The Origin of Species

14

Focus on the Concepts

Charles Darwin titled his famous book *On the Origin of Species*. Speciation—the evolution of new species—is the bridge between microevolutionary change and broader macroevolutionary themes. As you study this chapter, focus on these major concepts:

- There are several ways to define a species: The biological species concept defines a species as a group of populations whose members have the potential to interbreed in nature and produce fertile offspring. The morphological species concept is based on size, shape, and other body features. The ecological species concept identifies a species in terms of its roles in biological community, and the phylogenetic species concept defines a species as the smallest group with a common ancestor.
- Reproductive barriers keep species separate by restricting gene flow between populations. Prezygotic barriers, such as differences in structure or behavior, prevent mating or fertilization. Postzygotic barriers, such as reduced hybrid viability or fertility, prevent the development of fertile adults.
- In allopatric speciation, geographic isolation can lead to speciation. Populations split off by a geographic barrier, such as a canyon or mountain range, can be changed by genetic drift and natural selection. Speciation occurs if the gene pool of an isolated population undergoes changes that establish reproductive barriers between it and the parent population.
- Sympatric speciation occurs without geographic isolation. Sometimes this is a result of habitat preference or sexual selection. A common form of sympatric speciation in plants involves polyploidy, a change in the number of chromosomes. Errors in cell division may produce fertile tetraploid plants that are reproductively isolated from the diploid parent population. More often, hybridization of two species followed by chromosome duplication can result in a self-fertile plant isolated from both parent species.
- Reproductive barriers may result from genetic changes as populations adapt to different environments. Natural selection can reinforce a genetic barrier, reducing the formation of unfit hybrids. Or, if reproductive barriers are not strong, two hybridizing species may fuse into one. Sometimes, stability develops in the hybrid zone, with gene exchange between two species via hybrids.
- Formation of many diverse species from a common ancestor is called adaptive radiation. This occurs when a few organisms enter a new, unexploited area, or when environmental changes cause numerous extinctions, and new species can fill new habitats or roles. The fossil record suggests that much speciation occurs relatively rapidly, with periods of stability in between. Other examples are more gradual. In either case, timelines are long—tens of thousands to millions of years.

Review the Concepts

Work through the following exercises to review the concepts in this chapter. For additional review, check out the activities at www.masteringbiology.com. The website offers a pre-test that will help you plan your studies.

Exercise 1 (Modules 14.1–14.2)

There are several ways that biologists define a species. Several are listed below. Match each of the descriptions on the left with a species concept on the right. Some answers are used more than once.

____ 1. The smallest group that shares a common ancestor; one branch on the tree of life
____ 2. Body form; shape, size and other features; what the organism looks like
____ 3. Populations whose members can interbreed in nature and produce fertile offspring
____ 4 Organisms with particular niches or roles in the biological community
____ 5. Reproductive isolation is an important criterion for this species concept
____ 6. Used to identify most of the species named to date

A. Biological species concept
B. Ecological species concept
C. Phylogenetic species concept
D. Morphological species concept

Exercise 2 (Modules 14.2–14.3)

The biological species concept is one of the most useful ways to define a species, but it is not foolproof. Briefly explain why it might be difficult to apply the biological species concept in each of the following situations.

1. Fossils of "Java Man" and "Peking Man" are both thought to represent a single species—*Homo erectus*.

2. A tiger and a lion can interbreed in a zoo and produce a hybrid offspring called a tiglon.

3. Dogs come in many shapes and sizes, from Chihuahuas to Saint Bernards.

4. There are many strains and species of *Streptococcus* bacteria, which reproduce asexually.

5. Among *Clarkia* wildflowers in California, flowers of population A can interbreed and produce fertile offspring when crossed with flowers from population B. Similarly, B can interbreed with C. But A and C cannot successfully interbreed.

6. One bird guide calls flycatchers of the genus *Empidonax* "the bane of bird-watchers." Several species look so much alike that birders can distinguish them only by their songs.

7. A song sparrow population in Baja, California, is separated from other song sparrows by over a hundred miles of desert.

Exercise 3 (Module 14.3)

Review the reproductive barriers that separate species by categorizing the following examples. State whether each barrier is prezygotic (pre) or postzygotic (post), and then name the specific kind of barrier (such as temporal isolation or reduced hybrid viability) it exemplifies. Table 14.3A is a helpful summary.

	Pre or Post	*Kind of Barrier*	*Example*
1.	_____	_____	The salamanders *Ambystoma tigrinum* and *A. maculatum* breed in the same areas. *A. tigrinum* mates from late February through March. *A. maculatum* does not start mating until late March or early April.
2.	_____	_____	Two species of mice are mated in the lab and produce fertile hybrid offspring, but offspring of the hybrids are sterile.
3.	_____	_____	When fruit flies of two particular species are crossed in the lab, their offspring are unable to produce eggs and sperm.
4.	_____	_____	A zoologist observed two beetles of different species that were trying to mate with little success because they apparently did not "fit" each other.
5.	_____	_____	Male fiddler crabs (genus *Uca*) wave their large claws to attract the attention of females. Each species has a slightly different wave.
6.	_____	_____	When different species of tobacco plants are crossed in a greenhouse, the pollen tube usually bursts before the eggs are fertilized.
7.	_____	_____	Blackjack oak (*Quercus marilandica*) grows in dry woodlands, and scrub oak (*Q. ilicifolia*) grows in dry, rocky, open areas. Pollen of one species seldom pollinates the other.
8.	_____	_____	The tiglon offspring of a lion and a tiger are often weak and unhealthy.

Exercise 4 (Modules 14.4–14.5)

Allopatric speciation often begins with geographic isolation. For each of the organisms listed in the following, name two geographic barriers that might block gene flow between populations and possibly lead to allopatric speciation.

1. Daisy
2. Mouse
3. Trout
4. Oak tree
5. Sparrow
6. Sea star

Exercise 5 (Modules 14.6–14.7)

Many species of plants have arisen from accidents in cell division that result in extra sets of chromosomes. A change in chromosome number produces a reproductive barrier that isolates organisms from their parent populations. This is one way that sympatric speciation—speciation in the same geographic area as the parent species—can occur. Study the examples given in Modules 14.6 and 14.7. Then state whether you think each of the organisms in the following in italics would be able to reproduce (yes or no), whether it could represent a new species (yes or no), and how many chromosomes would be present in its cells.

	Reproduction	*New Species*	*No. of Chrom.*	*Example*
1.	_____	_____	_____	A flower has 18 chromosomes (2n=18). There is an error in cell division, producing tetratploid cells that grow into *tetraploid flowers,* capable of self-fertilization when mature.
2.	_____	_____	_____	A tree has 22 chromosomes (2n=22). An error in meiosis produces a diploid pollen grain, which fertilizes a normal haploid egg. The resulting polyploid zygote develops into a *full-grown tree.*
3.	_____	_____	_____	Antelope of two different species mate in a zoo. Species A has 36 chromosomes; species B has 34 chromosomes. They produce a *hybrid offspring.*
4.	_____	_____	_____	A lily of species A has 16 chromosomes. Species B has 20 chromosomes. A hybrid with 18 chromosomes undergoes chromosome duplication, producing a *lily* that is capable of self-pollination.
5.	_____	_____	_____	A botanist treats some tissue from a strawberry plant (2n=14) with a chemical that disrupts the mitotic spindle. This doubles the number of chromosomes in a cell. This cell is then cultured on a special medium, until it eventually develops into a *strawberry plant* that can self-pollinate.
6.	_____	_____	_____	Pollen from the cell-cultured strawberry in Question 5 is placed on the flower of a plant of the parent species, producing a *triploid hybrid zygote.*

Exercise 6 (Modules 14.8–14.9)

Speciation and adaptive radiation often occur on islands. But an island does not have to be a bit of land in the midst of an ocean for geographic isolation to occur. Try to come up with four examples of different kinds of "islands" and the kinds of species that could be isolated and evolve in each.

1.

2.

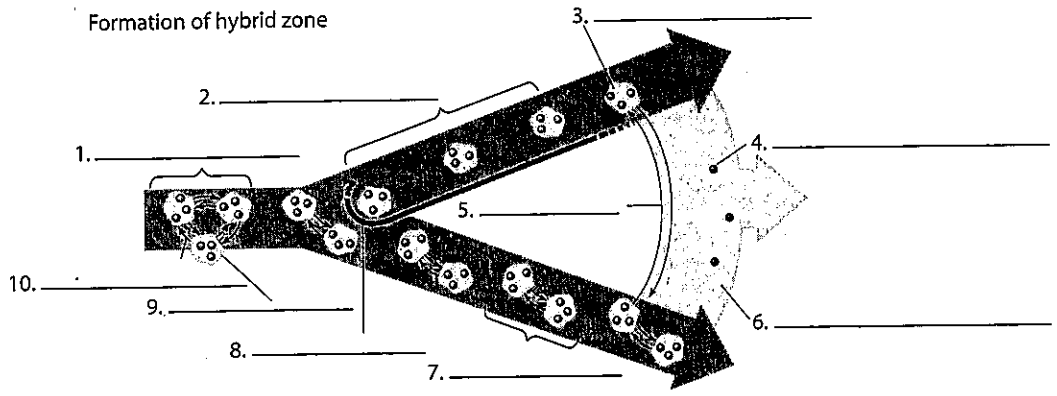
3.

4.

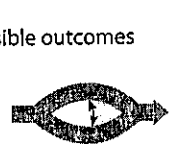
Exercise 7

After new species are formed, reproductive isolation is often tested in hybrid zones, where populations of closely-related species overlap. The diagrams that follow illustrate speciation, the formation of a hybrid zone, and three possible outcomes arising from hybridization. See if you understand the diagrams by labeling the organisms and processes involved. Choose from: **hybrid zone, hybrid individual, three populations of one species, gene flow, barrier to gene flow, newly formed species, populations of original species, divergence** of one population from the other two, **gene flow in the hybrid zone, population, stability, fusion, reinforcement.**

Formation of hybrid zone

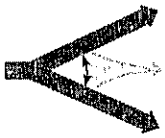


Possible outcomes



11. _____

12. _____



13. _____

Exercise 8 (Modules 14.3–14.11)

Speciation can occur when populations are geographically isolated (allopatric speciation) or when polyploidy or other factors restrict gene flow within an area (sympatric speciation). Reproductive barriers may then be reinforced or may break down. Review speciation and its aftermath by using the concepts and terms from this chapter to complete the following story about (imaginary) butterflies and asters.

The yellowspot butterfly is found over hundreds of square miles of land in the delta of an African river. Its primary food source is a species of purple aster—a flower related to daisies and dandelions. Patches of asters are scattered in sunny meadows in the delta, some several miles apart. The butterflies do not usually venture far for food. Each patch of asters supports a separate [1]_____ of yellowspots, but because the butterflies sometimes wander and mate with butterflies in other areas, until recently all the yellowspot butterflies have been classified as members of the same [2]_____.

Insect taxonomists noted that one population of yellowspots was centered across the main river channel from the other populations. They suspected that the river might act as a [3]_____ to the butterflies, since they do not usually fly far over water. The researchers examined the butterflies from the isolated population and found that the butterflies from across the river were a bit smaller than most yellowspots and

more orange in color, so the researchers nicknamed them "orangespots." The biologists found that the differences in appearance were inherited. They suspected these could reflect [4]_____ due to chance differences in the butterflies that founded the orangespot population. The researchers also noted that the environment was slightly warmer and drier on the far side of the river, so [5]_____ may have caused the orangespots to adapt to conditions there.

The scientists started to suspect that the two populations could represent different species. To test this hunch, they had to find out whether butterflies from the far side of the river could [6]_____ with individuals from the main population. The biologists captured some butterflies from both areas and placed them in a cage. Surprisingly, the orangespots and yellowspots largely ignored each other. The researchers found that the female butterflies rest on leaves and flash their wing spots to attract the males. Yellowspot females flash their wings at a much faster rate than orangespot females. Apparently the wing-flashing display acts as a [7]_____zygotic reproductive barrier. Apparently, [8]_____ isolation keeps the two populations of butterflies from interbreeding. In a few instances, the eggs of an orangespot female were fertilized by a yellowspot male, and vice-versa, but the embryos soon died. Apparently, there is also a [9]_____zygotic reproductive barrier between the butterflies. This particular type of barrier is called [10]_____. When hybrids are less fit than parent species, natural selection can [11]_____ reproductive barriers, reducing the production of unfit hybrids, and preventing [12]_____ of the two populations in the [13]_____ zone. (Studies of other species, such as snails and monkeyflowers, have shown that a change in a single [14]_____ can create such a barrier.) The researchers concluded that the reproductive barriers were effectively preventing interbreeding of the butterflies, making the yellowspots and orangespots separate [15]_____, according to the [16]_____ species concept.

A study of river sediments showed that the channel separating the two butterfly populations formed about a thousand years ago, when the river shifted course. It has indeed acted as a geographic barrier, [17]_____ the two populations from one another and eventually leading to [18]_____ speciation. A thousand years seems like a long time to us, but this is a relatively rapid rate of speciation. It would seem to support the idea of [19]_____ equilibria, where bursts of speciation alternate with long periods of stability.

While studying the habits of the butterflies, the biologists turned their attention to the flowers, and found a group of asters with oval-shaped leaves and slightly larger flowers than all the others. A study of their chromosomes showed that the unusual plants were [20]_____, having more than the usual two sets of chromosomes. All the other purple asters in the area had two sets of chromosomes and a 2n chromosome number of 26. The unusual plants were [21]_____, having four sets of chromosomes, for a total of 52. An error must have occurred during cell division in one of the diploid asters, creating cells with a total of [22]_____ sets of chromosomes . These cells must have formed a branch with flowers. Meiosis gave rise to gametes that each contained [23]_____ sets of chromosomes, and because the flowers could self-pollinate, zygotes were formed with four sets of chromosomes. The tetraploid plants that developed from these zygotes could interbreed with one another, but they were reproductively [24]_____ from the diploid parent species. They represented a new [25]_____ of aster, produced in one generation through the process of [26]_____ speciation.

Exercise 9 (Modules 14.1–14.11)

This chapter describes many examples of speciation. For one last review, try to match each description that follows with the correct species.

____ 1. Mammal species that overlap on the Great Plains, but mate at different times.
____ 2. 80% of these are descended from ancestors formed by polyploid speciation.
____ 3. Different species can't mate because their shells don't allow it.
____ 4. Different colors of two species attract different pollinators.
____ 5. Different diets led to reproductive barriers in a laboratory experiment.
____ 6. These animals are thought to have originated via polyploid speciation.
____ 7. Sometimes hybridize with grizzly bears.
____ 8. Adaptive radiation led to numerous species on different islands.
____ 9. Diverged after a population was split by the Grand Canyon.
____ 10. Eastern and western species look alike, but sing different songs.
____ 11. Different species blink their "taillights" in different rhythms.
____ 12. The Isthmus of Panama separated various species.
____ 13. Related species look less alike in their hybrid zone.
____ 14. Hundreds of species have evolved in Lake Victoria.
____ 15. A flightless species have evolved in the Galapagos Islands.
____ 16. One species lives mostly on land, and a related species mostly in the water.

A. Gray tree frogs
B. Cichlids
C. Pied flycatchers
D. Antelope squirrels
E. Darwin's finches
F. Monkey flowers
G. Cormorant
H. Garter snakes
I. Snails
J. Fruit flies
K. Spotted skunks
L. Fireflies
M. Plants
N. Polar bears
O. Meadowlarks
P. Snapping shrimp

Test Your Knowledge

Multiple Choice

1. According to the biological species concept, two animals are considered different species if they
   a. look different.
   b. cannot interbreed.
   c. live in different habitats.
   d. are members of different populations.
   e. are geographically isolated.

2. Which of the following is the first step in allopatric speciation?
   a. genetic drift
   b. geographic isolation
   c. polyploidy
   d. hybridization
   e. formation of a reproductive barrier

3. Bacteriologists usually use the morphological species concept to define species because
   a. bacteria often hybridize.
   b. bacteria reproduce sexually.
   c. bacteria are so small.
   d. bacteria reproduce very rapidly.
   e. bacteria reproduce asexually.

4. A new species can arise in a single generation
   a. through geographic isolation.
   b. in a very large population that is spread over a large area.
   c. if a change in chromosome number creates a reproductive barrier.
   d. if allopatric speciation occurs.
   e. because of hybrid breakdown.

5. The evolution of numerous species, such as Darwin's finches, from a single ancestor is called
   a. adaptive radiation.
   b. sympatric speciation.
   c. punctuated equilibrium.
   d. polyploidy.
   e. geographic isolation.

6. According to the ____ model, evolution occurs in spurts; species evolve relatively rapidly, then remain unchanged for long periods.
   a. allopatric
   b. gradual
   c. adaptive radiation
   d. punctuated equilibria
   e. geographic isolation

7. Most of the time, species are identified by their appearance. Why?
   a. If two organisms look alike, they must be the same species.
   b. This is the criterion used to define a biological species.
   c. If two organisms look different, they must be different species.
   d. This is the most convenient way of identifying species.
   e. Most organisms reproduce asexually.

8. Most species of ____ are descended from ancestors that underwent sympatric speciation by polyploidy.
   a. plants
   b. bacteria
   c. land mammals
   d. insects
   e. fish

9. Individuals of different species living in the same area may be prevented from interbreeding by responding to different mating dances. This is called
   a. ecological isolation.
   b. hybrid breakdown.
   c. mechanical isolation.
   d. temporal isolation.
   e. behavioral isolation.

10. It is unlikely that the human population will give rise to a new species because
    a. the human population is too large.
    b. geographic isolation is unlikely to occur.
    c. a change in chromosome number would be fatal.
    d. the human population is too diverse.
    e. natural selection cannot affect humans.

11. Which of the following could happen the fastest?
    a. sympatric speciation
    b. allopatric speciation
    c. adaptive radiation
    d. polyploid speciation
    e. natural selection

Essay

1. Give three situations in which it might be difficult to use the biological species concept to decide whether two organisms are of the same or different species.

2. Describe step-by-step how geographic isolation could lead to speciation.
3. Describe what has to happen for two species with different numbers of chromosomes to interbreed and produce a fertile hybrid. Will this hybrid be able to interbreed with either of its parents? Why? How common is this in nature?
4. Is a large, widely distributed population or a small, isolated population more likely to undergo speciation? Explain why.
5. Compare the gradual and the punctuated equilibrium models of species evolution. What would the fossil record of speciation look like if it supported the gradual model? What would it look like if punctuated equilibrium were the case? Which model does the fossil record seem to support most often? Why?

Apply the Concepts

Multiple Choice

1. Three species of frogs—*Rana pipiens*, *Rana clamitans*, and *Rana sylvatica*—all mate in the same ponds, but they pair off correctly because they have different mating calls. This illustrates a ____ and ____.
   a. prezygotic barrier . . . behavioral isolation
   b. postzygotic barrier . . . hybrid breakdown
   c. prezygotic barrier . . . temporal isolation
   d. postzygotic barrier . . . behavioral isolation
   e. prezygotic barrier . . . gametic isolation
2. Two closely related species of rabbits may occasionally mate, but their embryos are never viable. Which of the following is a possible consequence?
   a. hybridization
   b. reinforcement of reproductive barriers
   c. fusion of gene pools
   d. polyploidy
   e. a stable situation with gene flow between populations
3. Bullock's oriole and the Baltimore oriole are closely related, but are they the same species? To find out, you could see whether they
   a. sing similar songs.
   b. look alike.
   c. live in the same areas.
   d. have the same number of chromosomes.
   e. successfully interbreed.
4. Sometimes two quite different populations interbreed to a limited extent, so that it is difficult to say whether they are clearly separate species. This does not worry biologists much because it
   a. is quite rare.
   b. is true for almost every species.
   c. supports the theory of punctuated equilibrium.
   d. may illustrate the formation of new species in progress.
   e. happens only among plants, not among animals.
5. Two species of water lilies in the same pond do not interbreed because one blooms at night and the other during the day. The reproductive barrier between them is an example of
   a. temporal isolation.
   b. gametic isolation.
   c. mechanical isolation.
   d. hybrid breakdown.
   e. ecological isolation.
6. Comparison of fossils with living humans seems to show that there have been no significant physical changes in *Homo sapiens* in 30,000 to 50,000 years. What might an advocate of punctuated equilibria say about this?
   a. It is about time for humans to undergo a burst of change.
   b. That is about how long we have been reproductively isolated.
   c. It is impossible to see major internal changes by looking at fossils.
   d. You would expect lots of changes in the skeleton in that time period.
   e. Apparent lack of change is consistent with the punctuated equilibrium model.
7. Which of the following is an example of a postzygotic reproductive barrier?
   a. One species of frog mates in April; another mates in May.
   b. Two fruit flies of different species produce offspring that are sterile.
   c. The sperm of a marine worm only penetrate eggs of the same species.
   d. One species of flower grows in forested areas, another in meadows.
   e. Two pheasant species perform different courtship dances.

8. The Hawaiian Islands are home to more than twenty species of birds called honeycreepers, each with a slightly different diet and habits. All these birds probably evolved from one ancestor, an example of
   a. sympatric speciation.
   b. hybrid breakdown.
   c. adaptive radiation.
   d. gradualism.
   e. punctuated equilibrium.

9. A botanist found that a kind of white daisy had a diploid chromosome number of 16. In the same area, he found a yellowish daisy. Its cells contained 24 chromosomes. He found that the yellowish daisy was a polyploid descendant of the white daisies. These flowers can only reproduce sexually. Which of the following would describe this unusual plant? P: tetraploid, Q: triploid, R: probably sterile, S: a new species.
   a. P R S
   b. Q R
   c. Q R S
   d. P S
   e. Q S

10. A fossil expert finds an impression of an ancient marine creature called a trilobite in a layer of rock. In the adjacent layer is another species of trilobite, clearly related to the first but quite different in form. If the expert is a gradualist, how might he or she interpret this?
    a. This kind of change is exactly what gradualism would predict.
    b. Sympatric speciation must have occurred.
    c. Intermediate forms could have existed but were not fossilized.
    d. Internally, the creatures were identical; only the outer shell changed.
    e. This kind of abrupt transition is rare in the fossil record.

11. On a Caribbean island, one ancestral species of lizard appears to have given rise to at least six existing species. One lives on the ground, another on tree trunks, a third among the leaves of the forest canopy, and so on. Different species occasionally interbreed, but offspring are sterile. Which of the following terms applies to this situation?
    a. adaptive radiation
    b. sympatric speciation
    c. habitat differentiation
    d. postzygotic reproductive barrier
    e. all of the above

Essay

1. There are dozens of species of small rodents, such as rats and mice, in western North America, but relatively few species, ranging over much larger areas, in the east. Suggest a hypothesis related to speciation that might explain this.

2. The mating of a horse and a donkey produces a mule, which is strong and hard working, but sterile. A horse cell contains 64 chromosomes, a donkey cell 62 chromosomes. How many chromosomes would you expect to find in a cell from a mule? Why? Explain why a mule is sterile.

3. A dog (*Canis familiaris*) and a coyote (*Canis latrans*) will readily mate in captivity, and their offspring are healthy and fully fertile. Are we justified in saying they are distinct species? What might this tell us about the history of dogs and coyotes?

4. In terms of speciation, how might freshwater streams in a desert be like islands in the ocean?

5. Various sections of the Hawaiian Islands were formed by lava flows at different times. Kenneth Kaneshiro compared older populations of fruit flies living in older habitats with presumably younger populations living in more recently formed habitats. He found that male fruit flies in both areas are generally eager to mate, but females of older populations are much more selective about their partners than females of newer populations. Suggest a hypothesis to explain why this might be the case.

6. Critics of evolution often say things like, "Sure, insects and bacteria can adapt to a changing environment. But fruit flies are still fruit flies, and *Streptococcus* is still *Streptococcus*. Nobody has ever seen a new species evolve." Is this criticism valid? How would you respond to this comment?