17 Evolution of Populations

Big idea: Evolution

Q: How can populations evolve to form new species?

Poised on a flower, the two common blue butterflies (Polyommatus icarus) appear identical. However, if you look closely, you can see that the patterns on their wings are slightly different. Variations among individual members of a population provide the raw material for evolution and sometimes for the formation of new species.

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INSIDE:

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

EPIDEMIC

In 1918, an epidemic began that would go on to kill more than 40 million people. A doctor wrote: "Dead bodies are stacked about the morgue like cordwood."

What was this terrible disease? It was a variety of the same influenza virus that causes "the flu" you catch again and again. How did this strain of a common virus become so deadly? And could that kind of deadly flu epidemic happen again?

The answers to those questions explain why we can't make a permanent vaccine against the flu, as we can against measles or smallpox. They also explain why public health officials worry so much about something you may have heard referred to as "bird flu." As you read this chapter, look for evolutionary processes that might help explain how new strains of influenza virus appear all the time. Then, solve the mystery.

Never Stop Exploring Your World. Finding the solution to the epidemic mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

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17.1 Genes and Variation

Key Questions

- *How is evolution defined in genetic terms?*
- *What are the sources of genetic variation?*
- *What determines the number of phenotypes for a given trait?*

Vocabulary

gene pool
allele frequency
single-gene trait
polygenic trait

Taking Notes

Concept Map As you read about sources of genetic variation, construct a concept map to describe the sources.

THINK ABOUT IT Darwin developed his theory of natural selection without knowing how heredity worked. Mendel's studies on inheritance in peas were published during Darwin's lifetime, but no one (including Darwin) realized how important that work was. So Darwin had no idea how heritable traits pass from one generation to the next. What's more, although Darwin based his theory on heritable variation, he had no idea where that variation came from. What would happen when genetics answered those questions?

Genetics Joins Evolutionary Theory

How is evolution defined in genetic terms?

After Mendel's work was rediscovered around 1900, genetics took off like a rocket. Researchers discovered that heritable traits are controlled by genes that are carried on chromosomes. They learned how changes in genes and chromosomes generate variation.

All these discoveries in genetics fit perfectly into evolutionary theory. Variation is the raw material for natural selection, and finally scientists could study how and why variation occurs. Today, techniques of molecular genetics are used to form and test many hypotheses about heritable variation and natural selection. Modern genetics enables us to understand, better than Darwin ever could, how evolution works.

Genotype and Phenotype in Evolution Typical plants and animals contain two sets of genes, one contributed by each parent. Specific forms of a gene, called alleles, may vary from individual to individual. An organism's genotype is the particular combination of alleles it carries. An individual's genotype, together with environmental conditions, produces its phenotype. Phenotype includes all physical, physiological, and behavioral characteristics of an organism, such as eye color or height. Natural selection acts directly on phenotype, not genotype. In other words, natural selection acts on an organism's characteristics, not directly on its alleles.

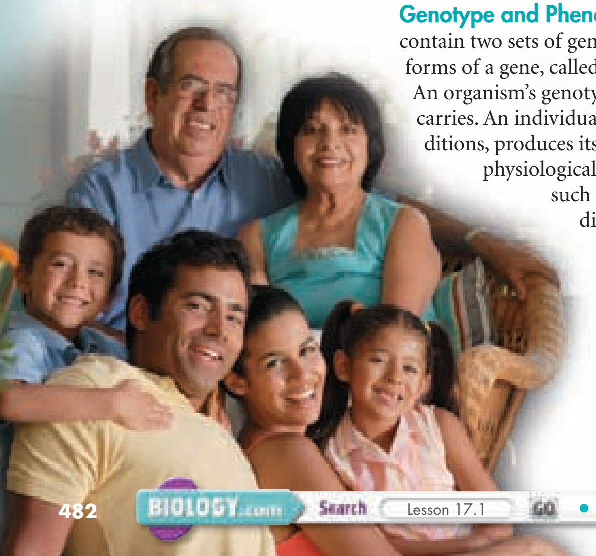


FIGURE 17–1 Genes and Variation Why do biological family members resemble each other, yet also look so different? Similarities come from shared genes. Most differences come from gene shuffling during reproduction and environmental influences. A few differences may be caused by random mutations.

How does that work? In any population, some individuals have phenotypes that are better suited to their environment than are the phenotypes of other individuals. The better-suited individuals produce more offspring than the less fit individuals do. Therefore, organisms with higher fitness pass more copies of their genes to the next generation.

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.

In Your Notebook *Describe how natural selection affects genotypes by acting on phenotypes.*

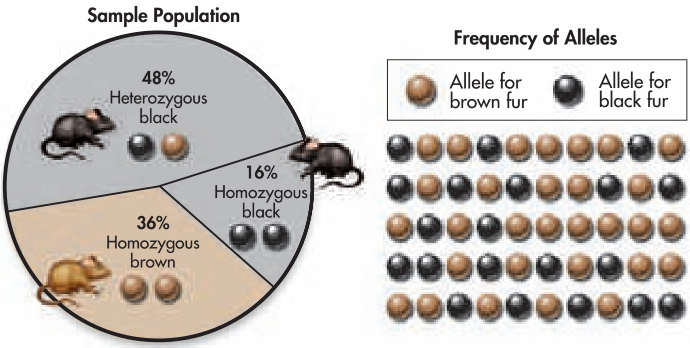


FIGURE 17–2 Alleles in a Population When scientists try to determine whether a population is evolving, they study its allele frequencies. This diagram shows allele frequencies for fur color in a mouse population. **Calculate** ***Here, in a total of 50 alleles, 20 alleles are* B *(black) and 30 are* b *(brown). How many of each allele would be present in a total of 100 alleles?*** MATH

Populations and Gene Pools Genetic variation and evolution are both studied in populations. A population is a group of individuals of the same species that mate and produce offspring. Because members of a population interbreed, they share a common group of genes called a gene pool. A **gene pool** consists of all the genes, including all the different alleles for each gene, that are present in a population.

Researchers study gene pools by examining the numbers of different alleles they contain. **Allele frequency** is the number of times an allele occurs in a gene pool, compared to the total number of alleles in that pool for the same gene. For example, in the mouse population in **Figure 17–2,** the allele frequency of the domiant *B* allele (black fur) is 40 percent, and the allele frequency of the recessive *b* allele (brown fur) is 60 percent. The allele frequency of an allele has nothing to do with whether the allele is dominant or recessive. In this mouse population, the recessive allele occurs more frequently than the dominant allele.

Evolution, in genetic terms, involves a change in the frequency of alleles in a population over time. For example, if the frequency of the *B* allele in **Figure 17–2** drops to 30 percent, the population is evolving. It's important to note that populations, not individuals, evolve. Natural selection operates on individual organisms, but the changes it causes in allele frequency show up in the population as a whole.

BUILD Vocabulary

MULTIPLE MEANINGS Perhaps the most common definition of the noun *pool* is a large man-made body of water in which you can swim. However, a *pool* can also refer to an available supply of a resource. In the case of a **gene pool,** the resource is genetic information.

FIGURE 17–3 Genetic Variation Genetic variation may produce visible variations in phenotype, such as the different-colored kernels in these ears of maize. Other kinds of genetic variation, such as resistance to disease, may not be visible, even though they are more important to evolutionary fitness.

Sources of Genetic Variation

What are the sources of genetic variation?

Genetics enables us to understand how heritable variation is produced. **Three sources of genetic variation are mutation, genetic recombination during sexual reproduction, and lateral gene transfer.**

Mutations A mutation is any change in the genetic material of a cell. Some mutations involve changes within individual genes. Other mutations involve changes in larger pieces of chromosomes. Some mutations—called neutral mutations—do not change an organism's phenotype.

Mutations that produce changes in phenotype may or may not affect fitness. Some mutations, such as those that cause genetic diseases, may be lethal. Other mutations may lower fitness by decreasing an individual's ability to survive and reproduce. Still other mutations may improve an individual's ability to survive and reproduce.

How common are mutations? Recent estimates suggest that each of us is born with roughly 300 mutations that make parts of our DNA different from that of our parents. Most of those mutations are neutral. One or two are potentially harmful. A few may be beneficial.

Note that mutations matter in evolution only if they can be passed from generation to generation. For that to happen, mutations must occur in the germ line cells that produce either eggs or sperm. A mutation in skin cells that produces a nonlethal skin cancer, for example, will not be passed to the next generation.

Genetic Recombination in Sexual Reproduction Mutations are not the only source of heritable variation. You do not look exactly like your biological parents, even though they gave you all your genes. You probably look even less like any brothers or sisters you may have. Yet no matter how you feel about your relatives, mutant genes are not primarily what makes them look so different from you. Most heritable differences are due not to mutations, but to genetic recombination during sexual reproduction. Remember that each chromosome in a pair moves independently during meiosis. In humans, who have 23 pairs of chromosomes, this process can produce 8.4 million gene combinations!

Crossing-over is another way in which genes are recombined. Recall that crossing-over occurs during meiosis. In this process, paired chromosomes often swap lengths of DNA at random. Crossing-over further increases the number of new genotypes created in each generation. You can now understand why, in species that reproduce sexually, no two siblings (except identical twins) ever look exactly alike. With all that independent assortment and crossing-over, you can easily end up with your mother's eyes, your father's nose, and hair that combines qualities from both your parents. You can also now understand why, as Darwin noted, individual members of a species differ from one another.

MYSTERY CLUE

The genes of flu viruses have very high mutation rates. How might this affect the amount of variation in the viral gene pool?

In Your Notebook *Which source of variation brings more diversity into a gene pool—mutation or sexual reproduction? Explain.*

Lateral Gene Transfer Most of the time, in most eukaryotic organisms, genes are passed only from parents to offspring (during sexual or asexual reproduction). Some organisms, however, pass genes from one individual to another, or even from individuals of one species to another. Recall, for example, that many bacteria swap genes on plasmids as though the genes were trading cards. This passing of genes from one organism to another organism that is not its offspring is called lateral gene transfer. Lateral gene transfer can occur between organisms of the same species or organisms of different species.

Lateral gene transfer can increase genetic variation in any species that picks up the "new" genes. This process is important in the evolution of antibiotic resistance in bacteria. Lateral gene transfer has been common, and important, in single-celled organisms during the history of life.

Single-Gene and Polygenic Traits

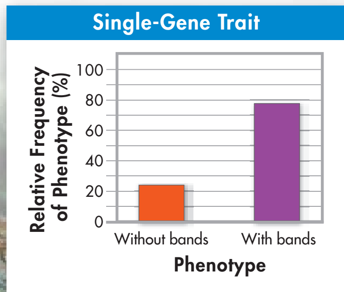
What determines the number of phenotypes for a given trait?

Genes control phenotype in different ways. In some cases, a single gene controls a trait. Other times, several genes interact to control a trait. **The number of phenotypes produced for a trait depends on how many genes control the trait.**

Single-Gene Traits In the species of snail shown below, some snails have dark bands on their shells, and other snails don't. The presence or absence of dark bands is a **single-gene trait**—a trait controlled by only one gene. The gene that controls shell banding has two alleles. The allele for a shell without bands is dominant over the allele for a shell with dark bands. All genotypes for this trait have one of two phenotypes—shells with bands or shells without bands. Single-gene traits may have just two or three distinct phenotypes.

The bar graph in **Figure 17–4** shows the relative frequency of phenotypes for this single gene in one population of snails. This graph shows that the presence of dark bands on the shells may be more common in a population than the absence of bands. This is true even though the allele for shells without bands is the dominant form. In populations, phenotypic ratios are determined by the frequency of alleles in the population as well as by whether the alleles are dominant or recessive.

FIGURE 17–4 Two Phenotypes In this species of snail, a single gene with two alleles controls whether or not a snail's shell has bands. The graph shows the percentages, in one population, of snails with bands and snails without bands.



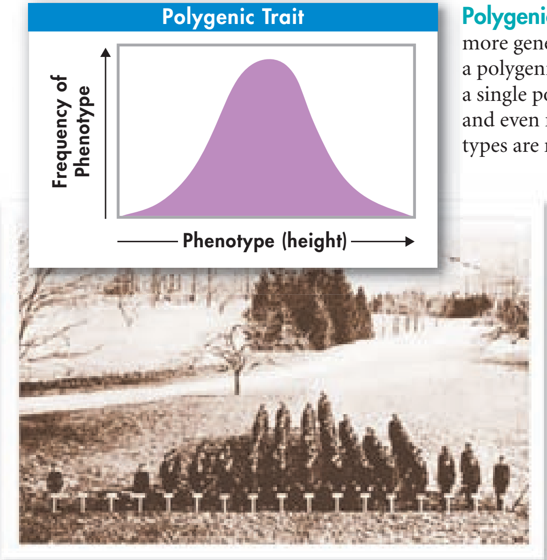


FIGURE 17–5 A Range of Phenotypes The graph above shows the distribution of phenotypes that would be expected for a trait if many genes contributed to the trait. The photograph shows the actual distribution of heights in a group of young men. **Interpret Graphs** ***What does the shape of the graph indicate about height in humans?***

Polygenic Traits Many traits are controlled by two or more genes and are called **polygenic traits.** Each gene of a polygenic trait often has two or more alleles. As a result, a single polygenic trait often has many possible genotypes and even more different phenotypes. Often those phenotypes are not clearly distinct from one another.

Height in humans is one example of a polygenic trait. Height varies from very short to very tall and everywhere in between. You can sample phenotypic variation in this trait by measuring the height of all the students in your class. You can then calculate average height for this group. Many students will be just a little taller or shorter than average. Some, however, will be very tall or very short. If you graph the number of individuals of each height, you may get a graph similar to the one in **Figure 17–5.** The symmetrical bell-like shape of this curve is typical of polygenic traits. A bell-shaped curve is also called a normal distribution.

17.1 Assessment

Review Key Concepts

1. a. **Review** Define the terms *gene pool* and *allele frequency*.
   b. **Explain** In genetic terms, what indicates that evolution is occurring in a population?
   c. **Predict** Suppose a dominant allele causes a plant disease that usually kills the plant before it can reproduce. Over time, what would probably happen to the frequency of that allele in the population?
2. a. **Review** List three sources of genetic variation.
   b. **Explain** How does genetic recombination result in genetic variation?
   c. **Relate Cause and Effect** Why does sexual reproduction provide more opportunities for genetic variation than asexual reproduction?
3. a. **Review** What is a single-gene trait? What is a polygenic trait?
   b. **Explain** How does the range of phenotypes for single-gene traits differ from the range for polygenic traits?
   c. **Infer** A black guinea pig and a white guinea pig mate and have offspring. All the offspring are black. Is the trait of coat color probably a single-gene trait or a polygenic trait? Explain.

WRITE ABOUT SCIENCE

Explanation

4. Explain how mutations are important in the process of biological evolution. (*Hint:* How does mutation affect genetic variation?)

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17.2 Evolution as Genetic Change in Populations

THINK ABOUT IT Ever since humans began farming, they have battled insects that eat crops. Many farmers now use chemicals called pesticides to kill crop-destroying insects. When farmers first used modern pesticides such as DDT, the chemicals killed most insects. But after a few years, many pesticides stopped working. Today, farmers fight an ongoing "arms race" with insects. Scientists constantly search for new chemicals to control pests that old chemicals no longer control. How do insects fight back? By evolving.

At first, individual pesticides kill almost all insects exposed to them. But a few individual insects usually survive. Why? Because insect populations often contain enough genetic variation that a few individuals, just by chance, are resistant to a particular pesticide. By killing most of the susceptible individuals, farmers increase the relative fitness of the few individuals that can resist the poison. Those insects survive and reproduce, passing their resistance on to their offspring. After a few generations, the descendants of the original, resistant individuals dominate the population.

To understand completely how pesticide resistance develops, you need to know the relationship between natural selection and genetics.

Key Questions

How does natural selection affect single-gene and polygenic traits?

What is genetic drift?

What conditions are required to maintain genetic equilibrium?

Vocabulary

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

Taking Notes

Preview Visuals Before you read, look at **Figure 17–6.** What evolutionary trend does it seem to show?

How Natural Selection Works

How does natural selection affect single-gene and polygenic traits?

Pesticide-resistant insects have a kind of fitness that protects them from a harmful chemical. In genetic terms, what does *fitness* mean? Each time an organism reproduces, it passes copies of its genes on to its offspring. We can, therefore, view evolutionary fitness as success in passing genes to the next generation. In the same way, we can view an evolutionary adaptation as any genetically controlled trait that increases an individual's ability to pass along its alleles.

MYSTERY CLUE

Normally, our immune systems kill or disable disease-causing viruses. What might happen if one flu virus had a mutation that enabled it to escape the body's defenses?

Natural Selection on Single-Gene Traits

Recall that evolution is any change over time in the allele frequency in a population. This process works somewhat differently for single-gene traits than for polygenic traits. **Natural selection on single-gene traits can lead to changes in allele frequencies and, thus, to changes in phenotype frequencies.** For example, imagine that a population of lizards experiences mutations in one gene that determines body color. The normal color of the lizards is brown. The mutations produce red and black forms, as shown in **Figure 17–6.** What happens to the new alleles? If red lizards are more visible to predators, they might be less likely to survive and reproduce. Therefore, the allele for red coloring might not become common.

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

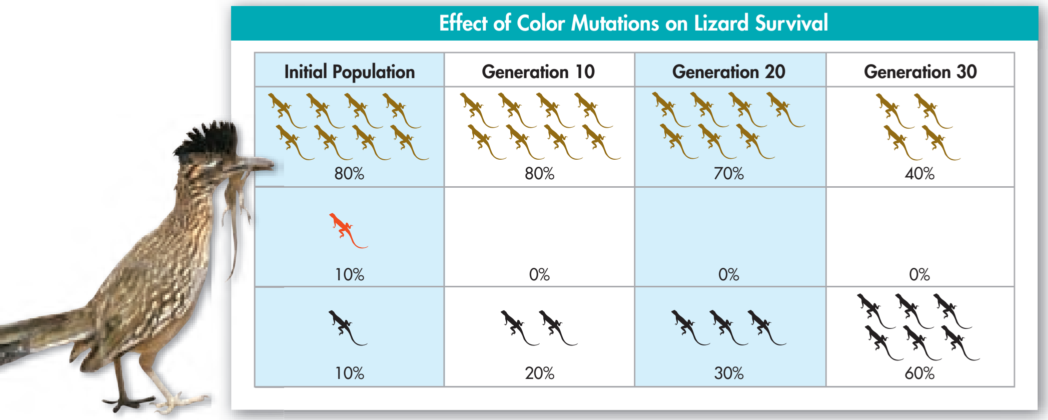


FIGURE 17–6 Selection on a Single-Gene Trait Natural selection on a single-gene trait can lead to changes in allele frequencies and, thus, to evolution. **Interpret Visuals** *What has happened to produce the population shown in Generation 30?*

Natural Selection on Polygenic Traits

When traits are controlled by more than one gene, the effects of natural selection are more complex. As you saw earlier, polygenic traits such as height often display a range of phenotypes that form a bell curve. The fitness of individuals may vary from one end of such a curve to the other. Where fitness varies, natural selection can act. **Natural selection on polygenic traits can affect the relative fitness of phenotypes and thereby produce one of three types of selection: directional selection, stabilizing selection, or disruptive selection.** These types of selection are shown in **Figure 17–7.**

In Your Notebook *As you read the text on the following page, summarize each of the three types of 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** occurs. The range of phenotypes shifts because some individuals are more successful at surviving and reproducing than are others.

Consider how limited resources, such as food, can affect individuals' fitness. Among seed-eating birds such as Darwin's finches, birds with bigger, thicker beaks can feed more easily on larger, harder, thicker-shelled seeds. Suppose the supply of small and medium-size seeds runs low, leaving only larger seeds. Birds with larger beaks would have an easier time feeding than would small-beaked birds. Big-beaked birds would therefore be more successful in surviving and passing genes to the next generation. Over time, the average beak size of the population would probably increase.

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

For example, the mass of human infants at birth is under the influence of stabilizing selection. Very small babies are likely to be less healthy and, thus, less likely to survive. Babies who are much larger than average are likely to have difficulty being born. The fitness of these smaller or larger babies is, therefore, lower than that of more average-size individuals.

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

Suppose a bird population lives in an area where medium-size 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 the graph, the population might split into two groups: one with smaller beaks and one with larger beaks.

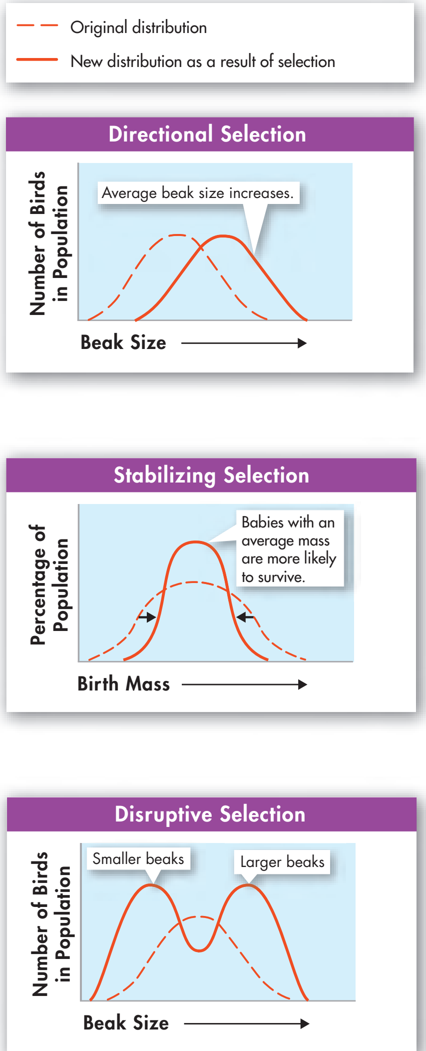


FIGURE 17–7 Selection on Polygenic Traits Natural selection on polygenic traits has one of three patterns—directional selection, stabilizing selection, or disruptive selection.

Genetic Drift

What is genetic drift?

Natural selection is not the only source of evolutionary change. In small populations, an allele can become more or less common simply by chance. **In small populations, individuals that carry a particular allele may leave more descendants than other individuals leave, just by chance. Over time, a series of chance occurrences can cause an allele to become more or less common in a population.** This kind of random change in allele frequency is called **genetic drift.**

BUILD Vocabulary

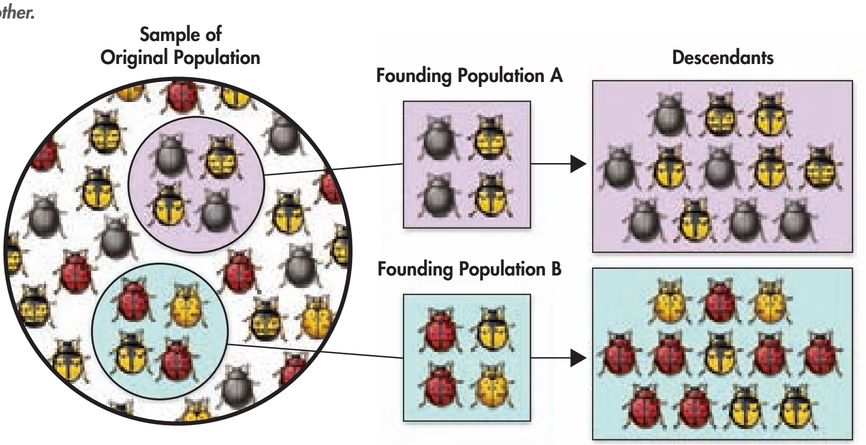
ACADEMIC WORDS The adjective **random** means "lacking a pattern" or "happening by chance." A random change is a change that happens by chance.

Genetic Bottlenecks Sometimes, a disaster, such as disease, can kill many individuals in a population. Just by chance, the smaller population's gene pool may have allele frequencies that are different from those of the original gene pool. If the reduced population later grows, its alleles will be different in frequency from the original population's. The **bottleneck effect** is a change in allele frequency following a dramatic reduction in the size of a population. A severe bottleneck effect can sharply reduce a population's genetic diversity.

The Founder Effect Genetic drift may also occur when a few individuals colonize a new habitat. These founding individuals may carry alleles that differ in relative frequencies from those of the main population, just by chance. The new gene pool may therefore start out with allele frequencies different from those of the parent gene pool, as shown in **Figure 17–8.** This 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 on different Hawaiian islands. All those species descended from the same mainland fruit fly population. However, species on different islands have allele frequencies that are different from those of the original species.

FIGURE 17–8 Founder Effect This illustration shows how two small groups from a large, diverse population could produce new populations that differ from the original group. **Compare and Contrast** *Explain why the two populations of descendants are so different from one another.*



Analyzing Data MATH

Allele Frequency

The Hardy-Weinberg principle can be used to predict the frequencies of certain genotypes if you know the frequency of other genotypes.

Imagine, for example, that you know of a genetic condition, controlled by two alleles *S* and *s*, which follow the rule of simple dominance at a single locus. The condition affects only homozygous recessive individuals. (The heterozygous phenotype shows no symptoms.) The population you are studying has a population size of 10,000 and there are 36 individuals affected by the condition. Based on this information, use the Hardy-Weinberg equations to answer the following questions.

1. **Calculate** What are the frequencies of the *S* and *s* alleles?
2. **Calculate** What are the frequencies of the *SS*, *Ss*, and *ss* genotypes?
3. **Calculate** What percentage of people, in total, is likely to be carrying the *s* allele, whether or not they know it?

Evolution Versus Genetic Equilibrium

What conditions are required to maintain genetic equilibrium?

One way to understand how and why populations evolve is to imagine a model of a hypothetical population that does not evolve. If a population is not evolving, allele frequencies in its gene pool do not change, which means that the population is in **genetic equilibrium.**

Sexual Reproduction and Allele Frequency Gene shuffling during sexual reproduction produces many gene combinations. But a century ago, researchers realized that meiosis and fertilization, by themselves, do not change allele frequencies. So hypothetically, a population of sexually reproducing organisms could remain in genetic equilibrium.

The Hardy-Weinberg Principle The **Hardy-Weinberg principle** states that allele frequencies in a population should remain constant unless one or more factors cause those frequencies to change. The Hardy-Weinberg principle makes predictions like Punnett squares—but for populations, not individuals. Here's how it works. Suppose that there are two alleles for a gene: *A* (dominant) and *a* (recessive). A cross of these alleles can produce three possible genotypes: *AA*, *Aa*, and *aa*. The frequencies of genotypes in the population can be predicted by these equations, where *p* and *q* are the frequencies of the dominant and recessive alleles:

In symbols:

$$p^2 + 2pq + q^2 = 1 \text{ and } p + q = 1$$

In words:

(frequency of *AA*) + (frequency of *Aa*) + (frequency of *aa*) = 100% and (frequency of *A*) + (frequency of *a*) = 100%

Suppose that, in one generation, the frequency of the *A* allele is 40 percent ($p = 0.40$) and the frequency of the *a* allele is 60 percent ($q = 0.60$).

FIGURE 17–9 A Large Population Large populations are unlikely to remain in genetic equilibrium.

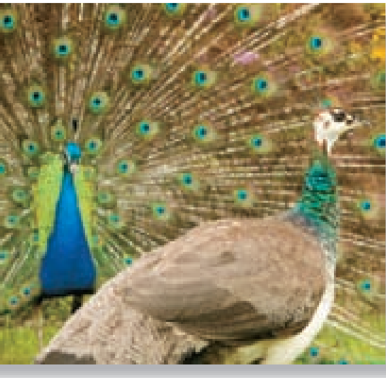


FIGURE 17–10 Choosing a Mate Random mating is one condition required to maintain genetic equilibrium in a population. However, in many species, mating is not random. Female peacocks, for example, choose mates on the basis of physical characteristics such as brightly patterned tail feathers. This is a classic example of sexual selection.

If this population is in genetic equilibrium, chances of an individual in the next generation having genotype *AA* would be 16% ($p^2 = 0.40^2 = 0.16$ or 16%). The probability of genotype *aa* would be 36% ($q^2 = 0.60^2 = 0.36$). The probability of genotype *Aa* would be 48% ($2pq = 2\ (0.40)\ (0.60) = 0.48$). If a population doesn't show these predicted phenotype frequencies, evolution is taking place. **The Hardy-Weinberg principle predicts that five conditions can disturb genetic equilibrium and cause evolution to occur: (1) nonrandom mating; (2) small population size; and (3) immigration or emigration; (4) mutations; or (5) natural selection.**

▶ ***Nonrandom Mating*** In genetic equilibrium, individuals must mate with other individuals at random. But in many species, individuals select mates based on heritable traits, such as size, strength, or coloration, a practice known as **sexual selection.** When sexual selection is at work, genes for the traits selected for or against are not in equilibrium.

▶ ***Small Population Size*** Genetic drift does not usually have major effects in large populations, but can affect small populations strongly. Evolutionary change due to genetic drift thus happens more easily in small populations.

▶ ***Immigration or Emigration*** Individuals who join a population may introduce new alleles into the gene pool, and individuals who leave may remove alleles. Thus, any movement of individuals into or out of a population can disrupt genetic equilibrium.

▶ ***Mutations*** Mutations can introduce new alleles into a gene pool, thereby changing allele frequencies and causing evolution to occur.

▶ ***Natural Selection*** If different genotypes have different fitness, genetic equilibrium will be disrupted, and evolution will occur.

Note that one or more of these conditions usually holds for real populations. This means that, in most species, most of the time, evolution happens.

17.2 Assessment

Review Key Concepts

1. **a. Review** How does natural selection affect a single-gene trait?
   b. Compare and Contrast Compare directional selection and disruptive selection.
2. **a. Review** Define genetic drift.
   b. Relate Cause and Effect How can the founder effect lead to changes in a gene pool?
3. **a. Review** What five conditions are necessary to maintain genetic equilibrium?
   b. Infer Why is genetic equilibrium uncommon in actual populations?

Apply the Big idea

Evolution

4. Do you think populations stay in genetic equilibrium after the environment has changed significantly? Explain your answer.

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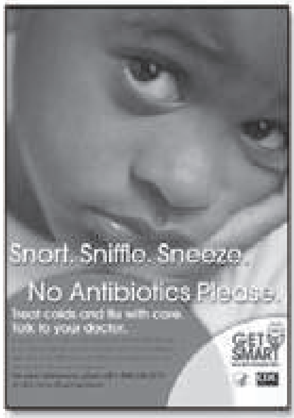
Biology & Society

Should Antibiotic Use Be Restricted?

Natural selection and evolution aren't just about fossils and finches. Many disease-causing bacteria are evolving resistance to antibiotics—drugs intended to kill them or interfere with their growth.

During your lifetime, antibiotics have always been available and effective. So it is probably hard for you to imagine what life was like before antibiotics were discovered. It wasn't pleasant. During the 1930s, it was not unusual for half of all children in a family to die from bacterial infections that are considered trivial today.

When antibiotics were developed, they rapidly became one of medicine's greatest weapons. Antibiotics saved thousands of lives during World War II by controlling bacterial infections among wounded soldiers. Soon, many bacterial diseases, such as pneumonia, posed much less of a threat. That's why antibiotics were called "magic bullets" and "wonder drugs." But the magic is fading as bacteria evolve.



Bacterial populations have always contained a few individuals with mutations that enabled them to destroy, inactivate, or eliminate antibiotics. But those individuals didn't have higher fitness, so those mutant alleles didn't become common.

Then, doctors began prescribing antibiotics widely, and farmers started feeding antibiotics to farm animals to prevent infections. As a result, antibiotics have become a regular part of the environment for bacteria.

In this new environment, individuals with resistance alleles have higher fitness, so the resistance alleles increase in frequency. Also, resistance alleles can be transferred from one bacterial species to another on plasmids. Thus, disease-causing bacteria can pick up resistance from harmless strains.

Many bacteria, including those that cause tuberculosis and certain forms of staph infections, are evolving resistance to not just one antibiotic, but to almost all medicines known. Many doctors are terrified. They fear the loss of one of the vital weapons against bacterial disease. Given this problem, should government agencies restrict antibiotic use?

The Viewpoints

Restrict Antibiotic Use Some people think that the danger of an incurable bacterial epidemic is so high that the government must take action. Doctors overuse antibiotics because patients demand them. The livestock industry likes using antibiotics and will not change their practice unless forced to do so.

Don't Restrict Use Other people think that the doctors and the livestock industry need the freedom to find solutions that work best for them. Researchers are constantly developing new drugs. Some of these drugs can be reserved for human use only.

Research and Decide

1. Analyze the Viewpoints Learn more about this issue by consulting library and Internet resources. Then, list the advantages and disadvantages of restricting antibiotic use.

2. Form Your Opinion Should antibiotics be restricted? Would regulations be more appropriate in some situations than in others?

17.3 The Process of Speciation

Key Questions

What types of isolation lead to the formation of new species?

What is a current hypothesis about Galápagos finch speciation?

Vocabulary

species
speciation
reproductive isolation
behavioral isolation
geographic isolation
temporal isolation

Taking Notes

Compare/Contrast Table
In a compare/contrast table, describe the three mechanisms of reproductive isolation.

THINK ABOUT IT How does one species become two? Natural selection and genetic drift can change allele frequencies, causing a population to evolve. But a change in allele frequency by itself does not lead to the development of a new species.

Isolating Mechanisms

What types of isolation lead to the formation of new species?

Biologists define a **species** as a population or group of populations whose members can interbreed and produce fertile offspring. Given this genetic definition of species, what must happen for one species to divide or give rise to a new species? The formation of a new species is called **speciation.**

Interbreeding links members of a species genetically. Any genetic changes can spread throughout the population over time. But what happens if some members of a population stop breeding with other members? The gene pool can split. Once a population has thus split into two groups, changes in one of those gene pools cannot spread to the other. Because these two populations no longer interbreed, **reproductive isolation** has occurred. **When populations become reproductively isolated, they can evolve into two separate species. Reproductive isolation can develop in a variety of ways, including behavioral isolation, geographic isolation, and temporal isolation.**

MYSTERY CLUE

A population of viruses inside a host's body is isolated from other viral populations. How might this isolation affect viral evolution?

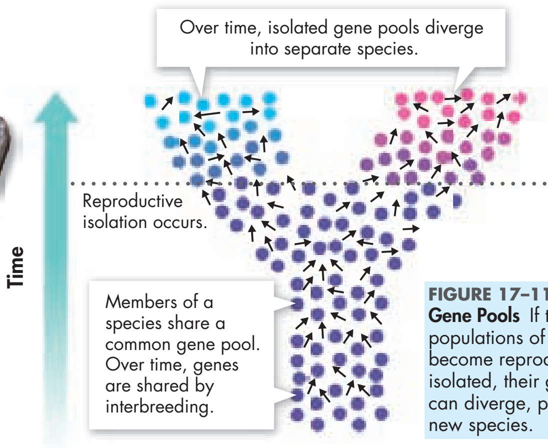
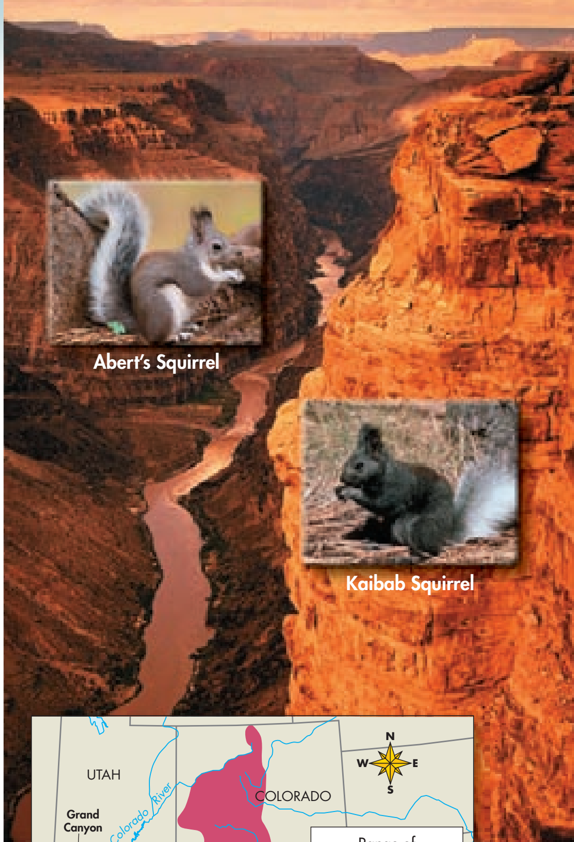


FIGURE 17–11 Diverging Gene Pools If two populations of a species become reproductively isolated, their gene pools can diverge, producing new species.

Behavioral Isolation Suppose two populations that are capable of interbreeding develop differences in courtship rituals or other behaviors. **Behavioral isolation** can then occur. For example, eastern and western meadowlarks are similar birds whose habitats overlap. But, members of the two species will not mate with each other, partly because they use different songs to attract mates. Eastern meadowlarks don't respond to western meadowlark songs, and vice versa.

Geographic Isolation When two populations are separated by geographic barriers such as rivers, mountains, or bodies of water, **geographic isolation** occurs. The Abert's squirrel in **Figure 17–12,** for example, lives in the Southwest. About 10,000 years ago, a small population became isolated on the north rim of the Grand Canyon. Separate gene pools formed. Genetic changes that appeared in one group were not passed to the other. Natural selection and genetic drift worked separately on each group and led to the formation of a distinct subspecies, the Kaibab squirrel. The Abert's and Kaibab squirrels are very similar, indicating that they are closely related. However, the Kaibab squirrel differs from the Abert's squirrel in significant ways, such as fur coloring.

Geographic barriers do not always guarantee isolation. Floods, for example, may link separate lakes, enabling their fish populations to mix. If those populations still interbreed, they remain a single species. Also, a geographic barrier may separate certain organisms but not others. A large river may keep squirrels and other small rodents apart but probably won't isolate bird populations.



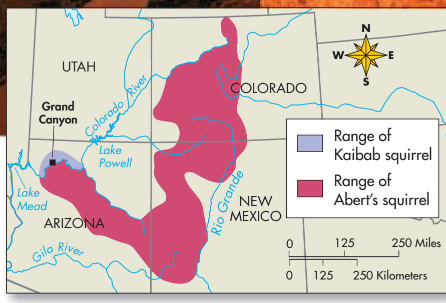


FIGURE 17–12 Geographic Isolation Abert's squirrel and the Kaibab squirrel are distinct subspecies within the same species. Their gene pools are separate. **Interpret Visuals** ***What geographic barrier separates the two populations of squirrels?***

Temporal Isolation A third isolating mechanism, known as **temporal isolation,** happens when two or more species reproduce at different times. For example, suppose three similar species of orchids live in the same rain forest. Each species has flowers that last only one day and must be pollinated on that day to produce seeds. Because the species bloom on different days, they cannot pollinate one another.

In Your Notebook *Explain how temporal isolation can lead to speciation.*

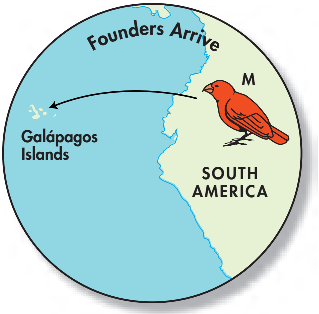
Speciation in Darwin's Finches

What is a current hypothesis about Galápagos finch speciation?

Recall that Peter and Rosemary Grant spent years on the Galápagos islands studying changes in finch populations. The Grants measured and recorded anatomical characteristics such as beak length of individual medium ground finches. Many of the characteristics appeared in bell-shaped distributions typical of polygenic traits. As environmental conditions changed, the Grants documented directional selection among the traits. When drought struck the island of Daphne Major, finches with larger beaks capable of cracking the thickest seeds survived and reproduced more often than others. Over many generations, the proportion of large-beaked finches increased.

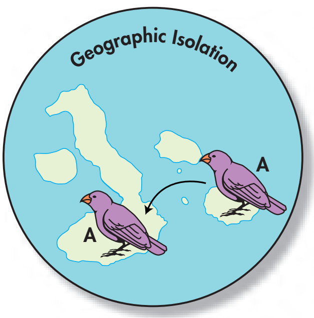
We can now combine these studies by the Grants with evolutionary concepts to form a hypothesis that answers a question: How might the founder effect and natural selection have produced reproductive isolation that could have led to speciation among Galápagos finches? **According to this hypothesis, speciation in Galápagos finches occurred by founding of a new population, geographic isolation, changes in the new population's gene pool, behavioral isolation, and ecological competition.**

FIGURE 17–13



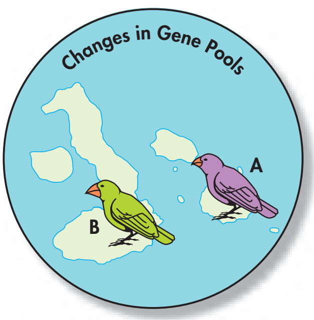
Founders Arrive Many years ago, a few finches from South America—species M—arrived on one of the Galápagos islands, as shown in **Figure 17–13.** These birds may have gotten lost or been blown off course by a storm. Once on the island, they survived and reproduced. Because of the founder effect, allele frequencies of this founding finch population could have differed from allele frequencies in the original South American population.

FIGURE 17–14



Geographic Isolation The island's environment was different from the South American environment. Some combination of the founder effect, geographic isolation, and natural selection enabled the island finch population to evolve into a new species—species A. Later, a few birds from species A crossed to another island. Because these birds do not usually fly over open water, they move from island to island very rarely. Thus, finch populations on the two islands were geographically isolated from each other and no longer shared a common gene pool.

FIGURE 17–15

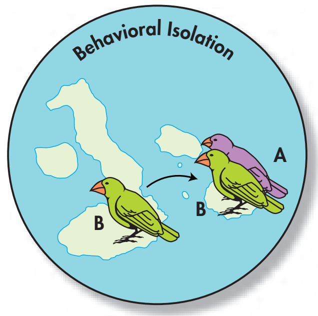


Changes in Gene Pools Over time, populations on each island adapted to local environments. Plants on the first island may have produced small, thin-shelled seeds, whereas plants on the second island may have produced larger, thick-shelled seeds. On the second island, directional selection would have favored individuals with larger, heavier beaks. These birds could crack open and eat the large seeds more easily. Thus, birds with large beaks would be better able to survive on the second island. Over time, natural selection would have caused that population to evolve larger beaks, forming a distinct population, B, characterized by a new phenotype.

Behavioral Isolation Now, imagine that a few birds from the second island cross back to the first island. Will population-A birds breed with population-B birds? Probably not. These finches choose mates carefully. During courtship, they closely inspect a potential partner's beak. Finches prefer to mate with birds that have the same-size beak as they do. Big-beaked birds prefer to mate with other big-beaked birds, and smaller-beaked birds prefer to mate with other smaller-beaked birds. Because the populations on the two islands have evolved differently sized beaks, they would probably not mate with each other.

Thus, differences in beak size, combined with mating behavior, could lead to reproductive isolation. The gene pools of the two bird populations remain isolated—even when individuals live in the same place. The populations have now become two distinct species.

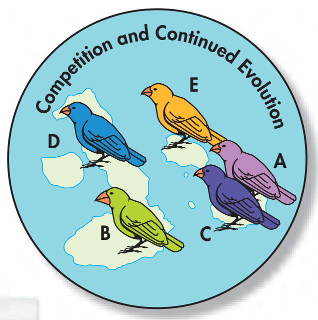
FIGURE 17–16



Competition and Continued Evolution As these two new species live together on the first island, they compete for seeds. During the dry season, birds that are most different from each other have the highest fitness. That is because the more specialized birds have less competition for certain kinds of seeds and other foods. Over time, species evolve in a way that increases the differences between them. The species-B birds on the first island may evolve into a new species, C.

The combined processes of geographic isolation on different islands, genetic change, and behavioral isolation could have repeated itself again and again across the Galápagos chain. Over many generations, the process could have produced the 13 different finch species found there today.

FIGURE 17–17



In Your Notebook *Explain how natural selection and behavioral isolation may have lead to reproductive isolation in Darwin's finches.*

17.3 Assessment

Review Key Concepts

1. a. **Review** What is geographic isolation?
   b. **Predict** A newly formed lake divides a population of a beetle species into two groups. What other factors besides isolation might lead to the two groups becoming separate species?
2. a. **Review** What types of reproductive isolation may have been important in Galápagos finch speciation? Explain.
   b. **Apply Concepts** Explain how the vegetarian tree finch, which feeds on fruit, might have evolved.

BUILD VOCABULARY

3. *Temporal* comes from the Latin word *tempus*, meaning "time." How is time a factor in temporal isolation?
4. *Isolation* is related to the Latin word *insula*, meaning "island." After reading about isolating mechanisms in this lesson, does the common origin of these two words make sense? Explain your answer.

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17.4 Molecular Evolution

Key Questions

What are molecular clocks?

Where do new genes come from?

How may Hox genes be involved in evolutionary change?

Vocabulary

molecular clock

Taking Notes

Outline As you read, make an outline of this lesson. Use the green headings as the main topics and the blue headings as the subtopics.

THINK ABOUT IT Recall that an organism's genome is its complete set of genetic information. Thousands of ongoing projects are analyzing the genomes of organisms ranging from viruses to humans. The analysis of genomes enables us to study evolution at the molecular level. By comparing DNA sequences from all of these organisms, we can often solve important evolutionary puzzles. For example, DNA evidence may indicate how two species are related to one another, even if their body structures don't offer enough clues.

Timing Lineage Splits: Molecular Clocks

What are molecular clocks?

When researchers use a **molecular clock,** they compare stretches of DNA to mark the passage of evolutionary time. **A molecular clock uses mutation rates in DNA to estimate the time that two species have been evolving independently.**

BUILD Vocabulary

ACADEMIC WORDS The word **sequence** means "the order in which parts are put together." The sequence of DNA is the order in which its molecules are arranged.

Neutral Mutations as "Ticks" To understand molecular clocks, think about old-fashioned pendulum clocks. They mark time with a swinging pendulum. A molecular clock also relies on a repeating process to mark time—mutation. As you've learned, simple mutations occur all the time, causing slight changes in the sequence of DNA. Some mutations have a major positive or negative effect on an organism's phenotype. These types of mutations are under powerful pressure from natural selection.

Many mutations, however, have no effect on phenotype. These neutral mutations tend to accumulate in the DNA of different species at about the same rate. Researchers can compare such DNA sequences in two species. The comparison can reveal how many mutations have occurred independently in each group, as shown in **Figure 17–18.** The more differences there are between the DNA sequences of the two species, the more time has elapsed since the two species shared a common ancestor.

In Your Notebook *Which kind of mutation—neutral or negative—will most likely persist in a population over time? Explain.*

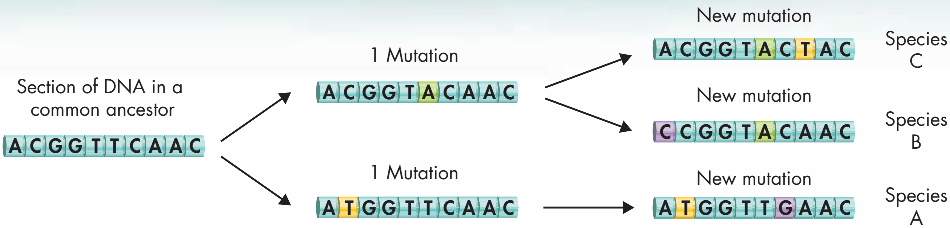


FIGURE 17–18 Molecular Clock
By comparing the DNA sequences of two or more species, biologists estimate how long the species have been separated. **Analyze Data** ***What evidence indicates that species C is more closely related to species B than to species A?***

Calibrating the Clock The use of molecular clocks is not simple, because there is not just one molecular clock in a genome. There are many different clocks, each of which "ticks" at a different rate. This is because some genes accumulate mutations faster than others. These different clocks allow researchers to time different evolutionary events. Think of a conventional clock. If you want to time a brief event, you use the second hand. To time an event that lasts longer, you use the minute hand or the hour hand. In the same way, researchers choose a different molecular clock to compare great apes than to estimate when mammals and fishes shared a common ancestor.

Researchers check the accuracy of molecular clocks by trying to estimate how often mutations occur. In other words, they estimate how often the clock they have chosen "ticks." To do this, they compare the number of mutations in a particular gene in species whose age has been determined by other methods.

Gene Duplication

Where do new genes come from?

Where did the roughly 25,000 working genes in the human genome come from? Modern genes probably descended from a much smaller number of genes in the earliest life forms. But how could that have happened? **One way in which new genes evolve is through the duplication, and then modification, of existing genes.**

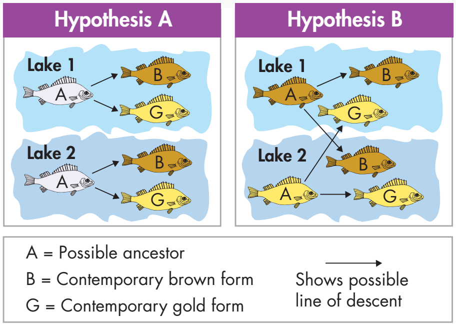
Copying Genes Most organisms carry several copies of various genes. Sometimes organisms carry two copies of the same gene. Other times there may be thousands of copies. Where do those extra copies come from, and what happens to them?

Remember that homologous chromosomes exchange DNA during meiosis in a process called crossing-over. Sometimes crossing-over involves an unequal swapping of DNA. In other words, one chromosome in the pair gets extra DNA. That extra DNA can carry part of a gene, a full gene, or a longer length of chromosome. Sometimes, in different ways, an entire genome can be duplicated.

Analyzing Data

Fishes in Two Lakes

A research team studied two lakes in an area that sometimes experiences flooding. Each lake contained two types of similar fishes: a dull brown form and an iridescent gold form. The team wondered how all the fishes were related, and they considered the two hypotheses diagrammed on the right.



1. Interpret Visuals Study the two diagrams. What does hypothesis A indicate about the ancestry of the fishes in Lake 1 and Lake 2? What does hypothesis B indicate?

2. Compare and Contrast According to the two hypotheses, what is the key difference in the way the brown and gold fish populations might have formed?

3. Draw Conclusions A DNA analysis showed that the brown and gold fishes from Lake 1 are the most closely related. Which hypothesis does this evidence support?

Duplicate Genes Evolve What's so important about gene duplication? Think about using a computer to write an essay for English class. You then want to submit a new version of the essay to your school newspaper. So, you make an extra copy of the original file and edit it for the newspaper.

Duplicate genes can work in similar ways. Sometimes, extra copies of a gene undergo mutations that change their function. The original gene is still around, just like the original copy of your English essay. So, the new genes can evolve without affecting the original gene function or product. **Figure 17–19** shows how this happens.

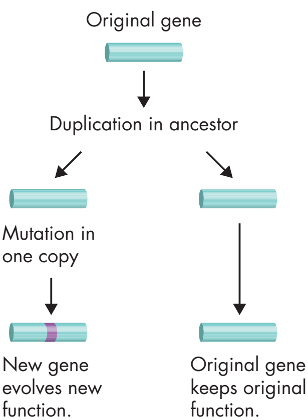


FIGURE 17–19 Gene Duplication In this diagram, a gene is first duplicated, and then one of the two resulting genes undergoes mutation.

Gene Families Multiple copies of a duplicated gene can turn into a group of related genes called a gene family. Members of a gene family typically produce similar, yet slightly different, proteins. Your body, for example, produces a number of molecules that carry oxygen. Several of these compounds—called globins—are hemoglobins. The globin gene family that produces them evolved, after gene duplication, from a single ancestral globin gene. Some of the most important evolution research focuses on another gene family—Hox genes.

Developmental Genes and Body Plans

How may Hox genes be involved in evolutionary change?

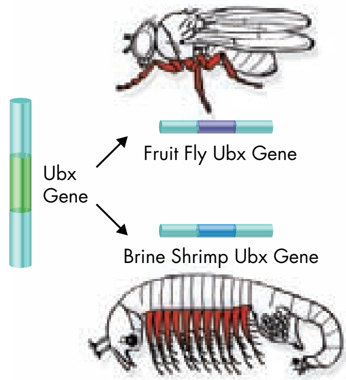
One exciting new research area is nicknamed "evo-devo" because it studies the relationship between evolution and embryological development. Darwin himself had a hunch that changes in the growth of embryos could transform adult body shape and size. Researchers now study how small changes in Hox gene activity could produce the kinds of evolutionary changes we see in the fossil record.

Hox Genes and Evolution As you read in Chapter 13, Hox genes determine which parts of an embryo develop arms, legs, or wings. Groups of Hox genes also control the size and shape of those structures. In fact, homologous Hox genes shape the bodies of animals as different as insects and humans—even though those animals last shared a common ancestor no fewer than 500 million years ago!

Small changes in Hox gene activity during embryological development can produce large changes in adult animals. For example, insects and crustaceans are related to ancient common ancestors that possessed dozens of legs. Today's crustaceans, including shrimp and lobsters, still have large numbers of paired legs, but insects have just 3 pairs of legs. What happened to those extra legs? Recent studies have shown that mutations in a single Hox gene, known as *Ubx*, turns off the growth of legs in the abdominal regions of insects. Thus, a change in one Hox gene accounts for a major evolutionary difference between two important animal groups.

Timing Is Everything Each part of an embryo starts to grow at a certain time, grows for a specific time, and stops growing at a specific time. Small changes in starting and stopping times can make a big difference in organisms. For example, small timing changes can make the difference between long, slender fingers and short, stubby toes. No wonder "evo-devo" is one of the hottest areas in evolutionary biology!

FIGURE 17–20 Change in a Hox Gene Insects such as fruit flies and crustaceans such as brine shrimp are descended from a common ancestor that had many legs. Due to mutations in the activity of a single Hox gene that happened millions of years ago, modern insects have fewer legs than do modern crustaceans. In the illustration, the legs of the fruit fly and the legs of the brine shrimp are the same color (red) because a variant of the same Hox gene, *Ubx*, directs the development of the legs of both animals.



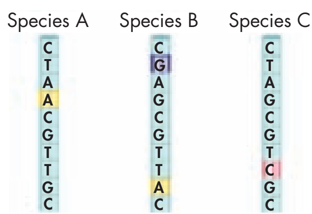
17.4 Assessment

Review Key Concepts

1. a. **Review** What is a molecular clock?
   b. **Explain** Why do molecular clocks use mutations that have no effect on phenotype?
2. a. **Review** How can crossing-over result in gene duplication?
   b. **Explain** Describe how duplicate genes form.
   c. **Relate Cause and Effect** Why is gene duplication important in evolution?
3. a. **Review** Use the evolution of the insect body plan to explain the significance of Hox genes in evolution.
   b. **Infer** In evolution, why have small changes in Hox genes had a great impact?

VISUAL THINKING

4. The colored bands in the diagrams below represent mutations in a segment of DNA in species A, B, and C. Which two of the three species probably share the most recent common ancestor?



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Pre-Lab: Competing For Resources

Problem How can competition lead to speciation?

Materials assorted tools, large and small seeds, large and small paper plates, timer or clock with second hand

⚠

Lab Manual Chapter 17 Lab

Skills Focus Use Models, Predict, Apply Concepts

Connect to the Big idea Speciation is not easy to see in nature. Usually, new phenotypes take years to emerge or become common enough to be noticed. Also, new phenotypes can be difficult to track in a complex environment. For scientists who want to study speciation, islands can provide an ideal environment.

Peter and Rosemary Grant spent years studying finches on the Galápagos Islands. They measured and recorded the traits and diets of hundreds of birds. During a year with a severe drought, the Grants were able to observe natural selection in action as food became scarce. In this lab you will model variation in bird beaks and diet to demonstrate the impact of competition on survival and speciation.

Background Questions

a. **Review** What is speciation?

b. **Relate Cause and Effect** How did geographic isolation lead to speciation among the Galápagos finches?

c. **Compare and Contrast** How does an adaptation differ from other inherited traits?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Use Models** In this lab, what do the different types of tools represent?

2. **Predict** Which tools do you think will work best for picking up small seeds? Which will work best for picking up large seeds?

3. **Design an Experiment** Why will the time you have to collect seeds be limited?

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Visit Chapter 17 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Climb the cliffs of Hawaii with the Untamed Science crew to discover how geographic isolation can result in a new species.

Data Analysis Find out what happened to Galápagos finches during a drought by comparing data on finches and their food sources.

Art Review Review your understanding of alleles and allele frequencies in a population.

Art in Motion Watch how different types of selection change the types of individuals that comprise a population.

Tutor Tube Learn more about the mechanisms of speciation from the tutor.

17 Study Guide

Big idea Evolution

A new species can form when a population splits into two groups that are isolated from one another. The gene pools of the two groups may become so different that the groups can no longer interbreed.

17.1 Genes and Variation

Evolution is a change in the frequency of alleles in a population over time.

Three sources of genetic variation are mutation, genetic recombination during sexual reproduction, and lateral gene transfer.

The number of phenotypes produced for a trait depends on how many genes control the trait.

gene pool (483)
allele frequency (483)
single-gene trait (485)
polygenic trait (486)

17.2 Evolution as Genetic Change in Populations

Natural selection on single-gene traits can lead to changes in allele frequencies and, thus, to changes in phenotype frequencies.

Natural selection on polygenic traits can affect the relative fitness of phenotypes and thereby produce one of three types of selection: directional selection, stabilizing selection, or disruptive selection.

In small populations, individuals that carry a particular allele may leave more descendants than other individuals leave, just by chance. Over time, a series of chance occurrences can cause an allele to become more or less common in a population.

The Hardy-Weinberg principle predicts that five conditions can disturb genetic equilibrium and cause evolution to occur: (1) nonrandom mating; (2) small population size; and (3) immigration or emigration; (4) mutations; or (5) natural selection.

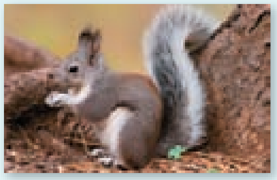
directional selection (489)
stabilizing selection (489)
disruptive selection (489)
genetic drift (490)
bottleneck effect (490)
founder effect (490)
genetic equilibrium (491)
Hardy-Weinberg principle (491)
sexual selection (492)

17.3 The Process of Speciation

When populations become reproductively isolated, they can evolve into two separate species. Reproductive isolation can develop in a variety of ways, including behavioral isolation, geographic isolation, and temporal isolation.

Speciation in Galápagos finches most likely occurred by founding of a new population, geographic isolation, changes in the new population's gene pool, behavioral isolation, and ecological competition.

species (494)
speciation (494)
reproductive isolation (494)
behavioral isolation (495)
geographic isolation (495)
temporal isolation (495)



17.4 Molecular Evolution

A molecular clock uses mutation rates in DNA to estimate the time that two species have been evolving independently.

One way in which new genes evolve is through the duplication, and then modification, of existing genes.

Small changes in Hox gene activity during embryological development can produce large changes in adult animals.

molecular clock (498)

Think Visually

Construct a concept map explaining the sources of genetic variation.

17 Assessment

17.1 Genes and Variation

Understand Key Concepts

1. The combined genetic information of all members of a particular population forms a
   a. gene pool.
   b. niche.
   c. phenotype.
   d. population.

2. Mutations that improve an individual's ability to survive and reproduce are
   a. harmful.
   b. neutral.
   c. beneficial.
   d. chromosomal.

3. Traits, such as human height, that are controlled by more than one gene are known as
   a. single-gene traits.
   b. polygenic traits.
   c. recessive traits.
   d. dominant traits.

4. Explain what the term *allele frequency* means. Include an example illustrating your answer.
5. Explain why sexual reproduction is a source of genetic variation.
6. Explain what determines the number of phenotypes for a given trait.
7. What is *lateral gene transfer*?
8. Define evolution in genetic terms.

Think Critically

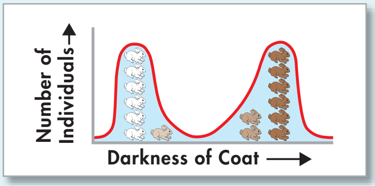
9. **Compare and Contrast** Which kind of mutation has the greater potential to affect the evolution of a population: a mutation to a body cell or a mutation in an egg cell? Explain.
10. **Apply Concepts** Explain how natural selection is related to phenotypes and genotypes.
11. **Apply Concepts** Explain how natural selection is related to individuals and populations.
12. **Relate Cause and Effect** How does genetic recombination affect genetic variation?

17.2 Evolution as Genetic Change in Populations

Understand Key Concepts

13. The type of selection in which individuals of average size have greater fitness than small or large individuals have is called
   a. disruptive selection.
   b. stabilizing selection.
   c. directional selection.
   d. neutral selection.

14. If coat color in a rabbit population is a polygenic trait, which process might have produced the graph below?



   a. disruptive selection
   b. stabilizing selection
   c. directional selection
   d. genetic equilibrium

15. A random change in a small population's allele frequency is known as
   a. a gene pool
   b. genetic drift
   c. variation
   d. fitness

16. What is *fitness* in genetic terms?
17. How do stabilizing selection and disruptive selection differ?
18. What is genetic equilibrium? In what kinds of situations is it likely to occur?

Think Critically

19. **Compare and Contrast** Distinguish between the ways in which natural selection affects single-gene traits and the ways in which it affects polygenic traits. How are phenotype frequencies altered in each case?
20. **Infer** In a certain population of plants, flower size is a polygenic trait. What kind of selection is likely to occur if environmental conditions favor small flowers?

21. **Infer** A road built through a forest splits a population of frogs into two large groups. The allele frequencies of the two groups are identical. Has genetic drift occurred? Why or why not?

22. **Form a Hypothesis** DDT is an insecticide that was first used in the 1940s to kill mosquitoes and stop the spread of malaria. As time passed, people began to notice that DDT became less effective. Explain, in genetic terms, how the insects became resistant to the pesticide.

17.3 The Process of Speciation

Understand Key Concepts

23. Temporal isolation occurs when two different populations
    - **a.** develop different mating behaviors.
    - **b.** become geographically separated.
    - **c.** reproduce at different times.
    - **d.** interbreed.

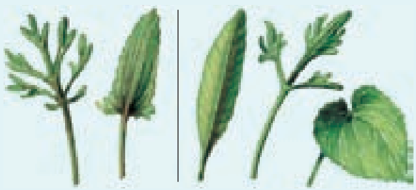
24. When two populations no longer interbreed, what is the result?
    - **a.** genetic equilibrium
    - **b.** reproductive isolation
    - **c.** stabilizing selection
    - **d.** artificial selection

25. Explain how the different species of Galápagos finches may have evolved.

Think Critically

26. **Relate Cause and Effect** Explain why reproductive isolation usually must occur before a population splits into two distinct species.

27. **Form a Hypothesis** A botanist identifies two distinct species of violets growing in a field, as shown in the left of the illustration below. Also in the field are several other types of violets that, although somewhat similar to the two known species, appear to be new species. Develop a hypothesis explaining how the new species may have originated.

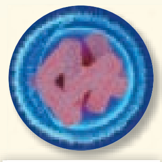


solve the CHAPTER MYSTERY

EPIDEMIC

The genes of flu viruses mutate often, and different strains can swap genes if they infect the same host at the same time. These characteristics produce genetic diversity that enables the virus to evolve.

Flu viruses also undergo natural selection. Think of our bodies as the environment for viruses. Our immune system attacks viruses by "recognizing" proteins on the surface of the viruses. Viruses whose proteins our bodies can recognize and destroy have low fitness. Viruses our bodies can't recognize have higher fitness.



Influenza Virus

Viral evolution regularly produces slightly different surface proteins that our immune systems can't recognize right away. These strains evade the immune system long enough to make people sick. That's why you can catch the flu every winter, and why new flu vaccines must be made every year.

But now and then, influenza evolution produces radically new molecular "disguises" that our immune systems can't recognize *at all*. These can be deadly, like the 1918 strain. If a strain like that were to appear today, it could kill many people. That's why researchers are worried about "bird flu"—a strain of flu that can pass from birds, such as chickens, to humans.

1. **Connect to the Big idea** Explain why mutation and natural selection make developing new flu vaccines necessary every year.

2. **Infer** People do not need to receive a new measles vaccination every year. What does this suggest about a difference between flu viruses and the measles virus?

3. **Apply Concepts** Can you think of any other issues in public health that relate directly to evolutionary change?

17.4 Molecular Evolution

Understand Key Concepts

28. A group of related genes that resulted from the duplication and modification of a single gene is called a

a. gene pool.
b. molecular clock.
c. lateral gene transfer.
d. gene family.

29. Each "tick" of a molecular clock is an occurrence of

a. genetic drift.
b. crossing-over.
c. DNA mutation.
d. mitosis.

30. How do chromosomes gain an extra copy of a gene during meiosis?

31. What are neutral mutations?

32. What is the study of "evo-devo," and how is it related to evolution?

Think Critically

33. Pose Questions What kinds of questions would scientists who are studying the evolution of Hox genes most likely be asking?

34. Apply Concepts Describe the relationship between evolutionary time and the similarity of genes in two species.

Connecting Concepts

Use Science Graphics

Use the data table to answer questions 35 and 36.

Frequency of Alleles

Year	Frequency of Allele *B*	Frequency of Allele *b*
1910	0.81	0.19
1930	0.49	0.51
1950	0.25	0.75
1970	0.10	0.90

35. Interpret Tables Describe the trend shown by the data in the table.

36. Form a Hypothesis What might account for the trend shown by the data?

Write About Science

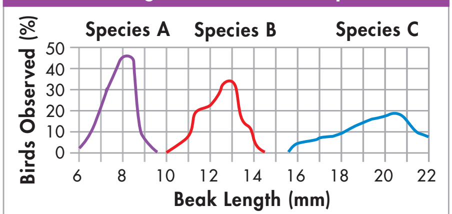
37. Explanation Explain the process that may have caused fruit flies to have fewer legs than their ancestors had.

38. Assess the Big idea Sometimes, biologists say, "Evolution is ecology over time." Explain that statement.

Analyzing Data

The graph shows data regarding the lengths of the beaks of three finch species. The percentage of individuals in each category of beak length is given.

Beak Length in Three Finch Species



39. Interpret Graphs What is the shortest beak length observed in species A?

a. 3 mm
b. 6 mm
c. 9 mm
d. 12 mm

40. Analyze Data Which of the following is a logical interpretation of the data?

a. Species B eats the smallest seeds.
b. About 50 percent of species C eats seeds that are 20 mm long.
c. Species C eats the largest seeds.
d. All three species eat seeds of the same size.

Standardized Test Prep

Multiple Choice

1. Which of the following conditions is MOST likely to result in changes in allele frequencies in a population?
A random mating
B small population size
C no migrations into or out of a population
D absence of natural selection

2. Mutations and the genetic recombination that occurs during sexual reproduction are both sources of
A genetic variation.
B stabilizing selection.
C genetic equilibrium.
D genetic drift.

3. In a population of lizards, the smallest and largest lizards are more easily preyed upon than medium-size lizards. What kind of natural selection is MOST likely to occur in this situation?
A genetic drift **C** stabilizing selection
B sexual selection **D** directional selection

4. Populations of antibiotic-resistant bacteria are the result of the process of
A natural selection. **C** genetic drift.
B temporal isolation. **D** artificial selection.

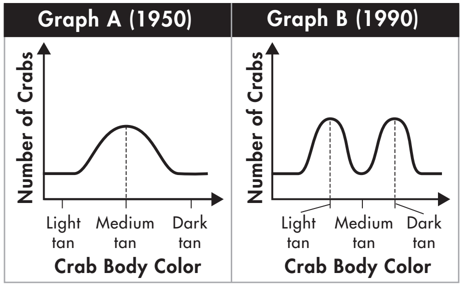
5. If species A and B have very similar genes and proteins, what is probably true?
A Species A and B share a relatively recent common ancestor.
B Species A evolved independently of species B for a long period.
C Species A is younger than species B.
D Species A is older than species B.

6. When two species reproduce at different times, the situation is called
A genetic drift.
B temporal selection.
C temporal isolation.
D lateral gene transfer.

7. The length of time that two taxa have been evolving separately can be estimated using
A genetic drift. **C** a molecular clock.
B gene duplication. **D** Hox genes.

Questions 8–9

The graphs below show the changes in crab color at one beach.



8. What process occurred over the 40-year period?
A artificial selection **C** stabilizing selection
B directional selection **D** disruptive selection

9. Which of the following is MOST likely to have caused the change in the distribution?
A A new predator arrived that preferred dark-tan crabs.
B A new predator arrived that preferred light-tan crabs.
C A change in beach color made medium-tan crabs the least visible to predators.
D A change in beach color made medium-tan crabs the most visible to predators.

Open-Ended Response

10. How does evolution change the relative frequency of alleles in a gene pool? Why does this happen?

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	17.3	17.1	17.2	17.2	17.4	17.3	17.4	17.2	17.2	17.1