16–2 Evolution as Genetic Change

A genetic view of evolution offers a new way to look at key evolutionary concepts. Each time an organism reproduces, it passes copies of its genes to its offspring. We can therefore view evolutionary fitness as an organism's success in passing genes to the next generation. In the same way, we can view an evolutionary adaptation as any genetically controlled physiological, anatomical, or behavioral trait that increases an individual's ability to pass along its genes.

Natural selection never acts directly on genes. Why? Because it is an entire organism—not a single gene—that either survives and reproduces or dies without reproducing. Natural selection, therefore, can only affect which individuals survive and reproduce and which do not. If an individual dies without reproducing, the individual does not contribute its alleles to the population's gene pool. If an individual produces many offspring, its alleles stay in the gene pool and may increase in frequency.

Now recall that evolution is any change over time in the relative frequencies of alleles in a population. This reminds us that it is populations, not individual organisms, that can evolve over time. Let us see how this can happen in different situations.

Natural Selection on Single-Gene Traits

Natural selection on single-gene traits can lead to changes in allele frequencies and thus to evolution. Imagine that a hypothetical population of lizards, shown in **Figure 16-5**, is normally brown, but experiences mutations that produce red and black forms. What happens to those new alleles? If red lizards are more visible to predators, they might be less likely to survive and reproduce, and the allele for red coloring might not become common.

Guide for Reading

Key Concepts
- How does natural selection affect single-gene and polygenic traits?
- What is genetic drift?
- What is the Hardy-Weinberg principle?

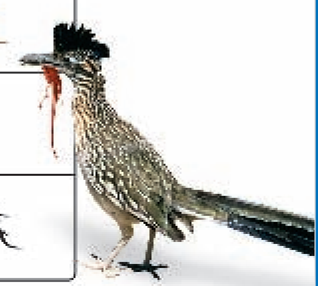
Vocabulary
directional selection
stabilizing selection
disruptive selection
genetic drift
founder effect
Hardy-Weinberg principle
genetic equilibrium

Reading Strategy: Outlining Before you read, use the headings to make an outline. As you read, add a sentence after each heading to provide key information.

▼ **Figure 16–5 Natural selection on single-gene traits can lead to changes in allele frequencies and thus to evolution.** Organisms of one color, for example, may produce fewer offspring than organisms of other colors.

Effect of Color Mutations on Lizard Survival

Initial Population	Generation 10	Generation 20	Generation 30
80%	80%	70%	40%
10%	0%	0%	0%
10%	20%	30%	60%



SECTION RESOURCES

Print:
- ***Laboratory Manual B,*** Chapter 16 Lab
- ***Teaching Resources,*** Lesson Plan 16–2, Adapted Section Summary 16–2, Adapted Worksheets 16–2, Section Summary 16–2, Worksheets 16–2, Section Review 16–2
- ***Reading and Study Workbook A,*** Section 16–2
- ***Adapted Reading and Study Workbook B,*** Section 16–2

Technology:
- ***iText,*** Section 16–2
- ***Transparencies Plus,*** Section 16–2
- ***Virtual Labs,*** Lab 14, Lab 15

Section 16–2

1 FOCUS

Objectives

16.2.1 ***Explain*** how natural selection affects single-gene and polygenic traits.
16.2.2 ***Describe*** genetic drift.
16.2.3 ***List*** the five conditions needed to maintain genetic equilibrium.

Guide for Reading

Vocabulary Preview

Challenge students to predict what the Vocabulary terms *directional selection, stabilizing selection*, and *disruptive selection* refer to. They should check to see if their predictions were correct after they read the section.

Reading Strategy

When completing their outlines, students should pay special attention to the highlighted, boldface terms and the boldface sentences.

2 INSTRUCT

Natural Selection on Single-Gene Traits

Use Visuals

Figure 16–5 Ask: **How does color affect the fitness of the lizards?** *(Both red and brown lizards are less fit than black lizards.)* **What do you predict the lizard population will look like by generation 50? Explain.** *(Students are likely to say that the lizard population will have more black lizards, fewer brown lizards, and no red lizards by generation 50. They should describe the environmental conditions that would support their prediction.)* L1 L2

16–2 (continued)

Quick Lab

Objective Students will be able to analyze data and infer that the environment affects survival. L1 L2

Skills Focus **Analyzing Data, Inferring**

Materials scissors, construction paper (several colors), transparent tape, 15-cm ruler, watch with a second hand

Time 20 minutes

Advance Prep Select surfaces that will not be harmed by tape. Provide students with construction paper in some colors that blend with and other colors that contrast with the selected surfaces.

Strategy Relate the lab to natural selection.

Expected Outcome Students will find that butterflies in contrasting colors are easier to see.

Analyze and Conclude

1. Butterflies in colors that contrast with the surfaces are the easiest to see. These butterflies would be the most easily caught by a predator.

2. After many generations, the population will be made up only of butterflies in colors that are difficult to see.

Natural Selection on Polygenic Traits

Build Science Skills

Inferring Explain that polygenic traits are often susceptible to environmental influences. In fact, a shift in the environment can lead to a corresponding shift in the phenotypes of a polygenic trait, which can mimic directional selection. Give students an example. Explain that during the 1900s, average height in the United States increased because of environmental factors. Ask: **What environmental factors do you think led to this shift in phenotype?** *(The increase in average height has been attributed largely to changes in diet and health care that maximized growth potential.)* L2

Quick Lab

Can the environment affect survival?

Materials scissors, construction paper (several colors), transparent tape, 15-cm ruler, watch with a second hand

Procedure

1. Choose three different-colored sheets of construction paper. Cut out a butterfly shape from each sheet, 5 × 10 cm in size. **CAUTION:** *Be careful with scissors.*
2. Tape your butterflies to different-colored surfaces. Then, return to your seat.
3. Record how many shapes of each color you can count from your desk in 5 seconds.
4. Exchange your observations with your classmates to determine the class total for each color.

Analyze and Conclude

1. **Analyzing Data** According to your class data, which colors of butterfly are easiest to see? Which color of butterfly would be most easily caught by a predator?
2. **Inferring** What will happen to the butterfly population after many generations if predators consume most of the easy-to-see butterflies?

Black lizards, on the other hand, might absorb more sunlight and warm up faster on cold days. If high body temperature allows them to move faster to feed and to avoid predators, they might produce more offspring than brown forms. The allele for black color might then increase in relative frequency. If a color change has no effect on fitness, the allele that produces it would not be under pressure from natural selection.

Natural Selection on Polygenic Traits

When traits are controlled by more than one gene, the effects of natural selection are more complex. As you learned earlier, the action of multiple alleles on traits such as height produces a range of phenotypes that often fit a bell curve. The fitness of individuals close to one another on the curve will not be very different. But fitness can vary a great deal from one end of such a curve to the other. And where fitness varies, natural selection can act. **Natural selection can affect the distributions of phenotypes in any of three ways: directional selection, stabilizing selection, or disruptive selection.**

Directional Selection When individuals at one end of the curve have higher fitness than individuals in the middle or at the other end, **directional selection** takes place. The range of phenotypes shifts as some individuals fail to survive and reproduce while others succeed. To understand this, consider how limited resources, such as food, can affect the long-term survival of individuals and the evolution of populations.

Among seed-eating birds such as Darwin's finches, for example, birds with bigger, thicker beaks can feed more easily on larger, harder, thicker-shelled seeds. Suppose a food shortage causes the supply of small and medium-sized seeds to run low, leaving only larger seeds. Birds whose beaks enable them to open those larger seeds will have better access to food. Birds with the big-beak adaptation would therefore have higher fitness than small-beaked birds. The average beak size of the population would probably increase, as shown in **Figure 16–6.**

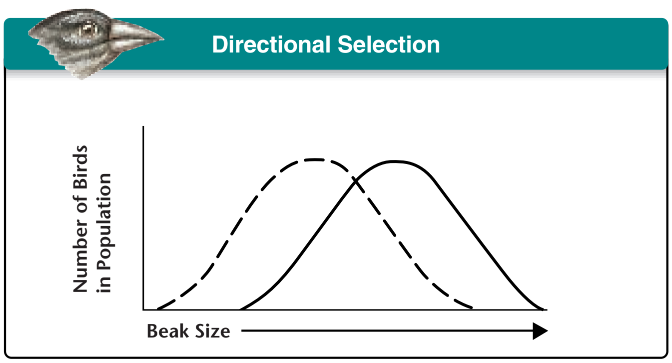


Figure 16–6 Directional selection occurs when individuals at one end of the curve have higher fitness than individuals in the middle or at the other end. In this example, a population of seed-eating birds experiences directional selection when a food shortage causes the supply of small seeds to run low. The dotted line shows the original distribution of beak sizes. The solid line shows how the distribution of beak sizes would change as a result of selection.

ESL SUPPORT FOR ENGLISH LANGUAGE LEARNERS

Comprehension: Ask Questions

Beginning To help students understand the relationship between genetics and natural selection, distribute a rewritten, modified version of the first three paragraphs on page 397 that includes the most important information. Ask students questions that can be answered directly from the rewritten text. For example: When an organism reproduces, what does it pass to its offspring? How do genes affect an organism's adaptations? L1

Intermediate Have students read the modified text that you prepared for beginning students and then read the actual text in the book. Students can work in groups to write questions about the text. Provide answers both orally and in writing. L2

Stabilizing Selection When individuals near the center of the curve have higher fitness than individuals at either end of the curve, **stabilizing selection** takes place. This situation keeps the center of the curve at its current position, but it narrows the overall graph.

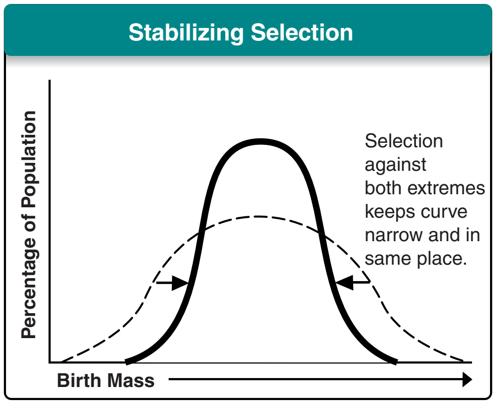
As shown in **Figure 16–7**, the mass of human infants at birth is under the influence of stabilizing selection. Human babies born much smaller than average are likely to be less healthy and thus less likely to survive. Babies that are much larger than average are likely to have difficulty being born. The fitness of these larger or smaller individuals is, therefore, lower than that of more average-sized individuals.

Disruptive Selection When individuals at the upper and lower ends of the curve have higher fitness than individuals near the middle, **disruptive selection** takes place. In such situations, selection acts most strongly against individuals of an intermediate type. If the pressure of natural selection is strong enough and lasts long enough, this situation can cause the single curve to split into two. In other words, selection creates two distinct phenotypes.

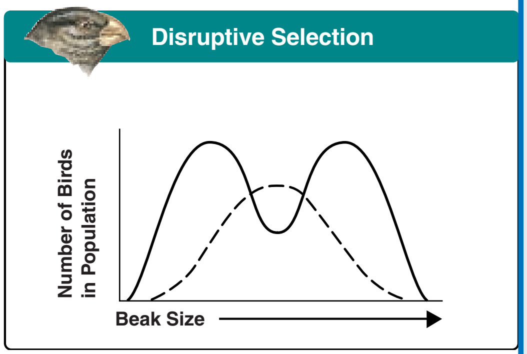
For example, suppose a population of birds lives in an area where medium-sized seeds become less common and large and small seeds become more common. Birds with unusually small or large beaks would have higher fitness. As shown in **Figure 16–8**, the population might split into two subgroups: one that eats small seeds and one that eats large seeds.

Genetic Drift

In small populations, an allele can become more or less common simply by chance, rather than because it has positive or negative effects on fitness. The smaller a population is, the greater the chance that it will experience this kind of random change in allele frequency. This kind of random change in allele frequency is called **genetic drift.** How does genetic drift take place? **In small populations, individuals that carry a particular allele may leave more descendants than other individuals, just by chance. Over time, a series of chance occurrences of this type can cause an allele to become common in a population.**



▲ **Figure 16–7** In this example of stabilizing selection, human babies born at an average mass are more likely to survive than babies born either much smaller or much larger than average.



▲ **Figure 16–8** In this example of disruptive selection, average-sized seeds become less common, and larger and smaller seeds become more common. As a result, the bird population splits into two subgroups specializing in eating different-sized seeds.

Demonstration

Show students illustrations of monarch and viceroy butterflies. Challenge them to detect any visible differences between the two species. Explain that monarch butterflies are avoided by bird predators because they taste bitter and that viceroy butterflies are avoided by bird predators because they resemble the bitter-tasting monarch butterflies, a situation called mimicry that has evolved through natural selection. L2 L3

Use Visuals

Figure 16–7 Ask: **If the fitness of phenotypes at both ends of the curve were to decrease even more, how would it affect the shape of the curve?** *(The curve would become narrower.)* **If medical advances could prevent problems for high birth weight babies but not for low birth weight babies, how might the curve change then?** *(There might be a shift in the curve toward higher birth weights or at least a broadening of the curve at the high end.)* L1 L2

Genetic Drift

Build Science Skills

Using Models Divide the class into groups, and provide each group with a bowl containing 10 beans each of 5 different types, such as pinto, kidney, navy, white, and lima beans. Challenge groups to brainstorm for a way to use the beans to model genetic drift. *(One way is by randomly selecting only some of the beans from the bowl to represent alleles in the next generation.)* Ask: **How would you show with your model that genetic change had occurred?** *(By calculating the relative frequencies of the different types of beans in the next generation to show that their frequencies had changed)* L2

16–2 (continued)

Make Connections

Environmental Science State that the founder effect may be especially likely to occur when natural disasters take place. Challenge students to think of ways in which natural disasters might result in a small number of individuals from a population becoming and remaining isolated from the rest of the group. *(As one example, students might describe how a forest fire isolates a few rodents in a small remnant of forest.)* L1 L2

Go Online active art

For: Genetic Drift activity
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Students explore the concept of genetic drift online.

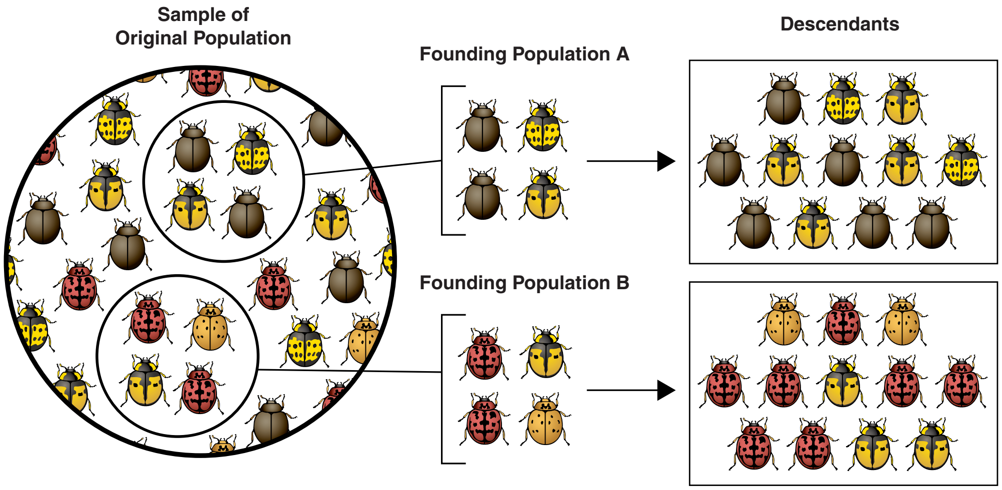

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Figure 16–9 **In small populations, individuals that carry a particular allele may have more descendants than other individuals. Over time, a series of chance occurrences of this type can cause an allele to become more common in a population.** This model demonstrates how two small groups from a large, diverse population could produce new populations that differ from the original group.

Genetic drift may occur when a small group of individuals colonizes a new habitat. These individuals may carry alleles in different relative frequencies than did the larger population from which they came. If so, the population that they found will be genetically different from the parent population. Here, however, the cause is not natural selection but simply chance—specifically, the chance that particular alleles were in one or more of the founding individuals, as shown in **Figure 16–9.** A situation in which allele frequencies change as a result of the migration of a small subgroup of a population is known as the **founder effect.** One example of the founder effect is the evolution of several hundred species of fruit flies found on different Hawaiian Islands. All of those species descended from the same original mainland population. Those species in different habitats on different islands now have allele frequencies that are different from those of the original species.

Hardy-Weinberg and Genetic Equilibrium

To clarify how evolutionary change operates, scientists often find it helpful to determine what happens when *no* change takes place. So biologists ask: Are there any conditions under which evolution will not occur? Is there any way to recognize when that is the case? The answers to those questions are provided by the Hardy-Weinberg principle, named after two researchers who independently proposed it in 1908.

The **Hardy-Weinberg principle** states that allele frequencies in a population will remain constant unless one or more factors cause those frequencies to change. The situation in which allele frequencies remain constant is called **genetic equilibrium.** If the allele frequencies do not change, the population will not evolve.

BIO INSIGHTS — FACTS AND FIGURES

***Mutiny on the* Bounty**

A good example of founder effect in human populations is the population of Pitcairn Island in the South Pacific. The island's population today has limited genetic variability because it was founded by only a handful of people in the late 1700s. The founders consisted of nine mutineers from the HMS *Bounty*, all of whom were English, along with a small number of Tahitian men and Tahitian women. A few years after the population was founded, the number of people declined even more because of a disagreement between the English and Tahitian men. When Pitcairn Island was discovered by American whalers in 1808, the population consisted of just one Englishman, several Tahitian women, and some children. Because the population was geographically isolated, few new genes entered the gene pool over subsequent years, and genetic variation remained limited.

Under what conditions does the Hardy-Weinberg principle hold? **Five conditions are required to maintain genetic equilibrium from generation to generation: (1) There must be random mating: (2) the population must be very large; and (3) there can be no movement into or out of the population, (4) no mutations, and (5) no natural selection.**

In some populations and in rare situations, these five conditions may be met or nearly met for long periods of time. If, however, the conditions are not met, the genetic equilibrium will be disrupted, and the population will evolve.

Solving Problems Using Hardy-Weinberg

It turns out that the Hardy-Weinberg principle is based on an equation that allows us to check its predictions. That equation can also be used to calculate and predict the frequency of certain genotypes.

Imagine that you are a geneticist studying a trait controlled by two alleles, *A* and *a*. You know that these alleles follow rules of simple dominance. You survey a population for the trait, and discover that 4% of the population exhibits the phenotype produced by the homozygous recessive genotype *aa*. Fully 96% of the population is *AA* or *Aa* and exhibits the dominant phenotype.

The Hardy-Weinberg equations represent the frequency of the dominant *A* allele as p and the frequency of the recessive *a* allele as q. The sum of the frequencies must always equal the entire population (100%). In mathematical form, this can be written as the equation:

$$r + q = 1$$

Recall from Chapter 11, that any cross that involves these alleles can produce three possible genotypes: *AA*, *Aa*, and *aa*.

Now, when eggs and sperm are produced in members of this population, those gametes will carry these alleles in the same relative frequencies at which those alleles occur in the population. Thus, the relative frequency of eggs and sperm that carry the *A* allele will be equal to p, and the relative frequency of eggs and sperm that carry the *a* allele will be equal to q. The three types of zygotes produced by these eggs and sperm will have the same relative numbers as the individuals in the Punnett square.

▲ **Figure 16–10** **One of the five conditions that are needed to maintain genetic equilibrium from one generation to the next is large population size.** The allele frequencies of large populations, such as this group of birds, are less likely to be changed through the process of genetic drift.

Hardy-Weinberg and Genetic Equilibrium

Make Connections

Mathematics Explain that in addition to allele frequencies remaining constant when a population is in genetic equilibrium, genotype proportions also remain constant and can be calculated from the allele frequencies. If p is the frequency of allele *A* for a trait and q is the frequency of allele *a* for the same trait, then genotype proportions are given by $(p + q)^2 = p^2\ (AA) + 2pq\ (Aa) + q^2\ (aa)$. Ask: **If a population is in genetic equilibrium and the value of p is 0.3, what proportion of the population has each genotype?** *(The proportion of* AA *individuals is p^2, or 0.09; the proportion of* Aa *individuals is 2pq, or 0.42; and the proportion of* aa *individuals is q^2, or 0.49.)* Point out that the genotype proportions must add up to 1.00. L2 L3

Solving Problems Using Hardy-Weinberg

Build Science Skills

Inferring Explain that selection for heterozygotes can also lead to equilibrium in allele frequencies, and give the following example. State that, in some African populations where malaria is prevalent, heterozygotes for sickle cell hemoglobin have the highest fitness, because they are somewhat resistant to malaria and largely unaffected by sickle cell anemia. Homozygotes for sickle cell hemoglobin have the lowest fitness, because they have sickle cell anemia. Normal homozygotes have somewhat reduced fitness, because they have no resistance to malaria. As a result, the allele for sickle cell hemoglobin persists in these populations. Ask: **What do you think would happen to the sickle cell allele in these populations if malaria were eradicated?** *(The allele would be selected against and become less common.)* L2

TEACHER TO TEACHER

Using a series of overhead transparencies, I explain the Hardy-Weinberg principle to the entire class. Then, I distribute a problem sheet to the students and have them work in pairs. One student is the tutor, and the other is the learner. While students are teaching one another, I circulate through the classroom, providing help where needed. After each pair of students has solved three problems, I have the students reverse roles with their partners. I find that students understand the Hardy-Weinberg principle much more quickly and thoroughly when they are able to explain it to one another. At the end of this activity, I have each pair write a new problem on an overhead transparency. I then use these new problems as a warm-up activity for genetics.

—*Marion LaFemina*
Biology Teacher
Ridgewood High School
Ridgewood, NJ

16–2 (continued)

3 ASSESS

Evaluate Understanding

Ask students to write a paragraph summarizing the different types of natural selection on polygenic traits.

Reteach

Using the board or a transparency, work with students to make a concept map showing the conditions required for genetic equilibrium.

Sharpen Your Skills

One way students can model selection is to use the different-sized squares to represent individual phenotypes in a population. They can increase the number of either small or large squares to model directional selection, of medium-sized squares to model stabilizing selection, and of both small and large squares to model disruptive selection.

Those numbers can be expressed by the following equation:

$$p^2 + 2pq + q^2 = 1$$

p^2 = frequency of *AA* homozygotes

$2pq$ = the frequency of *Aa* heterozygotes

q^2 = the frequency of *aa* homozygotes

1 = the sum of frequencies of all genotypes (100%)

In a particular generation, we find that $p = 0.8$, and $q = 0.2$. How can you figure out the relative frequencies of *AA, Aa,* and *aa* individuals?

1. First, write the following equation:

$p^2 + 2pq + q^2 = 1$ (or $A^2 + 2Aa + a^2 = 1$)

2. Fill in the values.

$(0.8)^2 + 2(0.8 \times 0.2) + (0.2)^2 = 1$

3. Calculate.

$(0.8 \times 0.8) + 2(0.16) + (0.2 \times 0.2) = 1$

$0.64 + 0.32 + 0.04 = 1.00$

4. Convert the fractions to percentages.

$0.64 \times 100 = 64\%$, so 64% is the frequency of homozygous dominant individuals (*AA*).

$0.32 \times 100 = 32\%$, so 32% is the frequency of heterozygous recessive individuals (*Aa*).

$0.04 \times 100 = 4\%$, so 4% is the frequency of homozygous recessive individuals (*aa*).

As long as the Hardy-Weinberg equilibrium conditions hold, neither the frequency of the genotypes nor the frequencies of the alleles (p and q) will change from generation to generation.

16–2 Section Assessment

1. **Key Concept** Describe how natural selection can affect traits controlled by single genes.
2. **Key Concept** Describe three patterns of natural selection on polygenic traits. Which one leads to two distinct phenotypes?
3. **Key Concept** How does genetic drift lead to a change in a population's gene pool?
4. **Key Concept** What is the Hardy-Weinberg principle?
5. **Critical Thinking Calculating** You are studying a population of 100 people and discover that 36 of these people are *ss* for a genetic condition. Use the Hardy-Weinberg equation to figure out the frequencies of the *S* and *s* alleles. What are the frequencies of the *SS, Ss,* and *ss* genotypes?

Sharpen Your Skills

Using Models
Demonstrate natural selection on polygenic traits by cutting a sheet of paper into squares of five different sizes to represent sizes in a population. Use the squares to model directional, stabilizing, and disruptive selection.

16–2 Section Assessment

1. It can lead to changes in allele frequencies and the evolution of traits.
2. Directional selection favors one extreme; stabilizing selection favors the middle of the range; disruptive selection favors both extremes and leads to two phenotypes.
3. Genetic drift causes random changes in allele frequencies in small populations.
4. Allele frequencies in a population remain constant unless one or more factors cause the frequencies to change.
5. SS = 12.96%; Ss = 46.08%; ss = 40.96%

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 16–2.

Should the Use of Antibiotics Be Restricted?

Natural selection is everywhere. One dramatic example of evolution in action poses a serious threat to public health. Many kinds of disease-causing bacteria are evolving resistance to antibiotics—drugs intended to kill them or interfere with their growth.

Antibiotics are one of medicine's greatest weapons against bacterial diseases. When antibiotics were discovered, they were called "magic bullets" and "wonder drugs" because they were so effective. They have made diseases like pneumonia much less of a threat than they were about sixty years ago. However, people may be overusing antibiotics. Doctors sometimes prescribe them for diseases for which they are not effective. Commercial feed for chickens and other farm animals is laced with antibiotics to prevent infection.

This wide use has caused many bacteria—including *Mycobacterium tuberculosis,* which causes tuberculosis—to evolve resistance to antibiotics. This resistance is a prime example of the evolution of a genetically controlled physiological trait. Resistance evolved because bacterial populations contained a few individuals with genes that enabled them to destroy, inactivate, or eliminate antibiotics. Descendants of those physiologically similar individuals survived and reproduced, and became today's resistant strains. Once-powerful antibiotics are now useless against resistant bacteria. Given this risk, should government agencies restrict the use of antibiotics?

The Viewpoints

Antibiotic Use Should Be Restricted

The danger of an incurable bacterial epidemic is so high that action must be taken on a national level as soon as possible. Doctors overuse antibiotics in humans because patients demand them. The livestock industry likes using antibiotics in animal feeds and will not change their practice unless forced to do so.

Antibiotic Use Should Not Be Restricted

Researchers are coming up with new drugs all the time. These drugs can be reserved for human use only. Doctors need to be able to prescribe antibiotics as they choose, and our food supply depends on the use of antibiotics in agriculture. The medical profession and the livestock industry need the freedom to find solutions that work best for them.

Research and Decide

1. **Analyzing the Viewpoints** To make an informed decision, learn more about this issue by consulting library and Internet resources. Then, list the advantages and disadvantages of restricting the use of antibiotics.
2. **Forming Your Opinion** Should antibiotics be restricted? Are there some situations in which such regulations would be more appropriate than others?

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Suggest that students investigate the role patients play in the development of resistance by demanding antibiotics and then failing to take them correctly. Also, have students investigate bacterial resistance to other agents because of the widespread use of antibacterial products, ranging from disinfectant sprays to hand gels, soaps, and lotions.

Research and Decide

1. Advantages of restricting the use of antibiotics include a reduced risk of bacteria becoming resistant to antibiotics and less danger of an incurable bacterial epidemic. Disadvantages include the likelihood of more deaths and suffering from infectious diseases and a possible reduction in the food supply because of more infections in farm animals.
2. Some students might say that antibiotics should be restricted to human use or to people who have serious infectious diseases.

Go Online
PHSchool.com
Students can research antibiotic resistance on the site developed by authors Ken Miller and Joe Levine.