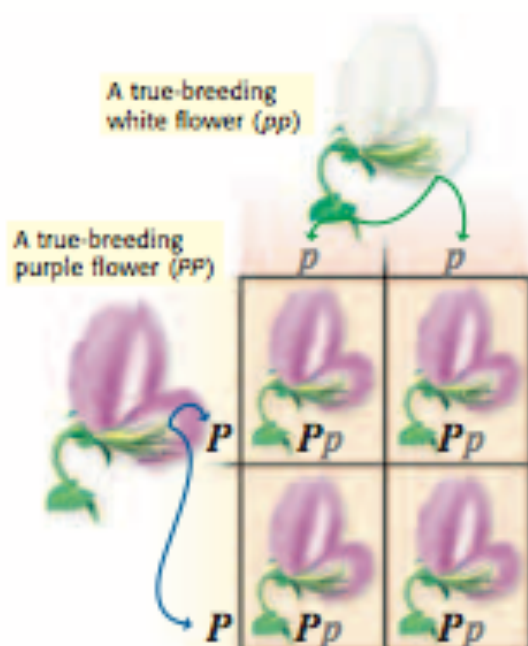


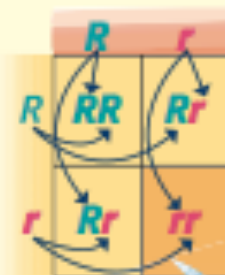
Figure 2 All of the offspring for this cross have the same genotype— Pp .

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

Quick Lab

Making a Punnett Square

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



Quick Lab

Taking Your Chances

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

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

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

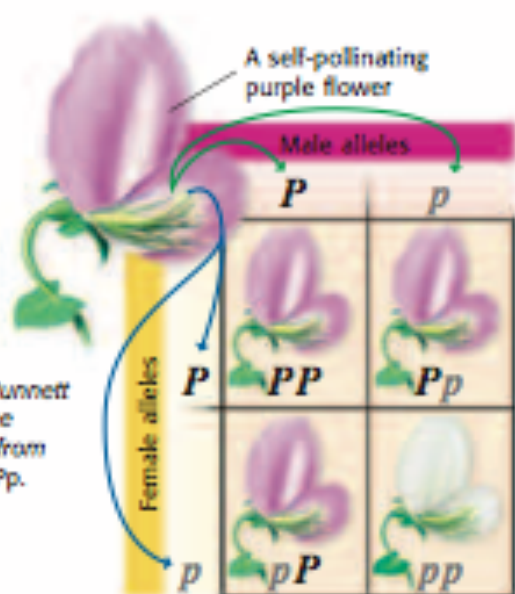


Figure 3 This Punnett square shows the possible results from the cross $Pp \times Pp$.

More Evidence for Inheritance

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

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

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

What Are the Chances?

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

Probability

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

Reading Check What is probability?

MATH Focus

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

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

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

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

Now It's Your Turn

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

Calculating Probabilities

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

Genotype Probability

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



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

CONNECTION TO Chemistry

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

Activity

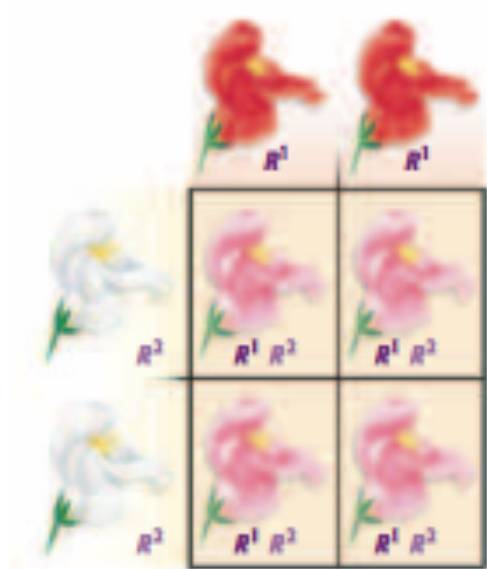


Figure 5 Cross-breeding two true-breeding snapdragons provides a good example of incomplete dominance.

More About Traits

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

Incomplete Dominance

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

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

Reading Check What is incomplete dominance?

One Gene, Many Traits

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



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

Many Genes, One Trait

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

The Importance of Environment

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



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

SECTION Review

Summary

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

Using Key Terms

- Use the following terms in the same sentence: *gene* and *allele*.
- In your own words, write a definition for each of the following terms: *genotype* and *phenotype*.

Understanding Key Ideas

- Use a Punnett square to determine the possible genotypes of the offspring of a $BB \times Bb$ cross.
 - all BB
 - BB , Bb
 - BB , Bb , bb
 - all bb
- How are genes and alleles related to genotype and phenotype?
- Describe three exceptions to Mendel's observations.

Math Skills

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

Critical Thinking

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

Interpreting Graphics

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

	B	b
B	BB	Bb
b	Bb	bb



- Given the combinations shown, what are the genotypes of the parents?
- If black fur had incomplete dominance over white fur, what color would the offspring be?

SCILINKS

NTA

Developed and maintained by the
National Science Teachers Association

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

Topic: Genotypes; Phenotypes

SciLink code: HSM0664; HSM1135