Genetic 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 9-2.

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 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 barrier is removed. As a result, new species have formed.
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. 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.

Sample Questions and Answers

Multiple-Choice Questions

Directions: Each of the following questions or statements is followed by five 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. Viruses
E. The absence of oxygen in the atmosphere

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

A. Genetic drift
B. Mutations
C. Gene flow
D. Sexual reproduction
E. 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. artificial selection
B. natural selection
C. genetic drift
D. gene flow
E. sexual reproduction

4. The appearance of a new mutation is

A. a random event
B. the result of natural selection
C. the result of artificial selection
D. the result of sexual reproduction
E. 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 Galapagos Islands
E. The ability of certain insects to avoid harm when consuming toxic plants.

6. 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. 0.42
D. 0.49
E. 0.7

7. 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. are $\sqrt{0.32}$ and $1 - \sqrt{0.32}$, respectively
E. cannot be determined because the population is not in Hardy-Weinberg equilibrium

8. *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
E. mutations

9. All of the following are homologous structures EXCEPT:

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

Answers to 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. **E.** 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. **D.** Gene flow is the increase in allele frequencies due to transfer from other populations.
4. **A.** Mutations occur randomly and are usually harmful. Whether or not 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. **E.** The information given in the question is summarized as follows:

   $$q^2 = 0.09 = \text{white sheep (homozygous recessives)}$$
   $$p^2 + 2pq = 0.91 = \text{black sheep (homozygous dominants and heterozygotes)}$$

   Then, calculate

   $$q = 0.3$$
   $$p = 1 - q = 0.7 \text{ (since } p + q = 1)$$

7. **E.** 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.
8. **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.
9. **C.** 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 (bats and humans) and birds (birds and penguins) are related by descent from an early reptile.
10. **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.
11. **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.
12. **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.