Chapter 10

Evolution

Review

In general, **evolution** is about changes in populations, species, or groups of species. More specifically, evolution is the process by which the frequency of heritable traits in a population changes from one generation to the next. For example, in one research study of Darwin finches, it was found that the average size of a bird beak (a heritable trait) increased by 10% over a period of about one year. That was evolution.

An allele is one of several (or many) varieties of a gene. Individuals inherit alleles that code for traits that establish morphology (form or structure), physiology, or behavior. Evolution is when the frequency of those alleles in the population changes over time.

One of the earliest advocates for evolution was naturalist **Jean-Baptiste Lamarck.** His theory included the following two ideas:

1. **Use and disuse** described how body parts of organisms can develop with increased usage, while unused parts weaken. This idea was correct, as is commonly observed among athletes who train for competitions.
2. **Inheritance of acquired characteristics** described how body features acquired during the lifetime of an organism (such as muscle bulk) could be passed on to offspring. This, however, was incorrect. Only changes in the genetic material of cells can be passed on to offspring.

Fifty years after Lamarck published his ideas, naturalist **Charles Darwin** published *The Origin of Species.* Darwin's theory, discussed later in this chapter, was that **natural selection,** or "survival of the fittest," was the driving force of evolution.

There is abundant evidence that evolution occurs—that some species change over time, that other species diverge and become one or more new species, and that still other species become extinct. The question that evolutionary biologists try to answer is *how* evolution occurs. For this they propose theories. Lamarck theorized, incorrectly, that evolution occurs through the inheritance of acquired characteristics. Darwin's theory was that evolution progresses through natural selection. These theories, together with others discussed in this chapter, propose mechanisms responsible for the evolutionary patterns unequivocally observed in nature.

Evidence for Evolution

Evidence for evolution is provided by the following five scientific disciplines:

1. **Paleontology** provides fossils that reveal the prehistoric existence of extinct species. As a result, changes in species and the formation of new species can be studied.
   - Fossil deposits are often found among sediment layers, where the deepest fossils represent the oldest specimens. For example, fossil oysters removed from successive layers of sediment show gradual changes in the size of the oyster shell alternating with rapid changes in shell size. Large, rapid changes produced new species.
   - The age of many fossils can be determined using C-14 dating. In this procedure, the natural decay rate of a radioactive isotope of carbon (C-14) is used to determine the age of the fossil.
2. **Biogeography** uses geography to describe the distribution of species. This information has revealed that unrelated species in different regions of the world look alike when found in similar environments. This provides strong evidence for the role of natural selection in evolution.
   - Rabbits did not exist in Australia until they were introduced by humans. A native Australian hare wallaby resembles a rabbit both in structure and habit. As similar as these two animals appear, they are not that closely related. The rabbit is a placental mammal, while the wallaby is a marsupial mammal. The fetus of

a placental mammal develops in the female uterus, obtaining nourishment from the mother through the placenta. The fetus of a marsupial leaves the mother's uterus at an early stage of development and completes the remaining development while attached to a teat in the abdominal pouch. The great similarity of the rabbit and the wallaby is the result of natural selection.

3. **Embryology** reveals similar stages in development **(ontogeny)** among related species. The similarities help establish evolutionary relationships **(phylogeny).**
   - Gill slits and tails are found in the embryos of fish, chickens, pigs, and humans.
4. **Comparative anatomy** describes two kinds of structures that contribute to the identification of evolutionary relationships among species.
   - **Homologous structures (homologies)** are body parts that resemble one another in different species because they have evolved from a common ancestor. Because anatomy may be modified for survival in specific environments, homologous structures may look different but will resemble one another in pattern (how they are put together). The forelimbs of cats, bats, whales, and humans are homologous because they have all evolved from a common ancestral mammal. In some species, homologous structures have become **vestigial,** that is, they no longer serve any function. The remnants of limbs in snakes, hind limbs in whales, and the wings of flightless birds are examples of vestigial structures, structures that provide evidence of evolutionary heritage.
   - **Analogous structures (analogies)** are body parts that resemble one another in different species, not because they have evolved from a common ancestor, but because they evolved independently as adaptations to their environments. Some species of plants in Africa resemble cacti of North America because both have photosynthetic green stems with spines. But the similar-looking plants differ markedly in their flower structures and their DNA. The similarities in appearance result from adaptations to a hot, dry environment.
5. **Molecular biology** examines the nucleotide and amino acid sequences of DNA and proteins from different species. Closely related species share higher percentages of sequences than species distantly related. In addition, all living things share the same genetic code and, with minor variations, the same basic biochemical pathways, including those for replication, protein synthesis, respiration, and photosynthesis. This data strongly favors evolution of different species through modification of ancestral genetic information.
   - More than 98% of the nucleotide sequences in humans and chimpanzees are identical.

Natural Selection

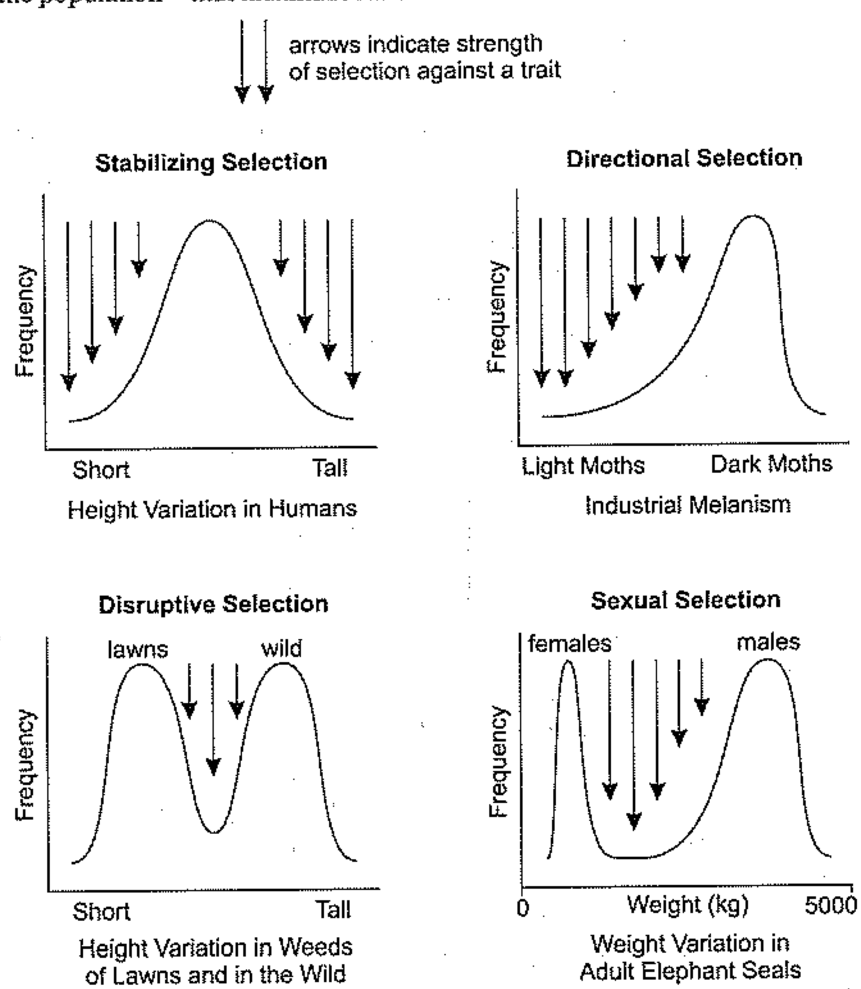
Natural selection is the differences in survival and reproduction among individuals in a population as a result of their interaction with the environment. In other words, some individuals possess alleles (genotypes) that generate traits (phenotypes) that enable them to cope more successfully in their environment than other individuals do. The more successful individuals produce more offspring. Superior inherited traits are **adaptations** to the environment and increase an individual's **fitness,** or relative ability to survive and leave offspring. When the environment favors a trait, that is, when a trait increases the survival of its bearer, selection is said to act for that trait. In contrast, selection is said to act against unfavorable traits. Favorable traits are adaptive, while unfavorable traits are maladaptive.

Darwin presented his theory of evolution by natural selection using the following arguments:

1. **Populations possess an enormous reproductive potential.** Darwin calculated that two elephants would produce a population of 19 million individuals after 750 years if all offspring survived to reproductive maturity and fostered their normal number of offspring.
2. **Population sizes remain stable.** Darwin observed that populations generally fluctuate around a constant size.
3. **Resources are limited.** Resources, such as food, water, or light, do not increase as populations grow larger.
4. **Individuals compete for survival.** Eventually, the needs of a growing population will exceed the available resources. As a result, individuals must compete for resources.

5. **There is variation among individuals in a population.** Most traits reveal considerable variety in their form. In humans, for example, skin, hair, and eye color occur as continuous variation from very dark to very light.
6. **Much variation is heritable.** Although Darwin was unaware of the mechanism for heredity, he recognized that traits were passed from parents to offspring. This contrasts with characteristics acquired during the life of an organism as a result of environmental influences. The amputation of a limb or characteristics acquired as the result of exposure to pathogens or radiation, for example, are not heritable. We now know that most traits are produced by the action of enzymes that are coded by DNA, the hereditary information that is passed from generation to generation.
7. **Only the most fit individuals survive.** "Survival of the fittest" occurs because individuals with traits best adapted for survival and reproduction are able to outcompete other individuals for resources and mates.
8. **Evolution occurs as favorable traits accumulate in the population.** The best adapted individuals survive and leave offspring who inherit the traits of their parents. In turn, the best adapted of these offspring leave the most offspring. Over time, traits best adapted for survival and reproduction, and the alleles that generate them, accumulate in the population.

Natural selection may affect populations in a variety of ways. These are illustrated in Figure 10-1 and discussed below. Note that in all cases, natural selection acts on individual phenotypes already present in the population. Alleles may be expressed with other alleles in new combinations (as a result of genetic recombination) to create novel phenotypes, or new phenotypes may appear in the population as a result of mutations. It is important to note that natural selection does *not* cause mutations or create new phenotypes. It only "selects" phenotypes—already present in the population—that maximize fitness.



Kinds of Selection

Figure 10-1

1. **Stabilizing selection** eliminates individuals that have extreme or unusual traits. Under this condition, individuals with the most common form of a trait are the best adapted, while individuals who differ from the common form are poorly adapted. As a result, stabilizing selection maintains the existing population frequencies of common traits while selecting against all other trait variations.
2. **Directional selection** favors traits that are at one extreme of a range of traits. Traits at the opposite extreme are selected against. If directional selection continues for many generations, favored traits become more and more extreme, leading to distinct changes in the allele frequencies of the population.
   - The Darwin finches described at the beginning of this chapter were an example of directional selection. Beak size increased because only large seeds with hard seed coats were available due to a drought. However, when rains returned, directional selection reversed direction toward smaller beaks as smaller seeds with softer seed coats dominated.
   - **Insecticide resistance** occurs as a result of directional selection. Because traits of individuals vary in a population, some individuals may possess some degree of resistance to the insecticide. These few individuals survive and produce offspring, most of whom will inherit the insecticide-resistance trait. After several generations of directional selection, the population will consist of nearly all insecticide-resistant individuals.
   - The **peppered moth** provides an example of directional selection of moth color from a light to a dark color. Before the industrial revolution, the light form of the moth was well camouflaged among the light-colored lichens that grew on tree barks around London. Since color variation is known to exist in other moths, the dark form of the moth probably existed but was never observed because it was so easily spotted and eaten by predator birds. With the advent of the industrial revolution, soot killed the pollution-sensitive lichens, exposing the dark tree bark below. As a result, the dark form of the moth became the better camouflaged of the two forms, and increased in frequency. A hundred years after the first dark moth was discovered in 1848, 90% of the moths were dark colored. Meanwhile, the light form of the moth continued to dominate populations in unpolluted areas outside London. The selection of dark-colored (melanic) varieties in various species of moths as a result of industrial pollution is called **industrial melanism.** It is an example of how changes in environmental conditions promote evolution.
   - As a result of global climate change, many habitats are experiencing **season creep,** the shortening of winters and earlier arrivals of spring. In response, there is selection for plants that germinate and flower earlier. In general, invasive plant species appear to be favored.
3. **Disruptive selection** (or **diversifying selection**) occurs when the environment favors extreme or unusual traits, while selecting against the common traits.
   - In the wild, many species of weeds occur in a range of heights, but tall forms predominate. Because of disruptive selection, however, only very short forms of these same weeds occur in lawns. On lawns, short weeds are selectively advantageous because they escape mowing, allowing them to flower and produce seeds. Weeds in the wild are primarily tall because tallness makes them better competitors for sunlight.
4. **Sexual selection** is the differential mating of males (sometimes females) in a population. Since females usually make a greater energy investment in producing offspring than males do, they can increase their fitness by increasing the *quality* of their offspring by choosing superior males. Males, on the other hand, contribute little energy to the production of offspring and, thus, increase their fitness by maximizing the *quantity* of offspring produced. Thus, traits (physical qualities or behaviors) that allow males to increase their mating frequency have a selective advantage and, as a result, increase in frequency within the population. This leads to two kinds of sexual selection, as follows:
   - **Male competition** leads to contests of strength that award mating opportunities to the strongest males. The evolution of antlers, horns, and large stature or musculature are examples of this kind of sexual selection.
   - **Female choice** leads to traits or behaviors in males that are attractive to females. Colorful bird plumage (the peacock's tail is an extreme example) or elaborate mating behaviors are examples.

   Sexual selection often leads to **sexual dimorphism,** differences in the appearance of males and females. When this occurs, sexual selection is a form of disruptive selection.

5. **Artificial selection** is a form of directional selection carried out by humans when they sow seeds or breed animals that possess desirable traits. Since it is carried out by humans, it is not "natural" selection, but it is given here for comparison.
   - The various breeds of dogs have originated as a result of humans breeding animals with specific desirable traits.
   - Brussels sprouts, broccoli, cabbage, and cauliflower are all varieties of a single species of wild mustard after artificial selection of offspring possessing specific traits.

Sources of Variation

In order for natural selection to operate, there must be variation among individuals in a population. Indeed, considerable variation exists in nearly all populations. The variation arises from or is maintained by the following mechanisms:

1. **Mutations** provide the raw material for new variation. All other contributions to variation, listed here, occur by rearranging existing alleles into new combinations. Mutations, however, can invent alleles that never before existed in the gene pool.
   - Antibiotic and pesticide resistance alleles can be introduced into populations by mutation. However, these alleles may already exist as part of the genetic variation of the population. The application of antibiotics or pesticides eliminates those susceptible individuals, allowing the nonsusceptible individuals to reproduce rapidly without competition.
2. **Sexual reproduction** creates individuals with new combinations of alleles. These rearrangements, or **genetic recombinations,** originate from three events during the sexual reproductive process, as follows:
   - **Crossing over,** or exchanges of DNA between nonsister chromatids of homologous chromosomes, occurs during prophase I of meiosis.
   - **Independent assortment of homologues** during metaphase I creates daughter cells with random combinations of maternal and paternal chromosomes.
   - **Random joining of gametes** during fertilization contributes to the diversity of gene combinations in the fertilized egg (zygote).
3. **Diploidy** is the presence of two copies of each chromosome in a cell. In the heterozygous condition (when two different alleles for a single gene locus are present), the recessive allele is hidden from natural selection, allowing variation to be "stored" for future generations. As a result, more variation is maintained in the gene pool.
4. **Outbreeding,** or mating with unrelated partners, increases the possibility of mixing different alleles and creating new allele combinations.
5. **Balanced polymorphism** is the maintenance of different phenotypes in a population. Often, a single phenotype provides the best adaptation, while other phenotypes are less advantageous. In these cases, the alleles for the advantageous trait increase in frequency, while the remaining alleles decrease. However, examples of polymorphism (the coexistence of two or more different phenotypes) are observed in many populations. These polymorphisms can be maintained in the following ways:
   - **Heterozygote advantage** occurs when the heterozygous condition bears a greater selective advantage than either homozygous condition. As a result, both alleles and all three phenotypes are maintained in the population by selection. For example, the alleles for normal and sickle-cell hemoglobin proteins (Hb^A and Hb^S, respectively) produce three genotypes: Hb^AHb^A, Hb^AHb^S, and Hb^SHb^S. Hb^AHb^A individuals are normal, while Hb^SHb^S individuals suffer from sickle-cell disease, because the sickle-cell allele produces hemoglobin with an impaired oxygen-carrying ability. Without medical intervention, most Hb^SHb^S individuals die early in life. The heterozygote Hb^AHb^S individuals are generally healthy, but their oxygen-carrying ability may be significantly reduced during strenuous exercise or exposure to low oxygen concentrations (such as at high altitudes). Despite fatal effects to homozygote Hb^SHb^S individuals and

reduced viability of heterozygote individuals, the frequency of the Hb^AHb^S condition exceeds 14% in parts of Africa, an unusually high value for a deleterious phenotype. However, heterozygote Hb^AHb^S individuals have a selective advantage (in Africa) because the Hb^AHb^S trait also provides resistance to malaria. When Hb^AHb^S phenotypes are selected, both Hb^A and Hb^S alleles are preserved in the gene pool, and all three phenotypes are maintained.

- **Hybrid vigor** (or **heterosis**) describes the superior quality of offspring resulting from crosses between two different inbred strains of plants. The superior hybrid quality results from a reduction of loci with deleterious homozygous recessive conditions and an increase in loci with heterozygote advantage. For example, a hybrid of corn, developed by crossing two different corn strains that were highly inbred, is more resistant to disease and produces larger corn ears than either of the inbred strains.
- **Frequency-dependent selection** (or **minority advantage**) occurs when the least common phenotypes have a selective advantage. Common phenotypes are selected against. However, since rare phenotypes have a selective advantage, they soon increase in frequency and become common. Once they become common, they lose their selective advantage and are selected against. With this type of selection, then, phenotypes alternate between low and high frequencies, thus maintaining multiple phenotypes (polymorphism). For example, some predators form a "search image," or standard representation of their prey. By standardizing on the most common form of its prey, the predator optimizes its search effort. The prey that is rare, however, escapes predation.

Not all variation has selective value. Instead, much of the variation observed, especially at the molecular level in DNA and proteins, is **neutral variation.** For example, the differences in fingerprint patterns among humans represent neutral variation. In many cases, however, the environment to which the variation is exposed determines whether a variation is neutral or has selective value.

Humans impact the evolutionary potential of many species by reducing the size of their populations and decreasing genetic variation. When genetic variation decreases, populations lack the variation necessary to respond to selection pressures imposed by changing environments.

- **Monocultures** in agriculture reduce genetic variation because only a few varieties (sometimes only one) of the many wild varieties of a plant are used. Meanwhile, wild varieties in their native habitats are lost due to habitat destruction or other human impacts. In addition, a monoculture, by definition, has no genetic variation and is extremely susceptible to changing environmental conditions. For example, potato crops infected with potato blight, a fungal disease, resulted in widespread crop failures and famine in the middle of the nineteenth century in Ireland.
- The **overuse of antibiotics** reduces variation in bacterial populations by eliminating those individuals that are susceptible to the antibiotic. In the absence of the susceptible individuals, however, nonsusceptible bacteria increase in number and dominate the population, causing new outbreaks of disease.

Causes of Changes in Allele Frequencies

Natural selection was the mechanism that Darwin proposed for evolution. With the understanding of genetics, it became evident that factors other than natural selection can change allele frequencies and, thus, cause evolution. These factors, together with natural selection, are given here:

1. **Natural selection** is the increase or decrease in allele frequencies due to the impact of the environment.
2. **Mutations** introduce new alleles that may provide a selective advantage. In general, however, most mutations are **deleterious,** or harmful.
3. **Gene flow** describes the movement of individuals between populations resulting in the removal of alleles from a population when they leave (emigration) or the introduction of alleles when they enter (immigration).
4. **Genetic drift** is a *random* increase or decrease of alleles. In other words, some alleles may increase or decrease for no other reason than by chance. When populations are small (usually fewer than 100 individuals), the effect of genetic drift can be very strong and can dramatically influence evolution.

- An analogy of genetic drift can be made with the chances associated with flipping a coin. If a coin is flipped 100 times, the number of heads obtained would approach the expected probability of ½. However, if the coin is flipped only 5 times (analogous to a small population), one may obtain, by chance, all tails. Similarly, gene frequencies, especially in small populations, may change by chance.

Two special kinds of genetic drift are commonly observed, as follows:

- The **founder effect** occurs when allele frequencies in a group of migrating individuals are, by chance, not the same as that of their population of origin. For example, one of the founding members of the small group of Germans who began the Amish community in Pennsylvania possessed an allele for polydactylism (more than five fingers or toes on a limb). After 200 years of reproductive isolation, the number of cases of this trait among the 8,000 Amish exceeded the number of cases occurring in the remaining world's population.
- A **bottleneck** occurs when a population undergoes a dramatic decrease in size. Regardless of the cause of the bottleneck (natural catastrophe, predation, or disease, for example), the small population that results becomes severely vulnerable to genetic drift. In addition, when bottlenecks are caused by forces that strike individuals randomly (such as natural catastrophes), gene frequencies may change due to chance. Which individuals survive such a catastrophe is random—being in the wrong place at the wrong time is a random event. The remaining allele frequencies in the population after the event can be very much different than those before the event. Destructive geological or meteorological events such as floods, volcanic eruptions, and ice ages have created bottlenecks and generated genetic drift for many populations of plants and animals.

5. **Nonrandom mating** occurs when individuals choose mates based upon their particular traits. For example, they may always choose mates with traits similar to their own or traits different from their own. Nonrandom mating also occurs when mates choose only nearby individuals. In all of these cases, mate selection is not random, and only the alleles possessed by the mating individuals are passed to the next generation. The following two kinds of nonrandom mating are commonly observed:
   - **Inbreeding** occurs when individuals mate with relatives.
   - **Sexual selection** occurs when females choose to mate with males based upon their attractive appearance or behavior or mate only with males who defeat other males in contests.

Hardy-Weinberg (Genetic) Equilibrium

When the allele frequencies in a population remain constant from generation to generation, the population is said to be in **Hardy-Weinberg equilibrium** or **genetic equilibrium.** *At Hardy-Weinberg equilibrium, there is no evolution.* In order for equilibrium to occur, the factors that normally change gene frequencies do not occur. Thus, the following conditions hold:

1. **All traits are selectively neutral (no natural selection).**
2. **Mutations do not occur.**
3. **The population must be isolated from other populations (no gene flow).**
4. **The population is large (no genetic drift).**
5. **Mating is random.**

Hardy-Weinberg equilibrium is determined by evaluating the following values:

1. Allele frequencies for each allele (p, q)
2. Frequency of homozygotes (p^2, q^2)
3. Frequency of heterozygotes ($pq + qp = 2pq$)

Also, the following two equations hold:

1. $p + q = 1$ (all alleles sum to 100%)
2. $p^2 + 2pq + q^2 = 1$ (all individuals sum to 100%)

As an example, suppose a plant population consists of 84% plants with red flowers and 16% with white flowers. Assume the red allele (R) is dominant and the white allele (r) is recessive. Using the above notation and converting percentages to decimals:

$$q^2 = 0.16 = \text{white-flowered plants } (rr \text{ trait})$$
$$p^2 + 2pq = 0.84 = \text{red-flowered plants } (RR \text{ and } Rr \text{ trait})$$

To determine the allele frequency of the white-flower allele, calculate q by finding the square root of q^2.

$$q = \sqrt{0.16} = 0.4$$

Since $p + q = 1$, p must equal 0.6.

You can also determine the frequency (or percentages) of individuals with the homozygous dominant and heterozygous condition.

$$2pq = (2)(0.6)(.4) = 0.48 \text{ or } 48\% = \text{heterozygotes}$$
$$p^2 = (0.6)(0.6) = 0.36 \text{ or } 36\% = \text{homozygotes dominant}$$

In most natural populations, the conditions of Hardy-Weinberg equilibrium are not obeyed. However, the Hardy-Weinberg calculations serve as a starting point that reveal how allele frequencies are changing, which equilibrium conditions are being violated, and what mechanisms are driving the evolution of a population.

Speciation

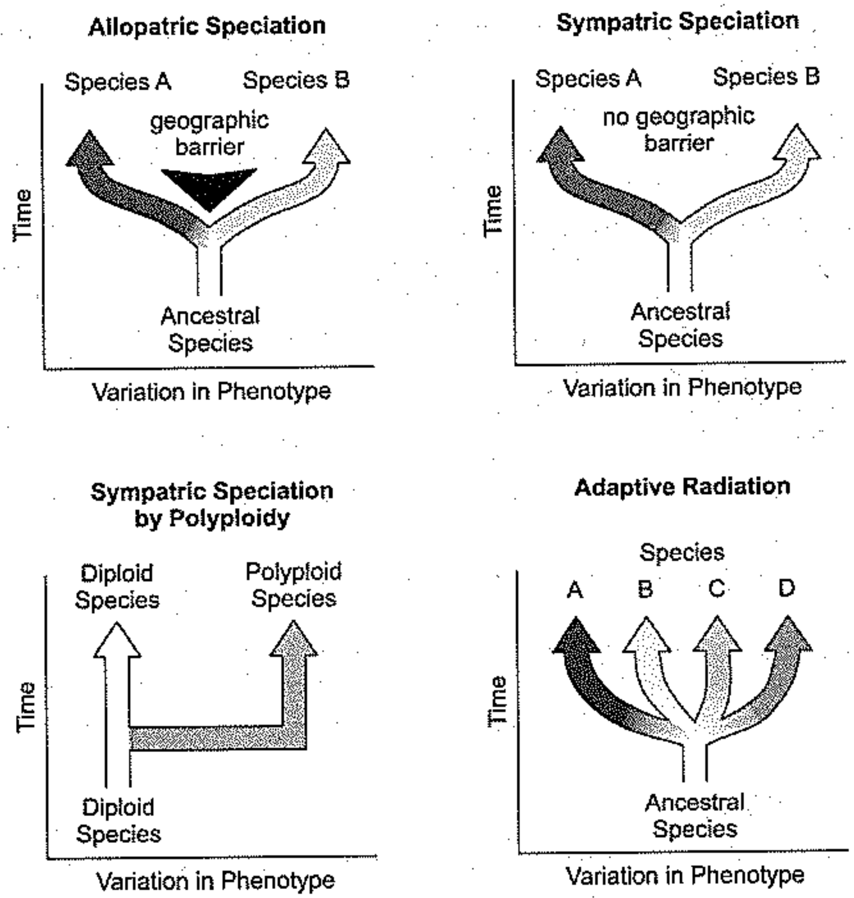
A **species** is usually defined as a group of individuals capable of interbreeding. **Speciation,** the formation of new species, occurs by the following processes, as illustrated in Figure 10-2:

1. **Allopatric speciation** begins when a population is divided by a geographic barrier so that interbreeding between the two resulting populations is prevented. Common barriers include mountain ranges or rivers, but any region that excludes vital resources, such as a region devoid of water, a burned area devoid of food, or an area covered with volcanic lava, can act as a barrier because individuals cannot survive its crossing. Once the two populations are reproductively isolated by the barrier, gene frequencies in the two populations can diverge due to natural selection (the environments may be slightly different), mutation, or genetic drift. If the gene pools sufficiently diverge, then interbreeding between the populations will not occur if the geographic barrier is removed. Instead, differential evolution creates reproductive barriers that prevent interbreeding. As a result, new species have formed. In summary,

   geographic barrier → reproductive isolation → differential evolution → reproductive barriers → new species

2. **Sympatric speciation** is the formation of new species without the presence of a geographic barrier. This may happen in several different ways, as follows:

   - **Balanced polymorphism** among subpopulations may lead to speciation. Suppose, for example, a population of insects possesses a polymorphism for color. Each color provides a camouflage to a different substrate, and if not camouflaged, the insect is eaten by a predator. Under these circumstances, only insects with the same color can associate and mate. Thus, similarly colored insects are reproductively isolated from other subpopulations, and their gene pools diverge as in allopatric speciation.
   - **Polyploidy** is the possession of more than the normal two sets of chromosomes found in diploid ($2n$) cells. Polyploidy often occurs in plants (and occasionally in animals) where triploid ($3n$), tetraploid ($4n$), and higher ploidy chromosome numbers are found. Polyploidy occurs as a result of nondisjunction of all chromosomes during meiosis, producing two viable diploid gametes and two sterile gametes with no chromosomes. A tetraploid zygote can be established when a diploid sperm fertilizes a diploid egg. Since normal meiosis in the tetraploid individual will continue to produce diploid gametes, reproductive isolation with other individuals in the population (and, thus, speciation) occurs immediately in a single generation.



Processes of Speciation

Figure 10-2

- **Hybridization** occurs when two distinctly different forms of a species (or closely related species that are normally reproductively isolated) mate and produce progeny along a geographic boundary called a **hybrid zone.** In some cases, the genetic variation of the hybrids is greater than that of either parent and permits the population of hybrids to evolve adaptations to environmental conditions in the hybrid zone beyond the range of either parent. Exposed to different selection pressures, the hybrids eventually diverge from both parent populations.

3. **Adaptive radiation** is the relatively rapid evolution of many species from a single ancestor. It occurs when the ancestral species is introduced to an area where diverse geographic or ecological conditions are available for colonization. Variants of the ancestral species diverge as populations specialize for each set of conditions.
   - The marsupials of Australia began with the colonization and subsequent adaptive radiation of a single ancestral species.
   - The 14 species of Darwin's finches on the Galápagos Islands evolved from a single ancestral South American mainland species.
   - Adaptive radiations occurred after each of the five big mass extinctions. With up to 90% of species going extinct, the periods following extinctions provided numerous ecological opportunities for species to colonize. Colonization was followed by competition, which, in turn, promoted speciation.

Maintaining Reproductive Isolation

If species are not physically separated by a geographic barrier, various mechanisms exist to maintain reproductive isolation and prevent gene flow. These mechanisms may appear randomly **(genetic drift)**, may occur from mutations, or may be the result of natural selection.

There are two categories of isolating mechanisms. The first category, **prezygotic isolating mechanisms,** consists of mechanisms that prevent fertilization:

1. **Habitat isolation** occurs when species do not encounter one another.
2. **Temporal isolation** occurs when species mate or flower during different seasons or at different times of the day.
3. **Behavioral isolation** occurs when a species does not recognize another species as a mating partner because it does not perform the correct courtship rituals, display the proper visual signals, sing the correct mating songs, or release the proper chemicals (scents, or pheromones).
4. **Mechanical isolation** occurs when male and female genitalia are structurally incompatible or when flower structures select for different pollinators.
5. **Gametic isolation** occurs when male gametes do not survive in the environment of the female gamete (such as in internal fertilization) or when female gametes do not recognize male gametes.

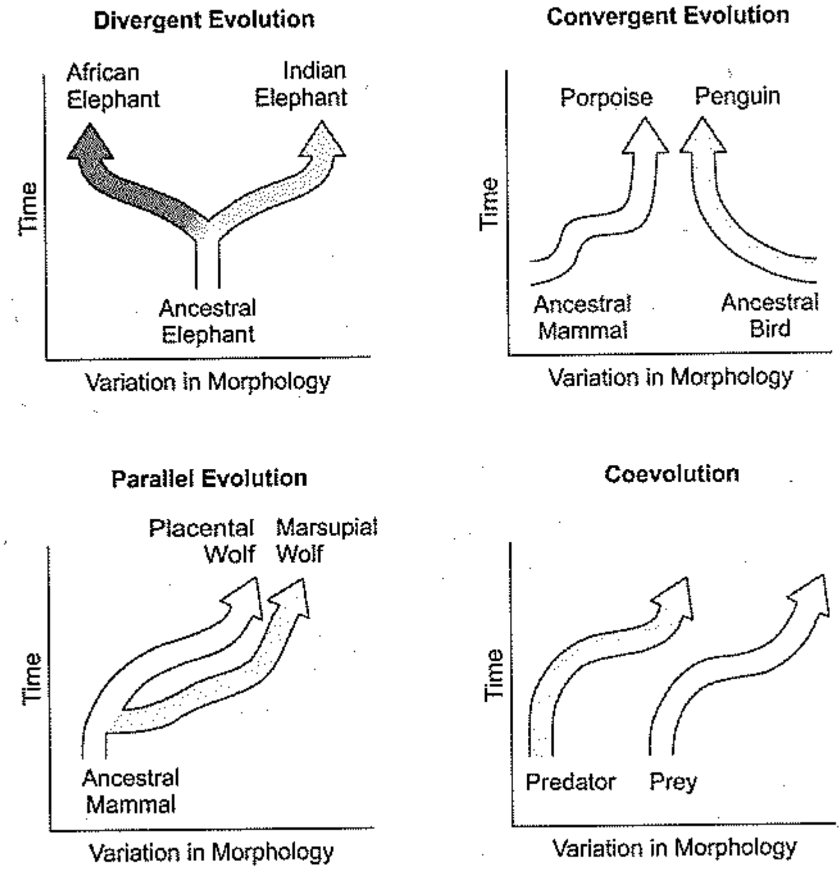
The second category, **postzygotic isolating mechanisms,** consists of mechanisms that prevent the formation of fertile progeny:

6. **Hybrid inviability** occurs when the zygote fails to develop properly and aborts, or dies, before reaching reproductive maturity.
7. **Hybrid sterility** occurs when hybrids become functional adults but are reproductively sterile (eggs or sperm are nonexistent or dysfunctional). The mule, a sterile offspring of a donkey and a horse, is a sterile hybrid.
8. **Hybrid breakdown** occurs when hybrids produce offspring that have reduced viability or fertility.

Patterns of Evolution

The evolution of species is often categorized into the following four patterns (Figure 10-3):

1. **Divergent evolution** describes two or more species that originate from a common ancestor and become increasingly different over time. This may happen as a result of allopatric or sympatric speciation or by adaptive radiation.
2. **Convergent evolution** describes two unrelated species that share similar traits. The similarities arise, not because the species share a common ancestor, but because each species has independently adapted to similar ecological conditions or lifestyles. The traits that resemble one another are called **analogous** traits.
   - Sharks, dolphins, and penguins have torpedo-shaped bodies with peripheral fins. These traits arise as a result of adaptations to aquatic life and not because these animals inherited the traits from a recent, common ancestor.
   - The eyes of squids and vertebrates are physically and functionally similar. However, these animals do not share a recent common ancestor. The fact that the eyes in these two groups of animals originate from different tissues during embryological development confirms that they have evolved independently.
3. **Parallel evolution** describes two related species or two related lineages that have made similar evolutionary changes after their divergence from a common ancestor.
   - Species from two groups of mammals, the marsupial mammals and the placental mammals, have independently evolved similar adaptations when ancestors encountered comparable environments.
4. **Coevolution** is the tit-for-tat evolution of one species in response to new adaptations that appear in another species. Suppose a prey species gains an adaptation that allows it to escape its predator. Although most of the predators will fail to catch prey, some variants in the predator population will be successful. Selection favors these successful variants and subsequent evolution results in new adaptations in the predator species.
   - Coevolution occurs between predator and prey, plants and plant-eating insects, pollinators and flowering plants, and pathogens and the immune systems of animals.



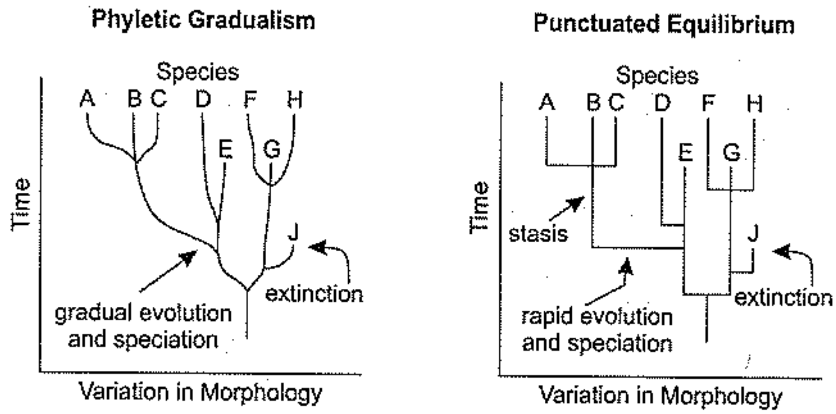
Patterns of Evolution

Figure 10-3

Microevolution vs. Macroevolution

There are two areas of evolutionary study:

1. **Microevolution** describes the details of how *populations* of organisms change *from generation to generation* and how new species originate. Microevolution is the subject of the previous sections in this chapter.
2. **Macroevolution** describes general patterns of change in *groups of related species* that have occurred over *broad periods of geologic time.* The patterns determine **phylogeny,** the evolutionary relationships among species and groups of species. Different interpretations of the fossil evidence have led to the development of two contrasting theories for the pace of macroevolution and the development of evolutionary history (Figure 10-4).
   - **Phyletic gradualism** argues that evolution occurs by the gradual accumulation of small changes. Individual speciation events or major changes in lineages occur over long periods of geologic time, from hundreds of thousands to millions of years. Fossil evidence provides snapshots of the evolutionary process, revealing only major changes in groups of organisms. That intermediate stages of evolution are not represented by fossils merely testifies to the incompleteness of the available fossil record.
   - **Punctuated equilibrium** argues that evolutionary history consists of geologically long periods of stasis with little or no evolution, interrupted, or "punctuated," by geologically short periods of rapid evolution ranging over tens of thousands of years. The fossil history, then, should consist of fossils mostly from the extended periods of stasis with few, if any, fossils available from the short bursts of evolution. Thus, in this theory, the absence of fossils revealing intermediate stages of evolution is considered data that confirm rapid evolutionary events.



Patterns of Macroevolution

Figure 10-4

The Origin of Life

A topic related to evolution is the study of how life began, or **chemical evolution.** This kind of evolution describes the processes that are believed to have contributed to the formation of the first living things. The steps hypothesized to have led to the first primitive cell and the subsequent steps that led to more complex living cells are outlined below with supporting information:

1. **The earth and its atmosphere formed 4.6 billion years ago (bya).**
   - There is considerable geologic evidence that the earth formed 4.6 bya. The earth remained inhospitable to life for billions of years.
   - The primordial atmosphere originated from outgassing of the molten interior of the planet (through volcanos) and consisted primarily of CO_2 and N_2, but little or no O_2.
2. **The primordial seas formed.**
   - As the earth cooled, gases condensed to produce primordial seas consisting of water and minerals.
3. **Organic molecules were synthesized.**
   - Energy catalyzed the formation of organic molecules from inorganic molecules. An organic "soup" formed.
   - Energy was provided mostly by ultraviolet (UV) light, but also lightning, radioactivity, and heat.
   - Complex molecules, such as amino acids, formed. These kinds of molecules would later serve as monomers, or unit building blocks, for the synthesis of polymers.
   - Simple molecules were able to form only because oxygen was absent. As a very reactive molecule, oxygen, had it been present, would have prevented the formation of organic molecules by supplanting most reactants in chemical reactions.
   - Chemist **Stanley Miller** simulated primordial conditions by applying electric sparks to a flask containing heated water and simple gases (but no oxygen). After one week, the water contained various organic molecules, including amino acids.
4. **Polymers and self-replicating molecules were synthesized.**
   - Monomers combined to form polymers. Some of these reactions may have occurred by dehydration reactions, in which polymers formed from monomers by the removal of water molecules.
   - Self-replicating molecules, like DNA or RNA, form. DNA may have been fashioned before RNA, but the recently proposed **RNA world hypothesis** argues the reverse. This is based upon recent discoveries of the many diverse functions of RNA molecules. In particular, RNA molecules can act both as enzymes **(ribozymes)** and as vehicles of information storage (genetic material). Thus, RNA can perform the functions of both proteins (enzymes) and DNA.

5. **Organic molecules were concentrated and isolated into protobionts.**
   - **Protobionts** were the precursors of cells. They were able to carry out chemical reactions enclosed within a border across which materials could be exchanged. Borders formed in the same manner as hydrophobic molecules aggregate to form membranes (as phospholipids form plasma membranes).
   - **Liposomes** and **coacervates** are experimentally (and abiotically) produced protobionts that have some selectively permeable qualities. Both have borders that form when molecules with similar chemical properties (like hydrophilic molecules, such as lipids) separate from other molecules with different chemical properties (such as water).

6. **Primitive heterotrophic prokaryotes formed about 3.2 bya.**
   - **Heterotrophs** are living organisms that obtain energy by consuming organic substances. Pathogenic bacteria, for example, are heterotrophic prokaryotes.
   - The organic "soup" was a source of organic material for heterotrophic cells. As these cells reproduced, competition for organic material increased. Natural selection would favor those heterotrophs most successful at obtaining food.
   - The earliest fossils date to between 3.2 and 3.5 bya.

7. **Primitive autotrophic prokaryotes were formed.**
   - As a result of mutation, a heterotroph gained the ability to produce its own food. Now, as an **autotroph,** this cell would be highly successful.
   - Autotrophs manufacture their own organic compounds using light energy or energy from inorganic substances. Cyanobacteria (photosynthetic bacteria), for example, are autotrophic prokaryotes that obtain energy and manufacture organic compounds by photosynthesis.

8. **Oxygen and the ozone layer formed and abiotic chemical evolution ended.**
   - As a by-product of the photosynthetic activity of autotrophs, oxygen was released and accumulated in the atmosphere. The interaction of UV light and oxygen produced the ozone layer.
   - As a result of the formation of the ozone layer, incoming UV light was absorbed, preventing most of it from reaching the surface of the earth. Thus, the major source of energy for the abiotic synthesis of organic molecules and primitive cells was no longer available.

9. **Eukaryotes formed.**

   Eukaryotes differ from prokaryotes by the presence of mitochondria, chloroplasts, the nucleus, and various other organelles. These bodies may have formed by either (or both) of the following mechanisms.
   - **Invagination** describes how the membranes of some organelles arose by the folding in (invagination) of the plasma membrane. After folding in and separating from the plasma membrane, a new membrane forms inside the cell enclosing and isolating specialized processes.
   - **Endosymbiotic theory** describes how eukaryotic cells originated from a mutually beneficial association (symbiosis) among various kinds of prokaryotes. Specifically, mitochondria, chloroplasts, and other organelles established residence inside another prokaryote, producing a eukaryote.

     There is considerable evidence for the endosymbiotic theory. A sample of that evidence follows:
     - Mitochondria and chloroplasts possess their own DNA. The DNA is circular and without histone proteins, as is the DNA of bacteria and cyanobacteria.
     - Ribosomes of mitochondria and chloroplasts resemble those of bacteria and cyanobacteria, with respect to size and nucleotide sequence.
     - Mitochondria and chloroplasts reproduce independently of their eukaryotic host cell by a process similar to the binary fission of bacteria.
     - Mitochondria and chloroplasts have two membranes (both phospholipid bilayers). The second membrane could have been acquired when the introduced prokaryote is surrounded, in endocytosis fashion, by a vesicle produced by the host prokaryote.
     - The thylakoid membranes of chloroplasts resemble the photosynthetic membranes of cyanobacteria.

Review Questions

Multiple-Choice Questions

The questions that follow provide a review of the material presented in this chapter. Use them to evaluate how well you understand the terms, concepts, and processes presented. Actual AP multiple-choice questions are often more general, covering a broad range of concepts, and often more lengthy. For multiple-choice questions typical of the exam, take the two practice exams in this book.

Directions: Each of the following questions or statements is followed by four possible answers or sentence completions. Choose the one best answer or sentence completion.

1. Which of the following was most responsible for ending chemical evolution?

A. natural selection
B. heterotrophic prokaryotes
C. photosynthesis
D. the absence of oxygen in the atmosphere

2. Which of the following generates the formation of adaptations?

A. genetic drift
B. mutations
C. sexual reproduction
D. natural selection

3. The B blood-type allele probably originated in Asia and subsequently spread to Europe and other regions of the world. This is an example of

A. natural selection
B. genetic drift
C. gene flow
D. sexual reproduction

4. The appearance of a new mutation is

A. a random event
B. the result of natural selection
C. the result of sexual reproduction
D. usually a beneficial event

5. Which of the following is an example of sexual selection?

A. dark-colored peppered moths in London at the beginning of the Industrial Revolution
B. the mane of a lion
C. insecticide resistance in insects
D. Darwin's finches in the Galápagos Islands

6. After test-cross experiments, it was determined that the frequencies of homozygous dominant, heterozygous, and homozygous recessive individuals for a particular trait were 32%, 64%, and 4%, respectively. The dominant and recessive allele frequencies

A. are 0.2 and 0.8, respectively
B. are 0.32 and 0.68, respectively
C. are 0.36 and 0.64, respectively
D. cannot be determined because the population is not in Hardy-Weinberg equilibrium

7. *Cepaea nemoralis* is a land snail. Individual snails have shells with zero to five dark bands on a yellow, pink, or dark brown background. The various shell patterns could have occurred by all of the following EXCEPT:

A. convergent evolution
B. natural selection
C. a balanced polymorphism
D. chance

8. All of the following are homologous structures EXCEPT:

A. a bird wing
B. a butterfly wing
C. a human arm
D. a penguin flipper

Use the following key for questions 9–12. Each answer in the key may be used once, more than once, or not at all.

A. bottleneck
B. adaptive radiation
C. directional selection
D. sexual reproduction

9. Because of human predation, the sizes of and genetic variation in populations of many whale species have dramatically declined.

10. Progeny possess new combinations of alleles every generation.

11. Many strains of *Mycobacterium tuberculosis,* the bacterium that causes tuberculosis, are resistant to standard drug therapy.

12. There are more than 750,000 named species of insects inhabiting a wide range of habitats.

13. All of the following are examples of evolution EXCEPT:

A. mutations in an individual
B. changes in an allele frequency in a population
C. changes in an allele frequency in a species
D. divergence of a species into two species

14. A population consists of 9% white sheep and 91% black sheep. What is the frequency of the black-wool allele if the black-wool allele is dominant and the white-wool allele is recessive?

A. 0.09
B. 0.3
C. 0.7
D. 0.91

15. A blood group consists of two alleles, *M* and *N*. Calculate the frequency of the *M* allele if the following data were obtained for a population:

Blood Types	Number of Individuals
M	80
MN	240
N	180

A. 0.16
B. 0.4
C. 0.6
D. 8.9

Free-Response Questions

The AP exam has long and short free-response questions. The long questions have considerable descriptive information that may include tables, graphs, or figures. The short questions are brief but may also include figures. Both kinds of questions have four parts and generally require that you bring together concepts from multiple areas of biology.

The questions that follow are designed to further your understanding of the concepts presented in this chapter. Unlike the free-response questions on the exam, they are narrowly focused on the material in this chapter. For free-response questions typical of the exam, take the two practice exams in this book.

Directions: The best way to prepare for the AP exam is to write out your answers as if you were taking the exam. Use complete sentences for all your answers and do *not* use outline form or bullets. You may use diagrams to supplement your answers, but be sure to describe the importance or relevance of your diagrams.

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1. Although muscles attach the human ear to the skull, few people can actually use these muscles to move their ears. Explain why the muscles are present if they serve no purpose.

2. "Species evolve because they have to adapt to survive." Explain why this statement is false.

3. Fingerprints, created by dermal ridges on fingers, are an example of neutral variation. The patterns vary among individuals, but differences have no selective value. If variation in fingerprints represents neutral variation, does this mean that the dermal ridges on fingers have no selective value? Justify your answer.

4. Describe how evolution occurs as a result of each of the following.

a. mutations
b. genetic drift
c. gene flow
d. nonrandom mating

5. Describe the process of speciation for each of the following.

a. allopatric speciation
b. sympatric speciation
c. adaptive radiation

6. Describe mechanisms that maintain reproductive isolation for

a. prezygotic
b. postzygotic

7. Explain how each of the following relates to speciation.
   a. geographic barriers
   b. polyploidy
   c. sexual selection

8. Explain how each of the following is important for Darwin's theory of natural selection.
   a. variation among individuals
   b. heritability of traits
   c. competition for resources

9. Explain how each of the following influenced the origin of living organisms.
   a. primordial atmosphere
   b. photosynthesis
   c. oxygen and the ozone layer
   d. endosymbiotic theory

Answers and Explanations

Multiple-Choice Questions

1. **C.** Chemical evolution was able to occur because highly reactive oxygen was not present. The production of oxygen from photosynthesis ended abiotic synthesis because oxygen interfered with the abiotic chemical reactions. Also, the oxygen interacted with UV light to form the ozone layer, which absorbed most incoming UV, the major energy source for abiotic reactions.

2. **D.** Only natural selection generates adaptations. Changes in gene frequencies from other factors may contribute to increases in fitness, but not because they produce adaptations. For example, mutations may introduce a new allele, but the allele will lead to an adaptation only if it increases in the population as a result of natural selection.

3. **C.** Gene flow is the increase in allele frequencies due to transfer from other populations.

4. **A.** Mutations occur randomly and are usually harmful. Whether the mutation increases or decreases in frequency in the population is the result of natural selection, genetic drift, gene flow, or nonrandom mating.

5. **B.** Only male lions have a mane. Differences in appearance between males and females (sexual dimorphisms) not directly required for reproduction are usually the result of sexual selection.

6. **D.** This population is not in Hardy-Weinberg equilibrium. The values given for p^2, $2pq$, and q^2 correctly total 1.

   Calculating the value of q from q^2 gives $q = \sqrt{0.04}$ or 0.2, and the value of p from p^2 gives $p = \sqrt{0.32}$, which is approximately 0.57. The sum of these *calculated* values for p and q gives 0.77. Since $p + q$ *must* equal 1 (there are only two alleles and their frequencies must total 1), the population cannot be in equilibrium. This can be caused by the nonrandom nature of a test cross, as a population in equilibrium must be mating randomly.

7. **A.** The maintenance of various patterned shells in the snail population is an example of a balanced polymorphism. It may be (and there is good evidence that it is) maintained by natural selection, genetic drift (chance), mutations, and other factors as well. Convergent evolution does not apply here because it refers to two or more species not of common ancestral origin that share similar traits. This question deals with phenotypic variation within a single species.

8. **B.** Structures in different species are homologous because they have been inherited from a common ancestor. Insects (butterflies) are not closely related to the other listed animals. Mammals (including bats) and birds (including penguins) are related by descent from an early reptile. Insect wings, instead, are analogous structures.

9. **A.** A bottleneck occurs when population size precipitously falls. Surviving individuals may possess only a limited amount of the total genetic variation present previously. In addition, the effect of genetic drift intensifies when populations are small.

10. **D.** A consequence of sexual reproduction is that crossing over during prophase I of meiosis, mixing of maternal and paternal chromosomes, and random union of gametes produce new combinations of alleles in every generation. Except for identical twins, no two individuals will ever have exactly the same genetic makeup.

11. **C.** As a result of genetic variation, there will be some bacteria that are resistant to antibiotics. Extensive use of antibiotics kills bacteria that are susceptible, but resistant variants survive and reproduce. After many generations of (directional) selection for resistant bacteria, most surviving bacteria are antibiotic resistant.

12. **B.** The variety of insects and their range of habitat and ecological influence is an example of adaptive radiation on a grand scale.

13. **A.** Evolution does not occur for an individual. Only groups of individuals (of the same species) evolve.

14. **C.** The information given in the question is summarized as follows:

    Let $q^2 = 0.09$ = white sheep (homozygous recessives). Then $p^2 + 2pq = 0.91$ = black sheep (homozygous dominants and heterozygotes).

    The question asks for the frequency of the black-wool allele, p. Calculate the square root of $q^2 = 0.09$, using your calculator if necessary:

    $$q = 0.3 \text{ or } 30\%$$

    Because $p + q = 1$, then

    $$p = 1 - q = 0.7$$

15. **B.** First, add up all the individuals to find the size of the population: 80 + 240 + 180 = 500. Letting p and q represent the allele frequencies of N and M, respectively, then $p^2 = 180 \div 500 = 0.36$ and $q^2 = 80 \div 500 = 0.16$. Take the square root of q^2 to find $q = 0.4$.

Free-Response Questions

1. The ear muscles are vestigial, inherited from ancestors in whom they served a function. For many mammals, these muscles still serve to rotate the ear to capture sound from different directions.

2. The statement is false because the words "have to" incorrectly imply that species or individuals in a population are actively contributing to changes that lead to adaptations and increase survival. In fact, adaptations are inherited. An individual either inherits an advantageous trait or does not. If he inherits an advantageous trait, then he survives and produces offspring with similar traits.

3. Dermal ridges do have selective value. The ridges provide friction that allows for a better grip. It is not the pattern of ridges that is important, but the presence (as opposed to the absence) of the ridges that provides the selective value.

4. **a.** Evolution occurs when allele frequencies change from generation to generation in a group of interbreeding organisms. When evolution occurs as a result of natural selection, alleles of those individuals with traits enabling them to survive and reproduce better than others get passed on to the next generation. Over time, the best alleles accumulate in the population. Natural selection acts upon the available traits in the population. Mutations add new alleles, increase variation, and may introduce traits that are more successful that others in the population. Variation can be introduced into the population by mixing up existing alleles through genetic recombination, but mutation is the raw material for variation. It is the only mechanism that can introduce new alleles that didn't previously exist.

b. Genetic drift is another mechanism that can cause evolution, that is, cause allele frequencies to change. Genetic drift describes random changes in allele frequencies. This is especially influential in evolution when populations are small. When a population bottleneck occurs as a result of some catastrophic event (flood, epidemic, ice age), the small surviving population may change due to genetic drift. A founder population may also be subject to the effects of genetic drift. For example, if a small group of individuals becomes separated from the mother population (perhaps by emigration), the allele frequencies of the founder group may differ from the mother population by chance.

c. Evolution may also occur when allele frequencies change due to gene flow—the movement of alleles between populations. Gene flow occurs when individuals immigrate, bringing alleles into the population, or when they emigrate, removing alleles from the population. When gene flow causes a change in the relative frequencies of alleles, evolution occurs.

d. Nonrandom mating may also contribute to changes in allele frequencies and, therefore, cause evolution. Nonrandom mating increases the frequencies of alleles for traits that occur among the mating individuals. For example, in sexual selection, allele frequencies increase if they produce traits that give individuals a better chance of obtaining a mate. Traits that help males win contests or traits that make them more attractive to females have a selective advantage. Inbreeding is another form of nonrandom mating.

This question is about how evolution occurs, so make sure that for each part of the question your answer makes it clear how the mechanism causes evolution. In other words, don't just define each of the mechanisms.

5. **a.** Allopatric speciation occurs when a geographic barrier, such as a river or mountain range, divides the existing population into two populations. Separated in this manner, the two populations are reproductively isolated and gene flow does not occur. As a result, changes in allele frequencies in one population may not occur in the other population. If the environmental conditions vary between the two populations, natural selection may favor different traits in the two populations. Genetic drift may also cause differences in allele frequencies, either because of the founder effect or because either (or both) new population is small. In these two cases, allele frequencies are strongly influenced by chance (genetic drift). Also, mutations in one population may introduce new alleles absent in the other population, thus providing new variation upon which natural selection can act.

b. The defining characteristic of sympatric speciation is that it occurs in the absence of a geographic barrier that would isolate one or more groups of individuals. Instead, reproductive isolation occurs as a result of one of several other causes. Polyploidy, for example, creates reproductive isolation in a single generation. As a result of nondisjunction during meiosis, gametes contain all of the chromosomes instead of half of them. If such a gamete is fertilized by a similar gamete, then the resulting zygote has twice the number of chromosomes and is immediately reproductively isolated from individuals with chromosome numbers like its parents. Though rare in animals, polyploidy is common in plants.

Another source of reproductive isolation can occur when the habitats of two different species meet. In the zone where the two populations meet and overlap, some individuals may mate because of incomplete prezygotic or postzygotic reproductive isolating mechanisms. If the hybrids that form are better adapted to the features of the hybrid zone than either of the parent populations, then successful mating among the hybrids may result in a population that is isolated from either parent population.

A third source of reproductive isolation can result when a population maintains a balanced polymorphism. A balanced polymorphism occurs when multiple forms of a trait are maintained in the population at frequencies higher than would be expected from random mating. In these cases, one or more of the forms possesses an adaptation that has a greater selective value to some specific feature of the environment than other forms. In some cases, the adaptation may also create an isolating mechanism. For example, in response to seed size, a population consists of birds with large and small beaks. If the beak size influences bird song expression and results in segregated mating behavior, reproductive isolation and speciation will result.

c. Adaptive radiation occurs when a population is introduced to an area where many geographic or ecological conditions are available. When the introduced species enters the various new habitats, selection pressures will vary with habitat. For example, in colder habitats, larger animals may be favored (for insulation). In a habitat with many fruit-producing plants, fruit-eating abilities among the animals may be favored. Adaptive radiation occurs among plants as well. For example, in a rain forest habitat, individual plants that have adaptations to wet conditions are favored, whereas in dry regions, plants with water conservation adaptations (thick wax on leaf surfaces, perhaps) are favored.

Darwin's finches are a model for adaptive radiation. The finches inhabit the Galápagos Islands, a group of isolated islands off the coast of South America. Descendants from a single mainland species spread to the various islands where different ecological regions were available for colonization. The bodies of water between the islands provided a barrier that maintained isolation and led to allopatric speciation. But on each individual island, sympatric speciation occurred as finches competed for common resources. The ability to obtain food, an essential characteristic for survival, led to specialization in sizes and shapes of beaks, and, eventually, speciation. Today, as a result of allopatric speciation of populations on separate islands and sympatric speciation on each individual island, there are 14 species of finches, each adapted for obtaining different kinds of food (seeds, fruit, nectar, insects) and different sizes of food.

6. *For this question, separate your answer into two parts, a and b. In part a, define a prezygotic isolating mechanism, list the different forms that it can take (habitat, temporal, behavioral, mechanical, and gametic), and provide an example of each. In part b of your answer, define postzygotic mechanism, follow with the different forms (hybrid inviability, hybrid sterility, and hybrid breakdown), and provide an example of each.*

7. a. A geographic barrier separates a population into groups between which gene flow cannot occur. Once geographically isolated, the evolution of the two new populations may differ. For example, natural selection in one group may be different from that of the other group because their habitats differ. Resources, such as food or water, or predation may differ. Also, mutations in each group may be different. Over time, the two groups may become so different that they cannot (or will not) reproduce with each other even if the barrier is removed. As a result, they are now reproductively isolated and each is a separate species.

b. Polyploidy is the possession of one or more extra sets of chromosomes. As a result of nondisjunction during meiosis, gametes (sperm and eggs) have double the normal number of chromosomes. When a sperm produced in this manner fertilizes a similarly produced egg, the resulting diploid zygote also contains twice the normal number of chromosomes. The result is a polyploid individual. When this new individual undergoes a normal meiosis, gametes will contain twice the number of chromosomes (like its parent) and will be able to fertilize only similarly produced gametes. Thus, the polyploid individual and its progeny are reproductively isolated from the original population. The result is a speciation event occurring in a single generation. Polyploidy is common among plants and rare in animals.

c. Sexual selection is the differential mating of males within a species. Only males that win contests with other males or possess features that are attractive to females are able to mate. As a result, traits that improve a male's success in these two areas carry a selective advantage. Sexual selection results in attributes that improve success in contests (such as horns, antlers, large size, or increased musculature) or traits that are attractive to females (such as good nest-building ability, large territories, or long or colorful feathers as in peacocks and birds of paradise). Although sexual selection may change allele frequencies over time and result in new traits, speciation (the formation of a new species) does not necessarily occur.

8. a. Natural selection favors individuals with traits that increase their fitness, that is, their ability to survive and leave fertile offspring. If all individuals in a population were identical, no one individual would be any more capable of leaving offspring than any other. Without variation there can be no natural selection.

b. If a trait is not heritable, it doesn't matter how much it may increase fitness because it cannot be passed on to the next generation and cannot accumulate in the population. Such "acquired" characteristics do not contribute to evolution. Even mutations that occur in somatic tissues do not count. In order for a trait to contribute to evolution, it must be encoded in alleles that will be incorporated into gametes.

c. If there are unlimited resources and unlimited availability of mates, differences among individuals won't have any effect on their ability to produce offspring. But, eventually, as the population continues to grow, resources will become limited. Then, individuals must compete for those resources. Individuals with the traits that increase their ability to obtain resources will produce more offspring, passing their genes to the next generation. Without competition, there is no natural selection and no evolution.

This question specifically asks you to address each part of the question as to how it is important to Darwin's theory of natural selection. Do not stray from this target. For example, you would not get any points for explaining how a lack of variation can cause genetic drift because genetic drift is not part of Darwin's theory. Also, no points would be awarded for describing how mutations contribute to variation because mutations are also not part of his theory.

9. *Each part of this question corresponds to a major step leading to the origin of life and to eukaryotic cells. See "The Origin of Life," earlier in this chapter, for specific information. Be sure to separate your answers into paragraphs corresponding to each part of the question, each labeled with the appropriate letter.*