Chapter 9

Introduction to Genetics

Although these puppies share many of their mother's characteristics, they are each unique. The process that determines an individual's traits—from eye color to height—lies in the division of cells and chromosomes.

Chapter Inquiry Developing Hypotheses

1. Obtain several varieties of the same type of flower from your teacher. Examine each flower carefully.

2. Construct a chart that lists the characteristics of the flowers that are the same and those that are different. Share your observations with the class.

Connect to the Main Ideas

Gregor Mendel explored questions of heredity by studying the traits of pea plants—much as you have examined these flowers. What do their similarities and differences tell you about inheritance? Why do you think flowers of the same type can have different characteristics?

CHAPTER PREVIEW

Main Ideas

In this chapter, you will learn about Mendel's work on heredity and his principles of dominance, segregation, and independent assortment. You will use Mendel's principles and the rules of probability to solve genetic problems. You will also examine the role that meiosis has in biological inheritance.

Reading Strategy

Reinforcing Main Ideas As you read this chapter, list the main characteristics of pea plants that Gregor Mendel observed. Then list, with an explanation for each, how Mendel prepared the different crosses: the F_1 cross, the two-factor F_1 cross, and the two-factor F_2 cross.

Journal Activity

Biology and Your World For 14 years, Gregor Mendel conducted experiments to unlock the secrets of heredity. He used all his free time and performed many painstaking—even tedious—activities to achieve his goal. Is there some endeavor you feel committed to in a similar way? In your journal, write about the goal, hobby, or cause to which you are committed.

9–1 The Work of Gregor Mendel

Guide For Reading

- What are some of the experiments that Mendel performed?
- What do the terms dominance, segregation, and independent assortment mean?

Biological inheritance, or **heredity,** is the key to differences between species. Cats give birth to kittens, dogs produce puppies, and oak trees produce acorns from which, as the saying goes, mighty oaks may grow. Heredity, however, is much more than the way in which a few superficial characteristics are passed from one generation to another. Heredity is at the very center of what makes each species unique, as well as what makes us human. The branch of biology that studies heredity is called **genetics.**

Early Ideas About Heredity

Until the nineteenth century, the most common explanation for the resemblances between parent and offspring was the theory of blending inheritance. People reasoned that because both a male and a female were involved in producing offspring, each parent contributed factors that were blended in their offspring. The nature of these factors was unknown.

At first, the theory of blending inheritance seemed a reasonable explanation: It is common to see a little bit of both parents in a child. So it seemed fair to say that the characteristics of the mother and father blended in making the new life. But in the last century, biologists began to look at the details of heredity. When they did, they began to develop a very different

Figure 9–1 *Why don't the two baby guinea pigs look like each other? Why are they different from their mother? The science of genetics helps us answer questions such as these.*

view. The work of the Austrian monk Gregor Mendel was particularly important in changing people's views about how characteristics are passed from one generation to the next.

Gregor Mendel

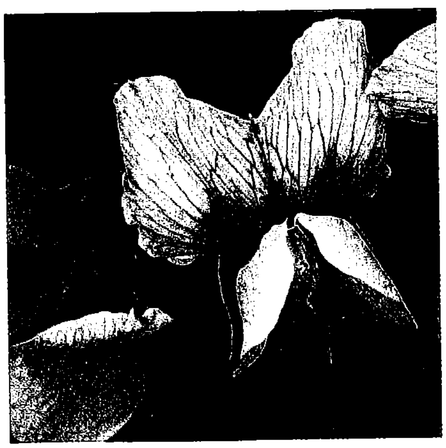
Gregor Mendel was born in 1822 to peasant parents in what is now the Czech Republic. He did very well in school and entered a monastery in the town of Brno at age 21. Four years later he was ordained a priest. The monastery was a center of scientific learning. In 1851, Mendel was sent to the University of Vienna to study science and mathematics. He returned two years later and spent the next fourteen years working in the monastery and teaching at the high school in Brno.

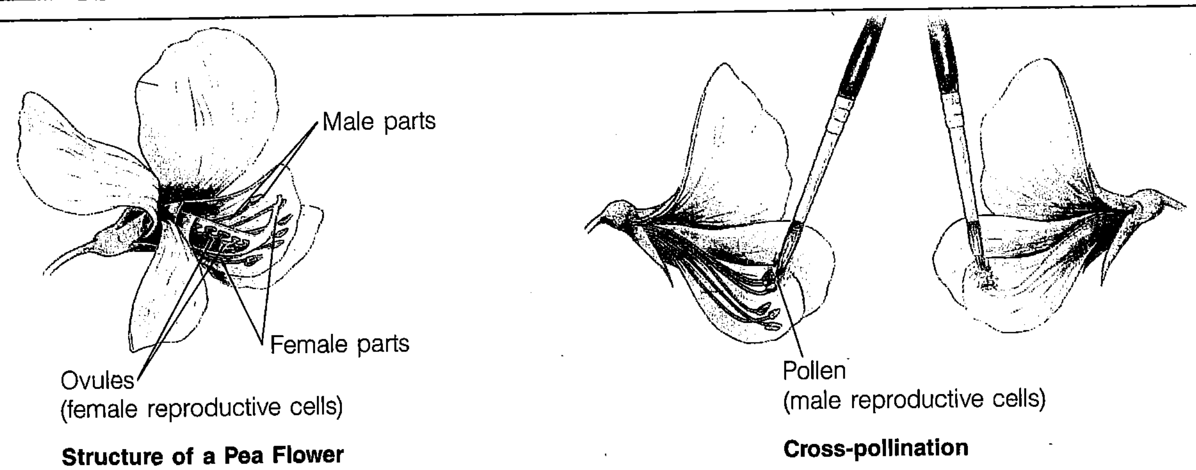
In addition to his teaching duties, Mendel had charge of the monastery garden. It was in this ordinary garden that he was to do the work that revolutionized biological science.

From his studies in biology, Mendel had gained an understanding of the sexual mechanisms of the pea plant. Pea flowers have both male and female parts. Normally, pollen from the male part of the pea flower fertilizes the female egg cells of the very same flower. Because the pollen produced by the plant fertilizes the egg cells of that very same plant, peas are said to produce seeds **by self-pollination**. Seeds produced by self-pollination inherit all of their characteristics from the single plant that bore them.

Mendel learned that self-pollination could be prevented. He carefully cut the male parts off all the flowers of one plant and the female parts off all the flowers of another plant. He then pollinated the two plants by dusting the pollen from one plant onto the flowers of the other plant. The fertilization of a plant's egg cells by the pollen of another plant is known as **cross-pollination**. Cross-pollination produces seeds that are the offspring of two different plants. With this technique, Mendel was able to cross plants with different characteristics.

Figure 9–2 *Mendel used the garden pea in his experiments on heredity (top). Garden peas usually reproduce by self-pollination because the male and female reproductive parts are tightly enclosed within the flower's petals (bottom left). One method Mendel used to cross-pollinate his pea plants was to cut off the male parts of a flower (thus preventing self-pollination) and then dust the pollen from another plant onto that flower (bottom right).*





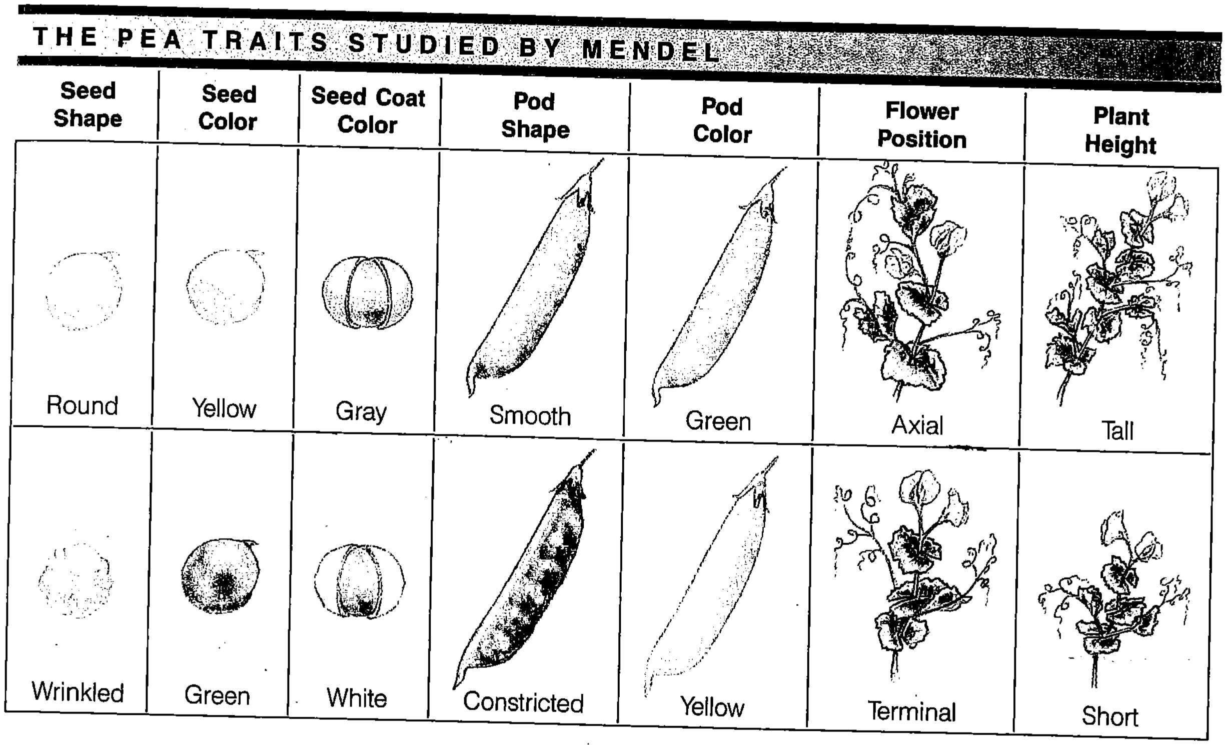


Figure 9–3 *The seven pea traits studied by Mendel are seed shape, seed color, seed coat color, pod shape, pod color, flower position, and plant height. Mendel chose these seven traits partly because each trait has only two contrasting characters, or forms.*

One of the gifts that Mendel received when he took charge of the monastery garden was a stock of peas developed by earlier gardeners. These peas were **purebred**. This means that if they were allowed to self-pollinate, the purebred peas would produce offspring that were identical to themselves. One line of plants would produce only tall plants, another only short plants. One line would produce only green seeds, another only yellow seeds. These purebred plants were the basis of Mendel's experiments.

In many respects, the most important decision Mendel made was to study just a few isolated **traits**, or characteristics, that could easily be observed. In the case of the peas, one trait was the size of the plant, another the shape of the pod, another the color of the seed. Figure 9–3 shows the seven traits that Mendel studied. By deciding to restrict his observations to just a few such traits, Mendel made his job of measuring the effects of heredity much easier.

Quick Lab

To reinforce the **Main Idea** of dominance, perform the Quick Lab activity called Comparing Phenotypes and Genotypes on p. 1085.

Genes and Dominance

What would you do if you were interested in heredity, had several kinds of purebred peas, and also knew how to cause cross-pollination? No, pea soup is not a good answer.

Mendel decided to see what would happen if he crossed pea plants with different characters for the same trait. A character is a form of a trait. For example, the flower-position trait has two characters: axial and terminal. Mendel crossed the tall

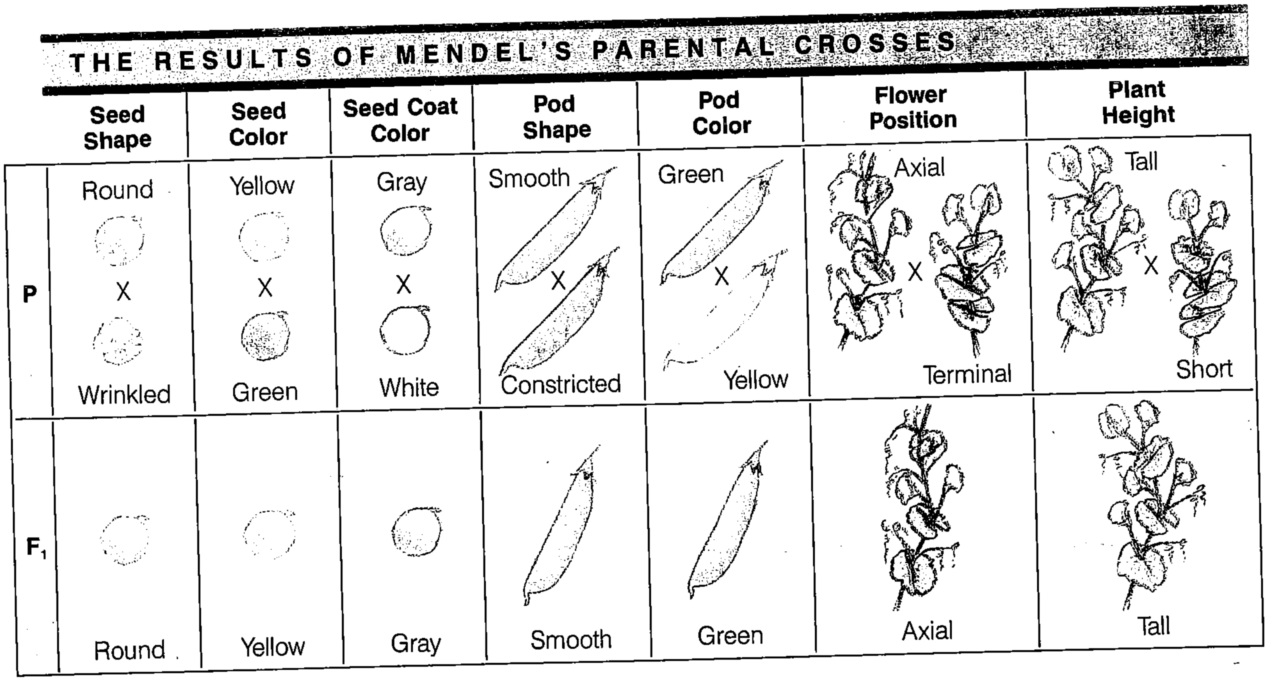


Figure 9–4 *When Mendel crossed plants with contrasting characters for the same trait, the resulting offspring had only one of the characters. From the results of these experiments, Mendel concluded that factors that do not blend control the inheritance of traits and that some of these factors are dominant, whereas others are recessive.*

plants with the short ones; the plants with yellow seeds with those with green seeds; and so on. From the crosses in his pea plants, Mendel obtained seeds that he then grew into plants. These plants were **hybrids**, or organisms produced by crossing parents with differing characters.

What were those hybrid plants like? Did the characters of the parent plants blend in the offspring? To Mendel's surprise, the plants were not half tall, nor were the seeds they produced half yellow. Instead, all of the offspring had the character of only one of the parents. The plants resulting from his crosses were all tall or produced only yellow seeds. The other character had apparently disappeared.

From this set of experiments, Mendel was able to draw two conclusions. The first is that individual factors, which do not blend with one another, control each trait of a living thing. Mendel used the word *Merkmal* to refer to these factors. *Merkmal* means character in German. Today the factors that control traits are called **genes**. Each of the traits Mendel studied was controlled by one gene that occurred in two contrasting forms. These contrasting forms produced the different characters of each trait. For example, the gene for plant height occurs in a tall form and a short form. The different forms of a gene are now called **alleles** (uh-LEELZ).

The second of Mendel's conclusions is often called the principle of **dominance**: Some factors (alleles) are **dominant**, whereas others are **recessive**. The effects of a dominant allele are seen even if it is present with a contrasting recessive allele. The effects of a recessive allele are not observed when the dominant allele is present. In Mendel's experiments, the tall and yellow alleles were dominant, whereas the short and green alleles were recessive. Although dominance is seen in the inheritance of many traits, it does not apply to all genes.

Segregation

Mendel was not content to stop his experimentation at this point. He wanted the answer to another question: What happened to the recessive characters? To answer this question, he allowed all seven kinds of hybrid plants to reproduce by self-pollination.

To keep the different groups of seeds and plants clear in his mind, Mendel gave them different names. He referred to the purebred parental plants as the P generation (P for parental). To the first generation of plants produced by cross-pollination, he gave the name F_1, which stood for first filial generation (from the Latin word *filius*, which means son). If the F_1 plants were crossed among themselves, he called the offspring F_2, for second filial generation, and so forth.

THE F_1 CROSS The results of the F_1 cross were remarkable. The recessive characters had not disappeared! Some of the F_2 plants produced by each of the F_1 crosses showed the recessive trait. This proved to Mendel that the alleles responsible for the recessive characters had not disappeared. But why did the recessive alleles disappear in the F_1 generation and reappear in the F_2? To answer this question, let's take a closer look at one of Mendel's crosses. Keep in mind that the concepts that apply to the crosses involving the trait of plant height also apply to the crosses for the other six traits.

EXPLAINING THE F_1 CROSS To begin with, Mendel assumed that the presence of the dominant tall allele had masked

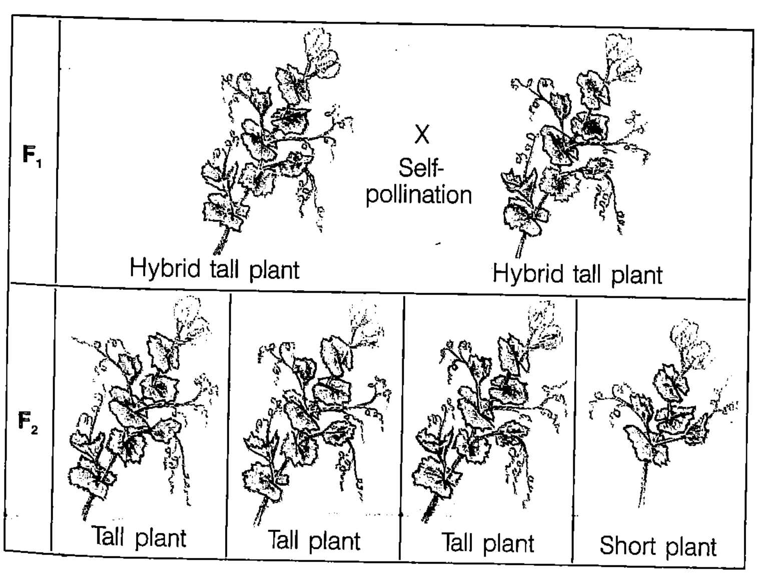


Figure 9–5 *When the F_1 hybrid plants were allowed to reproduce by self-pollination, some of the resulting F_2 offspring had the recessive character.*

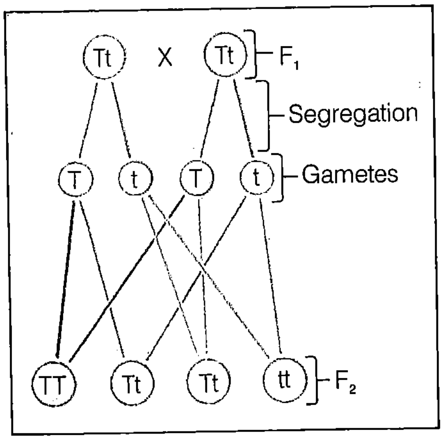
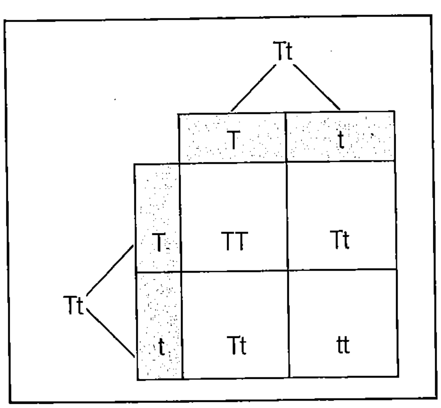


Figure 9–6 *Segregation of alleles occurs during gamete formation. The alleles are paired up again when gametes fuse during the process of fertilization.*

Figure 9–7 *This Punnett square shows a cross between two hybrid tall* (Tt) *pea plants.*



the recessive short **allele in the F_1 generation**. But the fact that the recessive allele was not masked in some of the F_2 plants indicated that the short allele had managed to get away from the tall allele. But how did this separation, or **segregation**, of alleles occur? Mendel suggested that during the formation of the reproductive cells (pollen and eggs), the tall and short alleles in the F_1 plants were segregated, or separated, from each other. Did that suggestion make sense?

Let's assume, as perhaps Mendel did, that the F_1 plants inherited an allele for tallness from one parent and an allele for shortness from the other parent. Because the tall allele is dominant, the F_1 plants appear tall. When the F_1 plant flowers, the two alleles must be separated from each other so that each reproductive cell carries only a single copy of each gene. Therefore, each F_1 plant produces two types of reproductive cells—those with the tall allele and those with the short allele.

If segregation occurs the way Mendel thought it did, then the possible gene combinations in the offspring that result from a cross can be determined by drawing a diagram known as a **Punnett square**. Biologists represent a particular allele by using a symbol. The dominant allele is represented by a capital letter. The recessive allele is represented by the corresponding lowercase letter. In this case, *T* represents the dominant tall allele and *t* represents the recessive short allele.

The Punnett square in Figure 9–7 shows the types of reproductive cells, or **gametes** (GAM-eets), produced by each F_1 parent along the top and left-hand side of the square. It also shows each possible gene combination for the F_2 **offspring** in the four boxes that make up the square.

You can see the probable results of the cross of two F_1 plants from the Punnett square: 1/4 of the F_2 plants have two tall alleles (*TT*); 2/4, or 1/2, of the F_2 plants have one tall allele and one short allele (*Tt*), and 1/4 of the F_2 plants have two short alleles (*tt*). Because tall is dominant over short, 3/4 of the F_2 plants should be tall and 1/4 of the F_2 plants should be short. These numbers are often expressed as ratios. For example, there are 3 tall plants for every 1 short plant in the F_2 generation. Thus the ratio of tall plants to short plants is 3:1, if, of course, Mendel's model of segregation is correct.

Did the data from Mendel's experiments fit his model? Yes. The predicted ratio—3 dominant to 1 recessive—showed up consistently, indicating that Mendel's assumptions about segregation had been correct. For each of his seven crosses, about 3/4 of the plants showed the dominant trait and about 1/4 showed the recessive trait. Segregation did indeed occur according to Mendel's model.

Look again at the Punnett square. You will see that three of the possible combinations result in tall plants. Because all these plants appear tall, we can say that they have the same **phenotype**, or physical characteristics. They do not, however, have the same **genotype**, or genetic makeup. The genotype of 1/3 of the tall plants is *TT*, whereas the genotype of 2/3 of the tall plants is *Tt*.

Organisms that have two identical alleles for a particular trait (*TT* or *tt* in our example) are said to be **homozygous** (hoh-moh-ZIGH-guhs) (*homo-* means same; *-zygous* refers to alleles). Organisms that have two different alleles for the same trait are **heterozygous** (heht-er-oh-ZIGH-guhs)(*hetero-* means different). In other words, homozygous organisms are purebred for a particular trait and heterozygous organisms are hybrid for a particular trait.

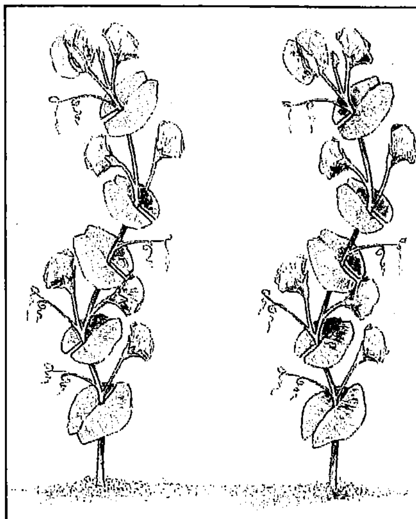


***Figure 9–8** Although these plants have different genotypes* (TT *and* Tt), *they have the same phenotype (tall).*

Independent Assortment

After establishing that alleles segregate during the formation of gametes (reproductive cells), Mendel began to explore the question of whether they do so independently. In other words, does the segregation of one pair of alleles affect the segregation of another pair of alleles? For example, does the gene that determines whether a seed is round or wrinkled in shape have anything to do with the gene for seed color? Must a round seed also be yellow? To answer these questions, Mendel first crossed purebred plants that produced round yellow seeds with purebred plants that produced wrinkled green seeds.

THE TWO-FACTOR CROSS: F_1 In this cross, the two kinds of plants would be symbolized like this:

Round yellow seeds *RRYY*

Wrinkled green seeds *rryy*

Because two traits are involved in this experiment, it is called a two-factor cross. As you examine this cross, keep in mind that you are looking at the kind of seeds the plant produces. (These seeds are not necessarily the same as the seeds from which the plants grew!)

The plant that bears round yellow seeds produces gametes that contain the alleles *R* and *Y*, or *RY* gametes. The plant that bears wrinkled green seeds produces *ry* gametes. An *RY* gamete and an *ry* gamete combine to form a fertilized egg with the genotype *RrYy*. Thus only one kind of plant will show up in the F_1 generation—plants that are heterozygous, or hybrid, for both traits. What is the phenotype of the F_1 plants? That is, what will the seeds produced by the F_1 plants look like? Because we know that round and yellow are dominant traits, we can conclude that the F_1 plants will produce seeds that are round and yellow. Remember that the concept of dominance tells us that the dominant traits will show up in a hybrid, whereas the recessive traits will seem to disappear.

This cross does not indicate whether genes assort, or segregate, independently. However, it provides the hybrid plants

***Figure 9–9** When an individual that is homozygous dominant for two traits is crossed with an individual that is recessive for the same two traits, all of the offspring are heterozygous dominant for those two traits.*

rryy

RRYY

	ry	ry	ry	ry
RY	RrYy	RrYy	RrYy	RrYy
RY	RrYy	RrYy	RrYy	RrYy
RY	RrYy	RrYy	RrYy	RrYy
RY	RrYy	RrYy	RrYy	RrYy