

## Section 11-3

### 1 FOCUS

#### Objectives

- 11.3.1 Explain** the principle of independent assortment.
- 11.3.2 Describe** the inheritance patterns that exist aside from simple dominance.
- 11.3.3 Explain** how Mendel's principles apply to all organisms.

#### Guide for Reading

#### Vocabulary Preview

Explain that the prefix *poly-* means "more than one." Ask: **What do you think a polygenic trait is?** (A trait controlled by more than one gene)

#### Reading Strategy

Before students read the section, suggest that they read the captions and study the art and diagrams in each figure.

### 2 INSTRUCT

## Independent Assortment

#### Build Science Skills

**Applying Concepts** Give students  $F_1$  corn cobs produced in a dihybrid cross between homozygous purple, starchy ( $PPSS$ ) and yellow, sweet parents ( $ppss$ ). Ask: **Which traits are controlled by dominant alleles?** (Purple and starchy) Then, have students construct a Punnett square to show all the possible gametes and offspring from the cross. (Punnett squares should look similar to the one in Figure 11-9. Possible gametes for the  $ppss$  parent are  $ps$ . Those for the  $PPSS$  parent are  $PS$ . All offspring will be heterozygous,  $PpSs$ .) **L2**

# 11-3 Exploring Mendelian Genetics

#### Guide for Reading

#### Key Concepts

- What is the principle of independent assortment?
- What inheritance patterns exist aside from simple dominance?

#### Vocabulary

independent assortment  
incomplete dominance  
codominance  
multiple alleles  
polygenic traits

#### Reading Strategy:

**Finding Main Ideas** Before you read, draw a line down the center of a sheet of paper. On the left side, write down the main topics of the section. On the right side, note supporting details and examples.

After showing that alleles segregate during the formation of gametes, Mendel wondered if they did 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?

## Independent Assortment

To answer these questions, Mendel performed an experiment to follow two different genes as they passed from one generation to the next. Mendel's experiment is known as a two-factor cross.

**The Two-Factor Cross:  $F_1$**  First, Mendel crossed true-breeding plants that produced only round yellow peas (genotype  $RRYY$ ) with plants that produced wrinkled green peas (genotype  $rryy$ ). All of the  $F_1$  offspring produced round yellow peas. This shows that the alleles for yellow and round peas are dominant over the alleles for green and wrinkled peas. A Punnett square for this cross, shown in **Figure 11-9**, shows that the genotype of each of these  $F_1$  plants is  $RrYy$ .

This cross does not indicate whether genes assort, or segregate, independently. However, it provides the hybrid plants needed for the next cross—the cross of  $F_1$  plants to produce the  $F_2$  generation.



**Figure 11-9** Mendel crossed plants that were homozygous dominant for round yellow peas with plants that were homozygous recessive for wrinkled green peas. All of the  $F_1$  offspring were heterozygous dominant for round yellow peas. **Interpreting Graphics** How is the genotype of the offspring different from that of the homozygous dominant parent?

		$rryy$			
		$ry$	$ry$	$ry$	$ry$
$RRYY$	$RY$	$RrYy$	$RrYy$	$RrYy$	$RrYy$
	$RY$	$RrYy$	$RrYy$	$RrYy$	$RrYy$
	$RY$	$RrYy$	$RrYy$	$RrYy$	$RrYy$
	$RY$	$RrYy$	$RrYy$	$RrYy$	$RrYy$



#### SECTION RESOURCES

##### Print:

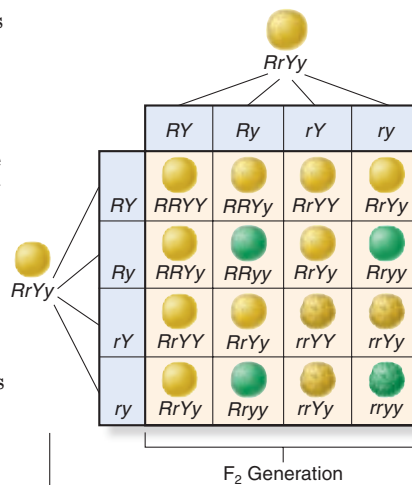
- **Laboratory Manual A**, Chapter 11 Lab
- **Laboratory Manual B**, Chapter 11 Lab
- **Teaching Resources**, Lesson Plan 11-3, Adapted Section Summary 11-3, Adapted Worksheets 11-3, Section Summary 11-3, Worksheets 11-3, Section Review 11-3
- **Reading and Study Workbook A**, Section 11-3
- **Adapted Reading and Study Workbook B**, Section 11-3

##### Technology:

- **iText**, Section 11-3
- **Transparencies Plus**, Section 11-3
- **Lab Simulations CD-ROM**, Mendelian Inheritance

**The Two-Factor Cross: F<sub>2</sub>** Mendel knew that the F<sub>1</sub> plants had genotypes of  $RrYy$ . In other words, the F<sub>1</sub> plants were all heterozygous for both the seed shape and seed color genes. How would the alleles segregate when the F<sub>1</sub> plants were crossed to each other to produce an F<sub>2</sub> generation? Remember that each plant in the F<sub>1</sub> generation was formed by the fusion of a gamete carrying the dominant  $RY$  alleles with another gamete carrying the recessive  $ry$  alleles. Did this mean that the two dominant alleles would always stay together? Or would they “segregate independently,” so that any combination of alleles was possible?

In Mendel’s experiment, the F<sub>2</sub> plants produced 556 seeds. Mendel compared the variation in the seeds. He observed that 315 seeds were round and yellow and another 32 were wrinkled and green, the two parental phenotypes. However, 209 of the seeds had combinations of phenotypes—and therefore combinations of alleles—not found in either parent. This clearly meant that the alleles for seed shape segregated independently of those for seed color—a principle known as **independent assortment**. Put another way, genes that segregate independently—such as the genes for seed shape and seed color in pea plants—do not influence each other’s inheritance. Mendel’s experimental results were very close to the 9 : 3 : 3 : 1 ratio that the Punnett square shown in **Figure 11–10** predicts. Mendel had discovered the principle of independent assortment. **The principle of independent assortment states that genes for different traits can segregate independently during the formation of gametes. Independent assortment helps account for the many genetic variations observed in plants, animals, and other organisms.**



**▲ Figure 11–10** When Mendel crossed plants that were heterozygous dominant for round yellow peas, he found that the alleles segregated independently to produce the F<sub>2</sub> generation.

## Use Visuals

**Figure 11–10** Have students give the phenotypic and genotypic ratios of the offspring for the cross shown in the figure. Ask: **What phenotypes would you observe if the alleles did not segregate independently?** (Round, yellow seeds and wrinkled, green seeds) **L2**

## Problem Solving

The 106 test plants were the result of the self-fertilization, or selfing, of the original lavender-flowering plant. Because the male and female gametes came from the same plant, they have the same genotype. You can compare this to the F<sub>1</sub> crosses set up by Mendel. **L2 L3**

### Defining the Problem

Develop true-breeding, or homozygous, lavender-flowering plants.

### Organizing Information

The allele for lavender flowers is dominant. The lavender-flowering plant is heterozygous. Students should show Punnett squares for a self-pollinating homozygous plant (would expect only one flower color) and a heterozygous plant (would expect two colors in a 3:1 ratio).

### Creating a Solution

The best plans will suggest collecting seeds from many plants with lavender flowers and sowing them in separate plots, one plot for seeds produced by each plant. Some plants should produce offspring with only lavender flowers. Sow seeds from these plants to be absolutely sure the plants are true-breeding.

### Presenting Your Plan

The best plans will include a step-by-step outline of the procedure to collect lavender-flowering plants that is genetically sound. The plan should include Punnett squares to support the genetic predictions of the crosses.

## Problem Solving

### Producing True-Breeding Seeds

Suppose you work for a company that specializes in ornamental flowers. One spring, you find an ornamental plant with beautiful lavender flowers. Knowing that these plants are self-pollinating, you harvest seeds from it. You plant the seeds the following season. Of the 106 test plants, 31 have white flowers. Is there a way to develop seeds that produce only lavender flowers?

**Defining the Problem** Describe the problem that must be solved to make the lavender-flowered plants a commercial success.

**Organizing Information** The first lavender flower produced offspring with both lavender and white flowers when allowed to self-pollinate. Use your knowledge of Mendelian genetics, including Punnett



squares, to draw conclusions about the nature of the allele for these lavender flowers.

**Creating a Solution** Write a description of how you would produce seeds guaranteed to produce 100 percent lavender plants. A single plant can produce as many as 1000 seeds.

**Presenting Your Plan** Prepare a step-by-step outline of your plan, including Punnett squares when appropriate. Present the procedure to your class.



## UNIVERSAL ACCESS

### Inclusion/Special Needs

Have students develop a table in which they list the five different patterns of gene expression, along with descriptions and examples of each. Encourage students to include Punnett squares that illustrate each pattern of inheritance.

**L1 L2**

### English Language Learners

Make sure students can differentiate between Mendel’s principles of segregation and independent assortment. Use diagrams like the one in Figure 11–5 to illustrate how alleles from different traits segregate independently. **L1 L2**

### Advanced Learners

Enable students to set up genetic crosses with fruit flies. Have enough varieties available for students to observe independent assortment and different inheritance patterns. Tell them how to use test crosses. Invite them to share their findings with the class. **L3**

## Answer to . . .

**Figure 11–9** The offspring are heterozygous.

## A Summary of Mendel's Principles



Download a worksheet on Mendelian genetics for students to complete, and find additional teacher support from NSTA SciLinks.

### Build Science Skills

**Applying Concepts** Challenge students to work in pairs to illustrate the summarized list of Mendel's principles. For reference, they can study figures in this chapter and in Chapter 12. **L1 L2**

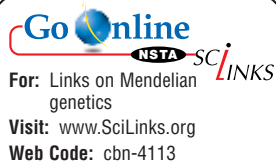
## Beyond Dominant and Recessive Alleles

### Build Science Skills

**Applying Concepts** Explain that for alleles that show incomplete dominance, such as those in **Figure 11-11**, the alleles work together to produce a “dosage effect.” For example, if a plant has one allele for red pigment and one allele for no pigment (which produces white flowers), then only half as much red pigment is produced, making the flowers pink. **L2**

### Build Science Skills

**Using Models** Challenge students to devise a model that shows the difference between incomplete dominance and codominance. One way to do this is to use paper and crayons. In incomplete dominance, two colors are blended together to form a new color. In codominance, the two individual colors are still distinctly visible; they are not blended together. **L1 L2**

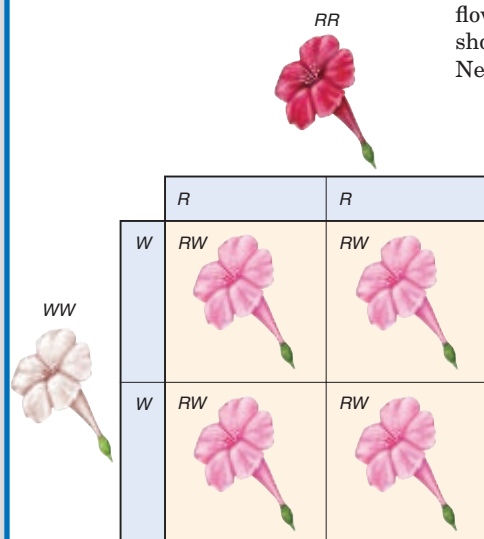


For: Links on Mendelian genetics  
Visit: [www.SciLinks.org](http://www.SciLinks.org)  
Web Code: cbn-4113



For: Punnett Square activity  
Visit: [PHSchool.com](http://PHSchool.com)  
Web Code: cbp-4112

**Figure 11-11** Some alleles are neither dominant nor recessive. In four o'clock plants, for example, the alleles for red and white flowers show incomplete dominance. Heterozygous ( $RW$ ) plants have pink flowers—a mix of red and white coloring.



## A Summary of Mendel's Principles

Mendel's principles form the basis of the modern science of genetics. These principles can be summarized as follows:

- The inheritance of biological characteristics is determined by individual units known as genes. Genes are passed from parents to their offspring.
- In cases in which two or more forms (alleles) of the gene for a single trait exist, some forms of the gene may be dominant and others may be recessive.
- In most sexually reproducing organisms, each adult has two copies of each gene—one from each parent. These genes are segregated from each other when gametes are formed.
- The alleles for different genes usually segregate independently of one another.

## Beyond Dominant and Recessive Alleles

Despite the importance of Mendel's work, there are important exceptions to most of his principles. For example, not all genes show simple patterns of dominant and recessive alleles. In most organisms, genetics is more complicated, because the majority of genes have more than two alleles. In addition, many important traits are controlled by more than one gene. **Some alleles are neither dominant nor recessive, and many traits are controlled by multiple alleles or multiple genes.**

**Incomplete Dominance** A cross between two four o'clock (*Mirabilis*) plants shows one of these complications. The  $F_1$  generation produced by a cross between red-flowered ( $RR$ ) and white-flowered ( $WW$ ) plants consists of pink-colored flowers ( $RW$ ), as shown in **Figure 11-11**. Which allele is dominant in this case?

Neither one. Cases in which one allele is not completely dominant over another are called **incomplete dominance**.

In incomplete dominance, the heterozygous phenotype is somewhere in between the two homozygous phenotypes.

**Codominance** A similar situation is **codominance**, in which both alleles contribute to the phenotype. For example, in certain varieties of chicken, the allele for black feathers is codominant with the allele for white feathers. Heterozygous chickens have a color described as “ermine,” speckled with black and white feathers. Unlike the blending of red and white colors in heterozygous four o'clocks, black and white colors appear separately. Many human genes show codominance, too, including one for a protein that controls cholesterol levels in the blood. People with the heterozygous form of the gene produce two different forms of the protein, each with a different effect on cholesterol levels.



## HISTORY OF SCIENCE

### Testing to identify $F_1$ genotypes

Mendel was very thorough in his methodology, so it really comes as no surprise that he devised a method to test his hypotheses in various ways. One method he used, which is used frequently by geneticists today, has come to be known as the testcross. A testcross is used to identify the genotype of  $F_1$  hybrids. For this cross,  $F_1$  hybrids are crossed back to the parent with the trait controlled by the recessive allele. When Mendel used

a testcross for his  $F_1$  offspring, he expected to observe approximately equal numbers of offspring with the traits controlled by the dominant and recessive alleles. That is what he observed. Today, a testcross is used to determine whether an individual with the phenotype controlled by the dominant allele is heterozygous or homozygous. If the individual is homozygous, none of the offspring will have the phenotype controlled by the recessive allele.



For: Punnett Square activity  
Visit: [PHSchool.com](http://PHSchool.com)  
Web Code: cbe-4112  
Students can make their own Punnett squares.



## FIGURE 11–12 MULTIPLE ALLELES

Coat color in rabbits is determined by a single gene that has at least four different alleles. Different combinations of alleles result in the four colors you see here.

**Interpreting Graphics** What allele combinations can a chinchilla rabbit have?



Full color:  $CC$ ,  $Cc^{ch}$ ,  $Cc^h$ , or  $Cc$



Chinchilla:  $c^{ch}c^{ch}$ ,  $c^{ch}c^h$ , or  $c^{ch}c$



Himalayan:  $c^hc$  or  $c^hc^h$



Albino:  $cc$

### Key

$C$  = full color; dominant to all other alleles

$c^{ch}$  = chinchilla; partial defect in pigmentation; dominant to  $c^h$  and  $c$  alleles

$c^h$  = Himalayan; color in certain parts of body; dominant to  $c$  allele

$c$  = albino; no color; recessive to all other alleles

**Multiple Alleles** Many genes have more than two alleles and are therefore said to have **multiple alleles**. This does not mean that an individual can have more than two alleles. It only means that more than two possible alleles exist in a population. One of the best-known examples is coat color in rabbits. A rabbit's coat color is determined by a single gene that has at least four different alleles. The four known alleles display a pattern of simple dominance that can produce four possible coat colors, as shown in **Figure 11–12**. Many other genes have multiple alleles, including the human genes for blood type.

**Polygenic Traits** Many traits are produced by the interaction of several genes. Traits controlled by two or more genes are said to be **polygenic traits**, which means “having many genes.” For example, at least three genes are involved in making the reddish-brown pigment in the eyes of fruit flies. Different combinations of alleles for these genes produce very different eye colors. Polygenic traits often show a wide range of phenotypes. For example, the wide range of skin color in humans comes about partly because more than four different genes probably control this trait.

**CHECKPOINT** What are multiple alleles?



### TEACHER TO TEACHER

When I teach introductory genetics, I find that students often lose interest studying only the inheritance of traits in pea plants. To keep them more interested, I like to relate inheritance to their world and insert many examples of human traits. Some human traits that show simple dominance include cystic fibrosis (recessive), freckles (dominant), and widow's peak (dominant). Blood type is controlled by 3 alleles in which

A ( $I^A$ ) and B ( $I^B$ ) are codominant, and both are dominant over O (ii). I devise genetics problems using these and other human traits for students to practice setting up Punnett squares and identifying genotypes and phenotypes.

—James Boal  
Biology Teacher  
Natrona County High School  
Casper, WY

## Address Misconceptions

Students might try to apply the ideas of simple dominance to other types of gene expression. Give students many different examples of incomplete dominance, codominance, multiple alleles, and polygenic traits. Collect pictures for students to compare the various phenotypes. **L1 L2**

## Use Visuals

**Figure 11–12** Explain that coat color in rabbits does show a pattern of simple dominance among four alleles. Have students study the genotypes of the rabbits in the figure. Challenge them to arrange the alleles for coat color in order from the most dominant to the least dominant. ( $C > c^{ch} > c^h > c$ ) Then, have students make up genetic crosses for coat color in rabbits and exchange them with partners. Partners should solve the problems using Punnett squares. **L2**

**Go Online**  
NSTA SciLinks  
Download a worksheet on Punnett squares for students to complete, and find additional teacher support from NSTA SciLinks.

## Applying Mendel's Principles

### Demonstration

Set up crosses between wild-type fruit flies and fruit flies with vestigial wings. Allow students to observe the parents of the cross and the  $F_1$  offspring. Ask: **Which trait is controlled by a dominant allele?** (*Normal wings*) Then, have student volunteers diagram a Punnett square on the board to predict the phenotypic ratio of the  $F_2$  offspring. Count all the  $F_2$  progeny from the cross and have students compare the actual phenotypic ratio with the predicted ratio. **L2**

### Answers to . . .

**CHECKPOINT** Genes that have more than two alleles

**Figure 11–12**  $c^{ch}c^h$ ,  $c^{ch}c^h$ , or  $c^{ch}c$

## 11-3 (continued)

# Genetics and the Environment

## Build Science Skills

**Designing Experiments** Give student groups two cuttings from the coleus plant that you started in potting soil about two weeks before. (The cuttings are genetically identical.) Challenge students to use these cuttings to design an experiment that shows how the environment affects phenotype. Students might grow one of the plants with less daylight, at warmer temperatures, or with added fertilizer. **L2**

## 3 ASSESS

### Evaluate Understanding

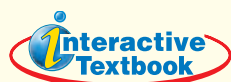
Play a game in which you ask student teams to solve various problems in genetics—from identifying the pattern of inheritance, such as simple dominance, incomplete dominance, or multiple alleles, to predicting the outcome of dihybrid crosses.

### Reteach

Students can make flashcards for each of the Vocabulary words. Student pairs can quiz each other on the meanings of the words.

#### Sharpen Your Skills

Students' problems should follow the rules of genetics and include correct and complete answers. Have pairs of students exchange and try to solve each other's problems.



If your class subscribes to the iText, use it to review the Key Concepts in Section 11-3.

#### Answer to . . .

**Figure 11-13** They are small, easy to keep in the laboratory, and produce large numbers of offspring in a short time.



▲ **Figure 11-13** The common fruit fly is a popular organism for genetic research. **Inferring** Why are fruit flies easier to use for genetic research than large animals, such as dogs?

## Applying Mendel's Principles

Mendel's principles don't apply only to plants. At the beginning of the 1900s, the American geneticist Thomas Hunt Morgan decided to look for a model organism to advance the study of genetics. He wanted an animal that was small, easy to keep in the laboratory, and able to produce large numbers of offspring in a short period of time. He decided to work on a tiny insect that kept showing up, uninvited, in his laboratory. The insect was the common fruit fly, *Drosophila melanogaster*, shown in **Figure 11-13**.

Morgan grew the flies in small milk bottles stoppered with cotton gauze. *Drosophila* was an ideal organism for genetics because it could produce plenty of offspring, and it did so quickly. A single pair of flies could produce as many as 100 offspring. Before long, Morgan and other biologists had tested every one of Mendel's principles and learned that they applied not just to pea plants but to other organisms as well.

Mendel's principles also apply to humans. The basic principles of Mendelian genetics can be used to study the inheritance of human traits and to calculate the probability of certain traits appearing in the next generation. You will learn more about human genetics in Chapter 14.

## Genetics and the Environment

The characteristics of any organism, whether bacterium, fruit fly, or human being, are not determined solely by the genes it inherits. Rather, characteristics are determined by interaction between genes and the environment. For example, genes may affect a sunflower plant's height and the color of its flowers. However, these same characteristics are also influenced by climate, soil conditions, and the availability of water. Genes provide a plan for development, but how that plan unfolds also depends on the environment.

## 11-3 Section Assessment

1. **Key Concept** Explain what *independent assortment* means.
2. **Key Concept** Describe two inheritance patterns besides simple dominance.
3. What is the difference between incomplete dominance and codominance?
4. Why are fruit flies an ideal organism for genetic research?
5. **Critical Thinking Comparing and Contrasting** A geneticist studying coat color in animals crosses a male rabbit having the genotype CC with a female having genotype Cc<sup>h</sup>. The geneticist then crosses a cc<sup>h</sup> male with a Cc<sup>h</sup> female. In which of the two crosses are the offspring more likely to show greater genetic variation? Use Punnett squares to explain your answer.

## Sharpen Your Skills

### Problem Solving

Construct a genetics problem to be given as an assignment to a classmate. The problem must test incomplete dominance, codominance, multiple alleles, or polygenic traits. Your problem must have an answer key that includes all of your work.

## 11-3 Section Assessment

1. During gamete formation, pairs of alleles for different traits segregate, or separate, independently of each other.
2. Answers include descriptions for any two: incomplete dominance, codominance, multiple alleles, or polygenic traits.
3. In incomplete dominance, two alleles combine their effects to produce a single in-between phenotype, such as pink flowers from red and white parents. In codominance, each allele is expressed separately, as when erminette chickens have both black and white feathers.
4. They are small, easy to keep in the laboratory, and produce large numbers of offspring in a short period of time.
5. The offspring in the second cross will show greater variation because 100 percent of the offspring from the first cross (CC x Cc<sup>h</sup>) will be full color.