UNIT 4

History of Biological Diversity

THEMES

Scientific Inquiry Darwin's studies led to the theory of evolution by natural selection.

Diversity Today's diversity is classified using genetics and phylogeny.

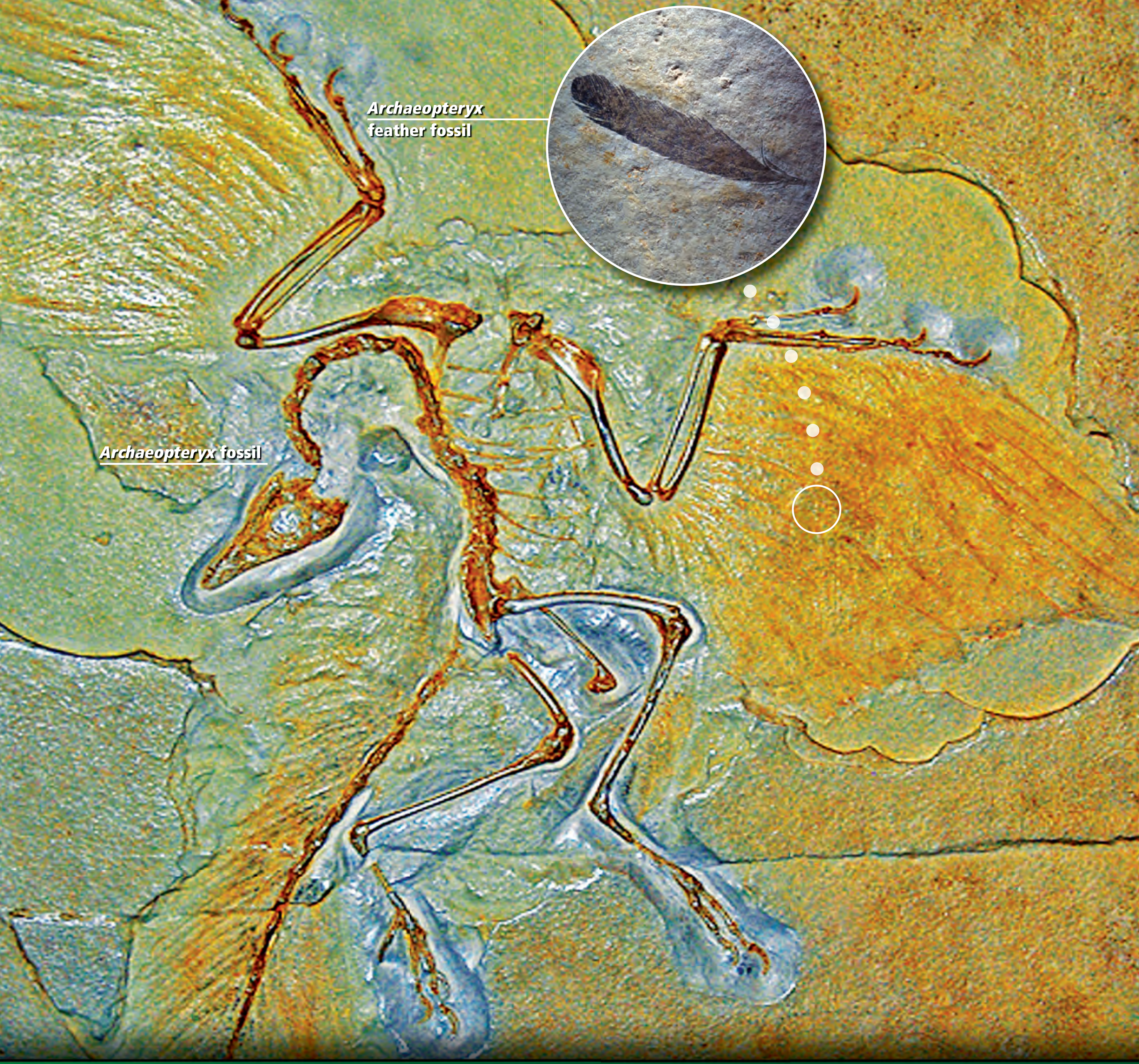
Energy Converted energy is used by organisms for daily life functions.

Homeostasis Long-term changes lead to adaptations in a population.

Change Natural selection results in the evolution of new species.

WebQuest **CAREERS IN BIOLOGY**

Paleontologists study the origins of life on Earth by studying the fossil records. Paleontologists work with other scientists to identify fossils of microscopic organisms, plants, invertebrates, and vertebrates at archaeological sites.



THEME FOCUS Change

Various lines of evidence indicate changes in Earth's environment and life forms over time.

BIG Idea Fossils provide key evidence for understanding the origin and the history of life on Earth.

CHAPTER 14

The History of Life

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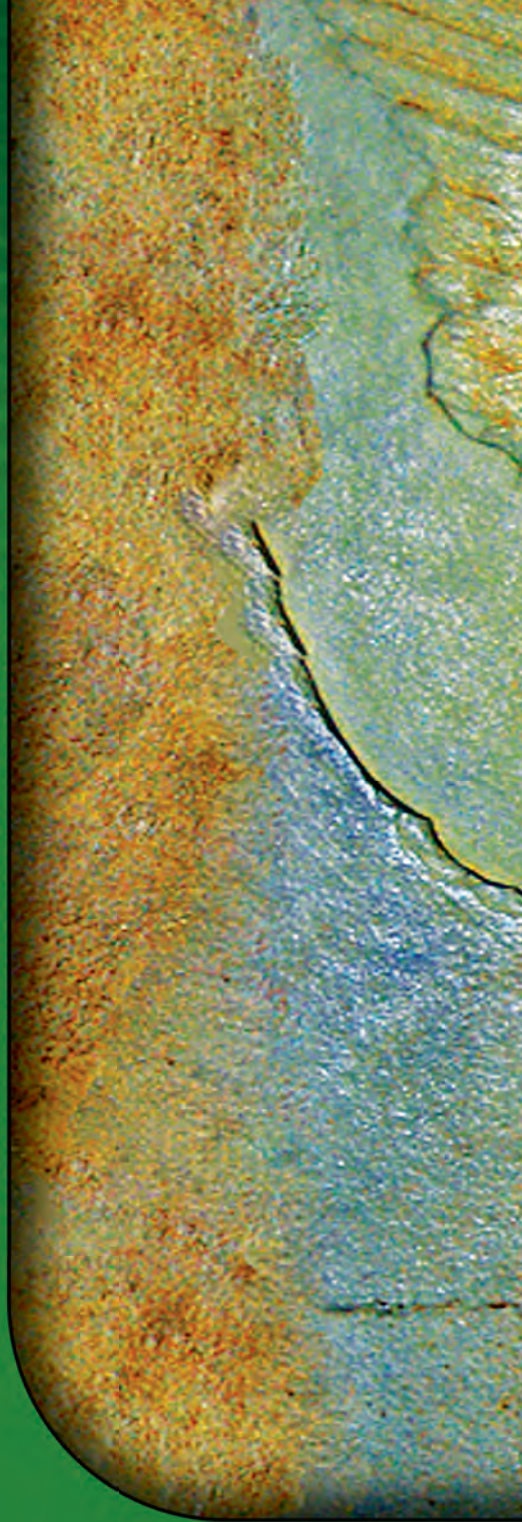


Launch Lab

What can skeletal remains reveal?

Fossils are all that remain of extinct organisms. Paleontologists study fossils to understand how organisms looked and behaved when they lived on Earth. In this lab, you will infer an organism's characteristics based on skeletal remains.

For a lab worksheet, use your StudentWorks™ Plus Online.

Inquiry Launch Lab

FOLDABLES®

Make a folded chart using the titles shown. Use it to organize your notes on the scientists.

Section 1

Reading Preview

Essential Questions

- What are the similarities and differences between Earth's early environment and Earth's current environment?
- What is a typical sequence of events in fossilization?
- How are the different techniques for dating fossils used?
- What are the major events on the geologic time scale?

Review Vocabulary

extinction: the death of all individuals of a species

New Vocabulary

fossil
paleontologist
relative dating
law of superposition
radiometric dating
half-life
geologic time scale
epoch
period
era
eon
Cambrian explosion
K-T boundary
plate tectonics

g Multilingual eGlossary

Fossil Evidence of Change

MAIN Idea Fossils provide evidence of the change in organisms over time.

Real-World Reading Link Did you know that when you look at the stars at night you are looking into the past? The stars are so far away that the light you see left the stars thousands and sometimes millions of years ago. You also are looking into the past when you look at rocks. The rocks formed thousands or even millions of years ago. Rocks can tell us what Earth was like in the distant past, and sometimes they can tell us what lived during that time.

Earth's Early History

What were the conditions on Earth as it formed, and how did life arise on a lifeless planet? Because there were no people to witness Earth's earliest history, it might seem that this is an unsolvable mystery. Like any good mystery, however, it left clues behind. Each clue to Earth's history and life's origin is open to investigation by the scientists who study the history of the Earth.

Land environments By studying other planets in the solar system and rocks on Earth, scientists conclude that Earth was a molten body when it formed about 4.6 billion years ago. Gravity pulled the densest elements to the center of the planet. After about 500 million years, a solid crust formed on the surface, much like the crust that forms on the top of lava, shown in **Figure 1.** The surface was rich in lighter elements, such as silicon. From the oldest rocks remaining today, scientists infer that Earth's young surface included a number of volcanic features. In addition, the cooling interior radiated much more heat to the surface than it does today. Meteorites would have caused additional heating as they crashed into Earth's surface. If there had been any life on Earth, it most likely would have been consumed by the intense heat.

Figure 1 Lava, molten rock ejected from volcanoes, forms a crust as it cools.
***Infer** the importance of the crust to the origin of life on Earth.*

Molten lava flow

Atmosphere Because of its gravitational field, Earth is a planet that is able to maintain an atmosphere. However, no one can be certain about the exact composition of Earth's early atmosphere. The gases that likely made up the atmosphere are those that were expelled by volcanoes. Volcanic gases today include water vapor (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), carbon monoxide (CO), hydrogen sulfide (H_2S), hydrogen cyanide (HCN), nitrogen (N_2), and hydrogen (H_2). Scientists infer that the same gases would have been present in Earth's early atmosphere. The minerals in the oldest known rocks suggest that the early atmosphere, unlike today's atmosphere, had little or no free oxygen.

Clues in Rocks

Earth eventually cooled to the point where liquid water formed on its surface, which became the first oceans. It was a short time after this—maybe as little as 500 million years—that life first appeared. The earliest clues about life on Earth date to about 3.5 billion years ago.

The fossil record A **fossil** is any preserved evidence of an organism. Six categories of fossils are shown in **Table 1.** Plants, animals, and even bacteria can form fossils. Although there is a rich diversity of fossils, the fossil record is like a book with many missing pages. Perhaps more than 99 percent of the species that ever have lived are now extinct, but only a tiny percentage of these organisms are preserved as fossils.

Most organisms decompose before they have a chance to become fossilized. Only those organisms that are buried rapidly in sediment are readily preserved. This occurs more frequently with organisms living in water because the sediment in aquatic environments is constantly settling, covering, and preserving the remains of organisms.

Vocabulary

Word origin

Fossil
from the Latin word *fossilis,* meaning *dug up*

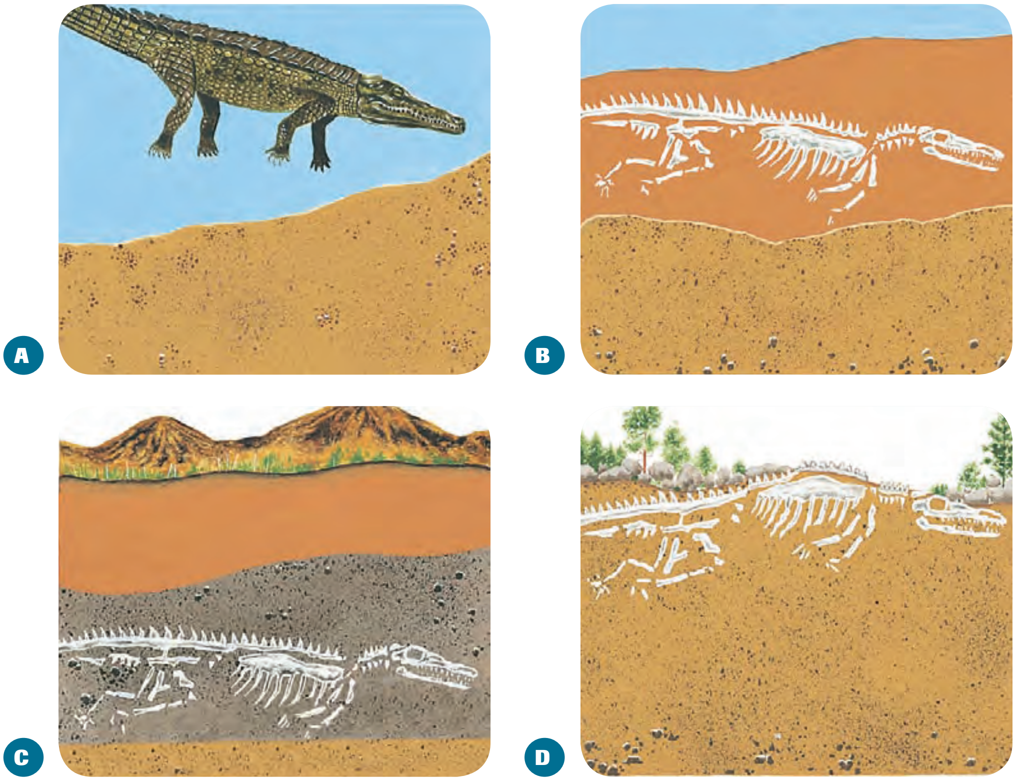
Video

What's BIOLOGY Got To Do With It?

Table 1 Categories of Fossil Types Concepts in Motion **Interactive Table**

Category	Trace fossil	Molds and casts	Replacement	Petrified or permineralized	Amber	Original material
Example						
Formation	A trace fossil is any indirect evidence left by an organism. Footprints, burrows, and fossilized feces are trace fossils.	A mold is an impression of an organism. A cast is a mold filled with sediment.	The original material of an organism is replaced with mineral crystals that can leave detailed replicas of hard or soft parts.	Empty pore spaces are filled in by minerals, such as in petrified wood.	Preserved tree sap traps an entire organism. The sap hardens into amber and preserves the trapped organism.	Mummification or freezing preserves original organisms.

Figure 2 (A) Organisms usually become fossilized after they die and are buried by sediment.
(B) Sediments build up in layers, eventually encasing the remains in sedimentary rock. (C) Minerals replace, or fill in the pore space of, the bones and hard parts of the organism. (D) Erosion can expose the fossils.



Fossil formation Fossils do not form in igneous (IHG nee us) or metamorphic (meh tuh MOR fihk) rocks. Igneous rocks form when magma from Earth's interior cools. Metamorphic rocks form when rocks are exposed to extreme heat and pressure. Fossils usually do not survive the heat or pressure involved in the formation of either of these kinds of rocks.

Nearly all fossils are formed in sedimentary rock through the process illustrated in **Figure 2.** The organism dies and is buried in sediments. The sediments build up until they cover the organism's remains. In some cases, minerals replace the organic matter or fill the empty pore spaces of the organism. In other cases, the organism decays, leaving behind an impression of its body. The sediments eventually harden into rock.

A **paleontologist** (pay lee ahn TAH luh jist) is a scientist who studies fossils. He or she attempts to read the record of life left in rocks. From fossil evidence, paleontologists infer the diet of an organism and the environment in which it lived. In fact, paleontologists often can create images of extinct communities.

Study Tip

Background Knowledge Check Based on what you know, predict the meaning of each new vocabulary term before reading the section. As you read, check the actual meaning compared to your prediction.

Connection to Earth Science When geologists began to study rock layers, or strata, in different areas, they noticed that layers of the same age tended to have the same kinds of fossils no matter where the rocks were found. The geologists inferred that all strata of the same age contained similar collections of fossils. This led to the establishment of a relative age scale for rocks all over the world.

Dating fossils **Relative dating** is a method used to determine the age of rocks by comparing them with those in other layers. Relative dating is based on the **law of superposition,** illustrated in **Figure 3,** which states that younger layers of rock are deposited on top of older layers. The process is similar to stacking newspapers in a pile as you read them each day. Unless you disturb the newspapers, the oldest ones will be on the bottom.

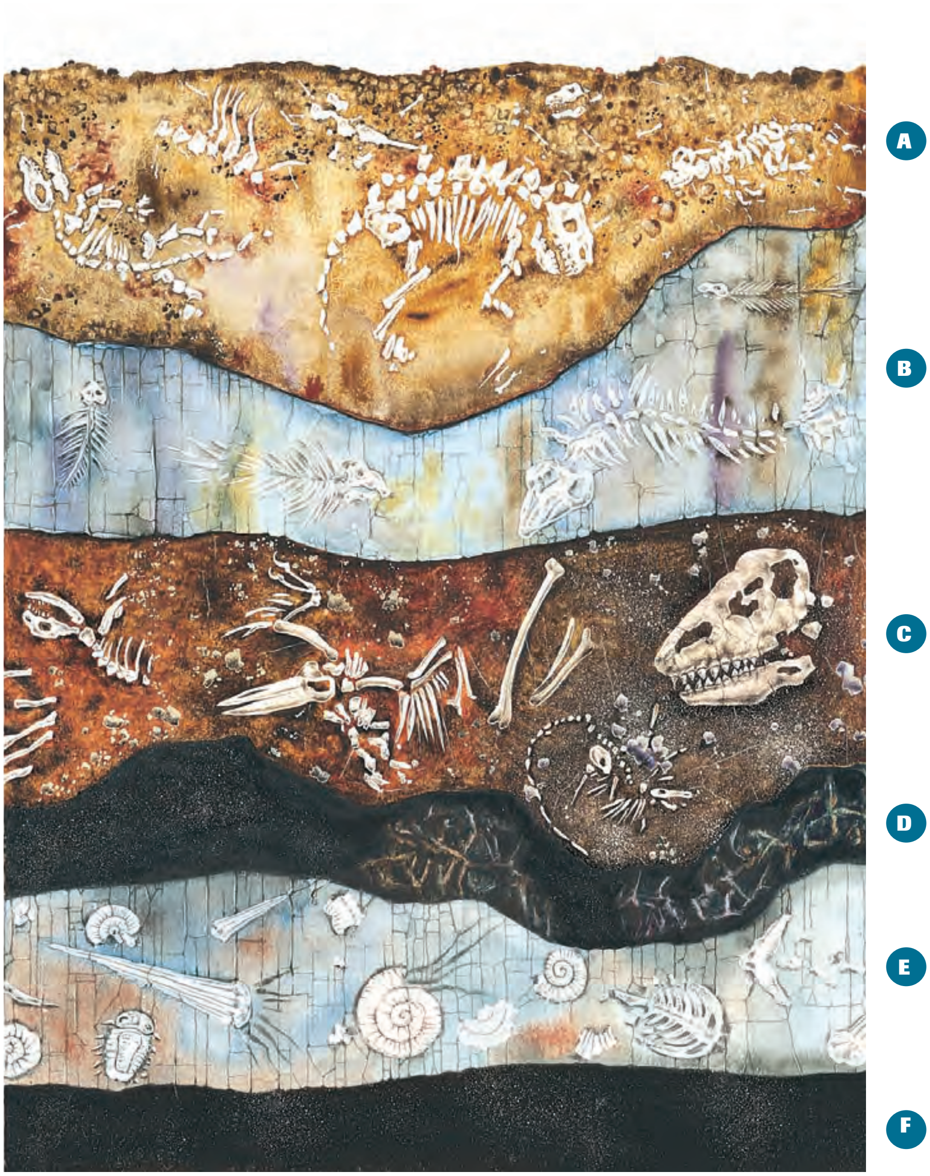


Figure 3 According to the law of superposition, rock layers are deposited with the youngest undisturbed layers on top. **Infer** ***which layer shows that an aquatic ecosystem replaced a land ecosystem.***

Radiometric dating uses the decay of radioactive isotopes to measure the age of a rock. Recall that an isotope is a form of an element that has the same atomic number but a different mass number. The method requires that the **half-life** of the isotope, which is the amount of time it takes for half of the original isotope to decay, is known. The relative amounts of the radioactive isotope and its decay product must also be known.

One radioactive isotope that is commonly used to determine the age of rocks is Uranium 238. Uranium 238 (U^{238}) decays to Lead 206 (Pb^{206}) with a half life of 4510 million years. When testing a rock sample, scientists calculate the ratio of the parent isotope to the daughter isotope to determine the age of the sample.

Radioactive isotopes that can be used for radiometric dating are found only in igneous or metamorphic rocks, not in sedimentary rocks, so isotopes cannot be used to date rocks that contain fossils. Igneous rocks that are found in layers closely associated with fossil-bearing sedimentary rocks often can be used for assigning relative dates to fossils.

Inquiry Virtual Lab

Video BrainPOP

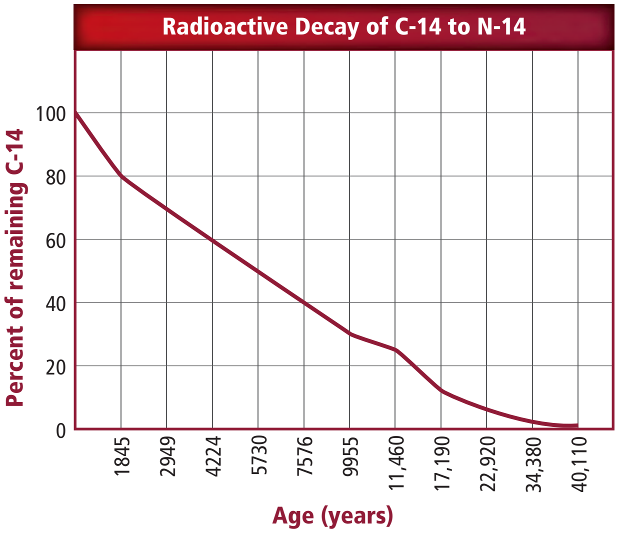


Figure 4 The graph shows how the percent of carbon-14 remaining in a sample indicates age.
Interpret the graph ***What would the age of a bone be if it contained only 10 percent of C-14?***

Materials, such as mummies, bones, and tissues, can be dated directly using carbon-14 (C-14). Given the half-life of carbon-14, shown in **Figure 4,** only materials less than 60,000 years old can be dated accurately with this isotope.

The Geologic Time Scale

Think of geologic time as a ribbon that is 4.6 m long. If each meter represents one billion years, each millimeter represents one million years. Earth was formed at one end of the ribbon, and humans appear at the tip of the opposite end.

The **geologic time scale** is a record of Earth's history. Major geological and biological events in Earth's history can be identified within the geologic time scale. Because geologic time spans more than 4 billion years, subdivisions of time are used to identify how many millions of years ago (mya) an event occurred. The geologic time scale is divided into two segments—Precambrian time and the Phanerozoic eon.

Epochs, which last several million years, are the smallest units of geologic time. **Periods,** which last tens of millions of years, are divisions of geologic time consisting of two or more epochs. An **era,** which lasts hundreds of millions of years, is a unit of geologic time consisting of two or more periods. An **eon** is the longest unit of time in the geologic time scale and can include billions of years. **Figure 5** shows a portion of the geologic time scale that includes the Phanerozoic eon.

Reading Check **Explain** why C-14 would not be useful for dating something from the Precambrian.

MiniLab 1

Inquiry MiniLab

Correlate Rock Layers Using Fossils

How can paleontologists establish relative age? Scientists use fossils from many locations to piece together the sequence of Earth's rock layers. This is the process of correlation.

Procedure

1. Read and complete the lab safety form.
2. Your teacher will assign you to a group and will give your group a **container** with layers of material embedded with fossils.
3. Carefully remove each layer, noting any embedded materials.
4. Make a sketch of the cross section, and label each layer and any materials contained within it.
5. Collect copies of sketches from the other groups and use them to determine the sequence of all the layers the class has studied.

Analysis

1. **Describe** the materials in each cross section. What patterns did you observe?
2. **Explain** how your analysis would be different if different layers contained the same materials. What if some of the layers didn't overlap? Suggest a way to gather additional data that might resolve these issues.

Visualizing the Geologic Time Scale

Figure 5

This figure illustrates the Phanerozoic eon of the geologic time scale. The major biologic events during the Phanerozoic eon are described in the figure. All of the times listed are approximate and as in all science fields, continuing research and discoveries might result in future revisions.

Eon	Era	Period	Epoch	MYA	Biological events
Phanerozoic	Cenozoic	Neogene	Holocene		• Humans form civilizations
			Pleistocene	0.01	• Ice ages occur • Modern humans appear
			Pliocene	1.8	• Hominins appear • Flowering plants are dominant
			Miocene	5.3	• Apes appear • Climate is cooler
			Oligocene	23.0	• Monkeys appear • Climate is mild
		Paleogene	Eocene	33.9	• Flowering plants scattered • Most mammal orders exist
			Paleocene	55.8	• Mammals, birds, and insects scatter • Climate is tropical
	Mass extinction K-T Boundary				
	Mesozoic	Cretaceous		65.5	• Flowering plants appear • Dinosaur population peaks
		Jurassic		145.5	• First birds appear • Dinosaurs scatter • Forests are lush
		Mass extinction			
		Triassic		199.6	• Gymnosperms are dominant • Dinosaurs appear • First mammals appear
	Mass extinction				
	Paleozoic	Permian		251.0	• Reptiles scatter • Gymnosperms appear
		Carboniferous		299.0	• Ferns and evergreens make up forests • Amphibians appear • Insects scatter
		Mass extinction			
		Devonian		359.2	• Sharks and bony fishes appear • Tetrapods appear
		Silurian		416.0	• Coral and other invertebrates are dominant • Land plants and insects appear
		Mass extinction			
		Ordovician		443.7	• First vertebrates appear • First plants appear
		Cambrian		488.3	• Cambrian explosion • All body plans arise

Concepts in Motion Animation

■ **Figure 6** Fossils much like these stromatolites are found in rocks almost 3.5 billion years old.
Explain ***the importance of the organisms that left these stromatolites.***

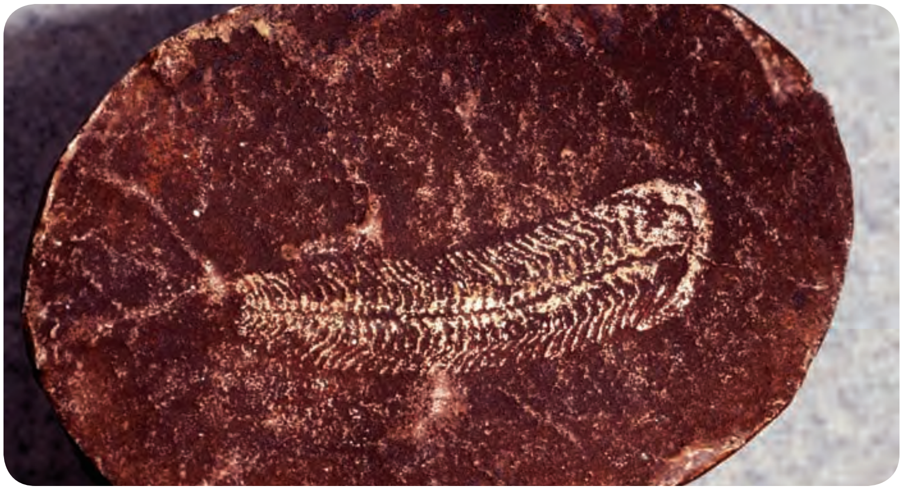
Precambrian The first 4 billion years of Earth's history make up the Precambrian. This is nearly 90 percent of Earth's entire history, stretching from the formation of Earth to the beginning of the Paleozoic era about 542 million years ago. During the Precambrian, Earth formed and life first appeared. Eventually, autotrophic prokaryotes, much like the cyanobacteria that made the stromatolites in **Figure 6,** enriched the atmosphere with oxygen. Eukaryotic cells also emerged, and by the end of the Precambrian, life was flourishing and the first animals had appeared.

Extensive glaciation marked the second half of the Precambrian. This might have delayed the further evolution of life until the ice receded at the beginning of the Ediacaran (ee dee UH kur uhn) period. The Ediacaran period was added to the time scale in 2004. It was the first new period added to the time scale since 1891 and reflects new knowledge of Earth's history. The Ediacaran period lasted from about 630 million years ago to about 542 million years ago, representing about three quarters of a meter on the time ribbon at the end of the Precambrian. Simple organisms, such as the fossil in **Figure 7,** inhabited Ediacaran marine ecosystems. Food chains probably were short, and were dominated by animals that consumed tiny particles suspended in the water and by animals that ate debris on the bottom of the sea.

Reading Check **Infer** the process by which early autotrophic prokaryotes produced oxygen.

The Paleozoic era A drastic change in the history of animal life on Earth marked the start of the Paleozoic (pay lee uh ZOH ihk) era. In the space of just a few million years, the ancestors of most major animal groups diversified in what scientists call the **Cambrian explosion.** Not all major groups of organisms evolved rapidly at this time, and paleontologists still do not know when the rapid changes started or ended.

Major changes in ocean life occurred during the Paleozoic. More importantly, it seems the first life on land emerged during this era. Life in the oceans continued to evolve through the Cambrian period. Fish, land plants, and insects appeared during the Ordovician and Silurian periods. Organisms of many kinds, including huge insects, soon flourished in swampy forests that dominated the land, as shown in **Figure 8.** Tetrapods, the first land vertebrates (animals with backbones), emerged in the Devonian period. By the end of the Carboniferous period, the first reptiles were roaming the forests.



■ **Figure 7** Paleontologists disagree about scarce Ediacaran fossils such as this one. Some paleontologists suggest that they are relatives of today's living invertebrates such as segmented worms, while others think they represent an evolutionary dead end of giant protists or simple metazoans.

■ **Figure 8** During the Carboniferous period, swamp forests covered much of Earth's land surface. Insects dominated the air, and tetrapods flourished in freshwater pools.
Infer ***how the plants of the Paleozoic era were different from those of today.***

A mass extinction ended the Paleozoic era at the end of the Permian period. Recall that a mass extinction is an event in which many species become extinct in a short time. Mass extinctions have occurred every several million years with varying frequencies. Between 60 and 75 percent of the species alive went extinct in each of these events. During the Permian mass extinction, 90 percent of marine organisms disappeared. Geologists disagree about the cause of the Permian extinction, but most agree that geological forces, including increased volcanic activity, would have disrupted ecosystems or changed the climate.

The Mesozoic era At the beginning of the Triassic period, the ancestors of early mammals were the dominant land animals. Mammals and dinosaurs first appeared late in the Triassic period, and flowering plants evolved from nonflowering plants. Birds evolved from a group of predatory dinosaurs in the middle Jurassic period. For the rest of the Mesozoic, reptiles, such as the dinosaurs illustrated in **Figure 9,** were the dominant organisms on the planet. Then, about 65 million years ago, a meteorite struck Earth.

The primary evidence for this meteorite impact is found in a layer of material between the rocks of the Cretaceous (krih TAY shus) period and the rocks of the Paleogene period, the first period of the Cenozoic era. Paleontologists call this layer the **K-T boundary.** Within this layer, scientists find unusually high levels of an element called iridium. Iridium is rare on Earth, but relatively common in meteorites. Therefore, the presence of iridium on Earth indicates a meteorite impact.

Many scientists think that this impact is related to the mass extinction at the end of the Mesozoic era, which eliminated all dinosaurs, with the exception of their avian and reptilian descendents, many marine invertebrates, and numerous plant species. The meteorite did not wipe out all of these species, but the debris from the impact probably stayed in the atmosphere for months or even years, affecting global climate. Species that could not adjust to the changing climate disappeared.

Reading Check **Recall** the dominant land animals in the Triassic and Jurassic periods.

■ **Figure 9** The dominant organisms during the Mesozoic era were dinosaurs. A mass extinction occurred at the end of the Mesozoic era that eliminated approximately 60 percent of all species living during the Mesozoic era.

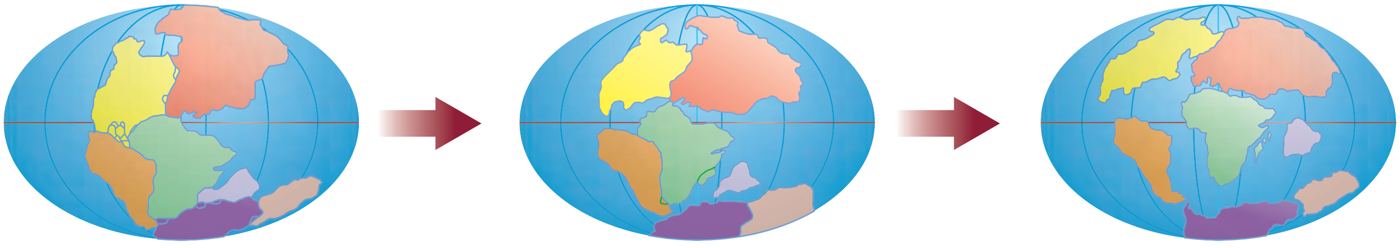


Figure 10 These illustrations show the movement of Earth's major tectonic plates from about 225 million years ago, when all of the continents were joined into one landmass called Pangaea, to 65 million years ago.

Concepts in Motion

Animation

Scientists also think that the course of evolution in the Cenozoic era was shaped by the massive geological changes shown in **Figure 10** that characterized the Mesozoic era. While it might appear to us that continents are immobile, they have been moving since they formed. Alfred Wegener, a German scientist, presented the first evidence for continental drift in the 1920s. Continental drift has since become part of the theory of plate tectonics. **Plate tectonics** describes the movement of several large plates that make up the surface of Earth. These plates, some of which contain continents, move atop a partially molten layer of rock underneath them.

The Cenozoic era The most recent era is the one in which mammals became the dominant land animals. At the beginning of the Cenozoic (sen uh ZOH ihk) era, which means "recent life," most mammals were small and resembled shrews. After the mass extinction at the end of the Mesozoic era, mammals began to diversify into distinct groups, including primates—the group to which you belong. Humans appeared very recently, near the end of the geologic time scale, in the current Neogene period. Humans survived the last ice age, but many species of mammals did not. To get an idea of how recently modern humans have appeared, you need to remove about two threads at the end of your geologic time ribbon. These threads represent the time that humans have existed on Earth.

Section 1 Assessment

Section Summary

- Fossils provide evidence of past life.
- Relative dating and radiometric dating are two methods used to determine the age of fossils.
- The geologic time scale is divided into eras, periods, and epochs.
- Major events in the geological time scale include both biological and geological changes.

Understand Main Ideas

1. MAIN Idea **Discuss** how fossils provide evidence of change from the earliest life-forms to those alive today.
2. **Diagram** a typical sequence of events in fossilization.
3. **Discuss** two ways that radiometric dating can be used to establish the age of a fossil.
4. **Compare** Earth's early land environment with today's land environment.

Think Critically

5. **Infer** what changes you might observe in the fossil record that would indicate the occurrence of a mass extinction.

MATH in Biology

6. Out of the total of Earth's history (approximately 4.6 billion years), modern humans have existed for only 100,000 years. To put this in perspective, calculate the percentage of Earth's history that modern humans have existed.

Assessment Online Quiz

Section 2

Reading Preview

Essential Questions

- What are the differences between spontaneous generation and biogenesis?
- What might have been the sequence of events that led to cellular life?
- What is the endosymbiont theory?

Review Vocabulary

amino acid: building blocks for proteins

New Vocabulary

spontaneous generation
theory of biogenesis
endosymbiont theory

Multilingual eGlossary

The Origin of Life

MAIN Idea Evidence indicates that a sequence of chemical events preceded the origin of life on Earth and that life has evolved continuously since that time.

Real-World Reading Link In a recipe, some steps can be out of order, but some steps have to occur earlier than others or the end result will be different from what was intended. In the same way, to arrive at the pattern of life that is seen today, events leading to the emergence of life had to occur in specific ways.

Origins: Early Ideas

Perhaps one of the oldest ideas about the origin of life is spontaneous generation. **Spontaneous generation** is the idea that life arises from nonlife. For example, at one time people thought that mice could be created by placing damp hay and corn in a dark corner, or that mud could give rise to worms, insects, and fish. These ideas might seem humorous to us today, but before much was known about reproduction, it is easy to see how someone might form these conclusions.

One of the first recorded investigations of spontaneous generation came in 1668. Francesco Redi, an Italian scientist, tested the idea that flies arose spontaneously from rotting meat. He hypothesized that flies—not meat—produced other flies. In his experiment, illustrated using present-day equipment in **Figure 11,** Redi observed that maggots, the larvae of flies, appeared only in flasks that were open to flies. Closed flasks had no flies and no maggots. The results of his experiments failed to convince everyone, however. Although people were beginning to use the microscope during Redi's time and knew that organisms invisible to the naked eye could be found almost everywhere, some thought that these tiny organisms must arise spontaneously, even if flies did not.

Figure 11 Francesco Redi showed that flies and maggots did not arise spontaneously from rotting meat.
Infer ***the purpose of the covered flask in Redi's experiment.***

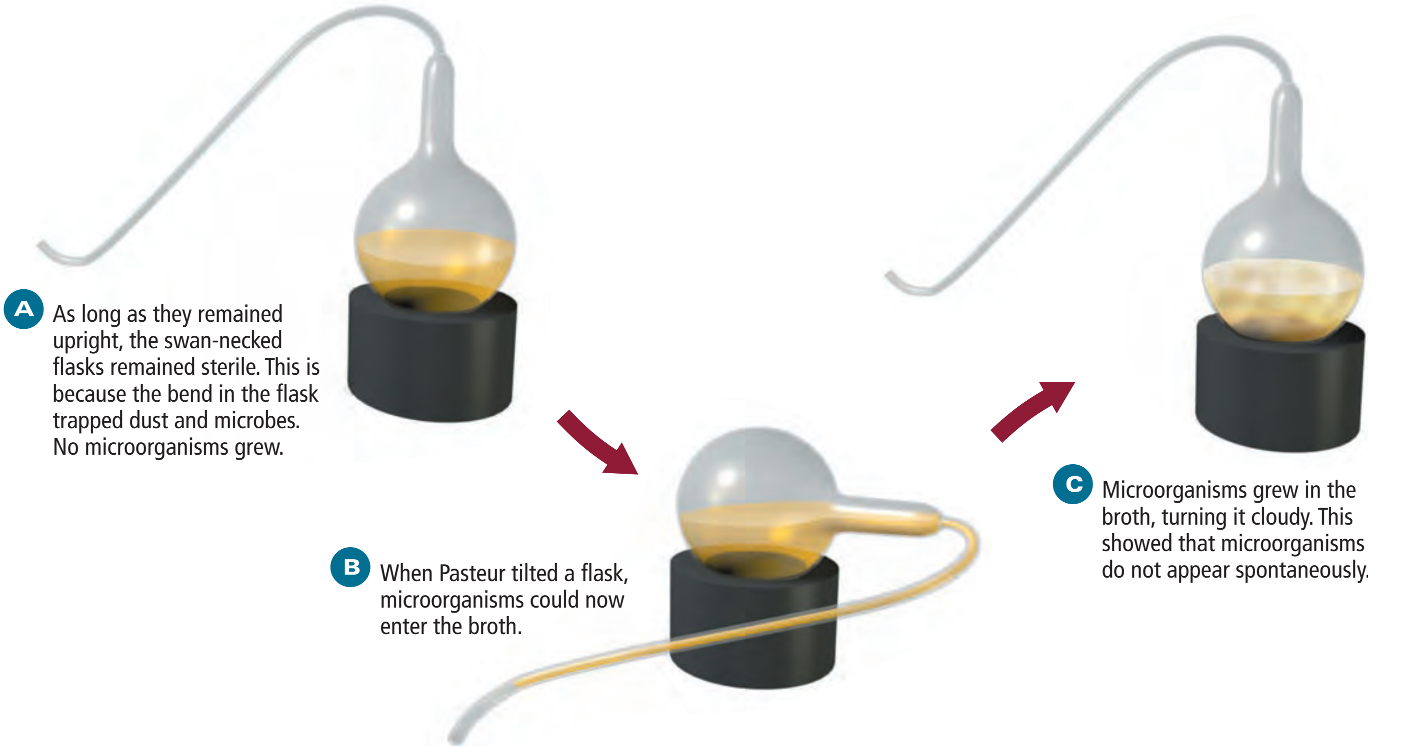


Figure 12 Pasteur's experiment showed that sterile broth remained free of microorganisms until exposed to air.

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Incorporate information from this section into your Foldable.

The idea of spontaneous generation was not completely rejected until the mid-1800s. It was replaced by the **theory of biogenesis** (bi oh JEN uh sus), which states that only living organisms can produce other living organisms. Louis Pasteur designed an experiment to show that biogenesis was true even for microorganisms. Pasteur's experiment is illustrated in **Figure 12.** In one flask, only air was allowed to contact a sterile nutrient broth. Nutrient broth supports the growth of microorganisms. In another flask, both air and microorganisms were allowed to contact the broth. No microorganisms grew in the first container. They did, however, grow in the second container.

Origins: Modern Ideas

If life can arise only from preexisting life, then how did the first life-form appear? Most biologists agree that life originated through a series of chemical events early in Earth's history. During these events, complex organic molecules were generated from simpler ones. Eventually, simple metabolic pathways developed. Such pathways allowed molecules to be synthesized or broken down more efficiently. These pathways might have led to the emergence of life as we know it. How this happened is a topic of ongoing research among scientists today.

Simple organic molecule formation The primordial soup hypothesis was an early hypothesis about the origin of life. Scientists Alexander Oparin and John Haldane suggested this hypothesis in the 1920s. They thought that if Earth's early atmosphere had a mix of certain gases, organic molecules could have been synthesized from simple reactions involving those gases in the early oceans. UV light from the Sun and electric discharge in lightning might have been the primary energy sources. They thought that these organic molecules would have eventually supplied the precursors to life.

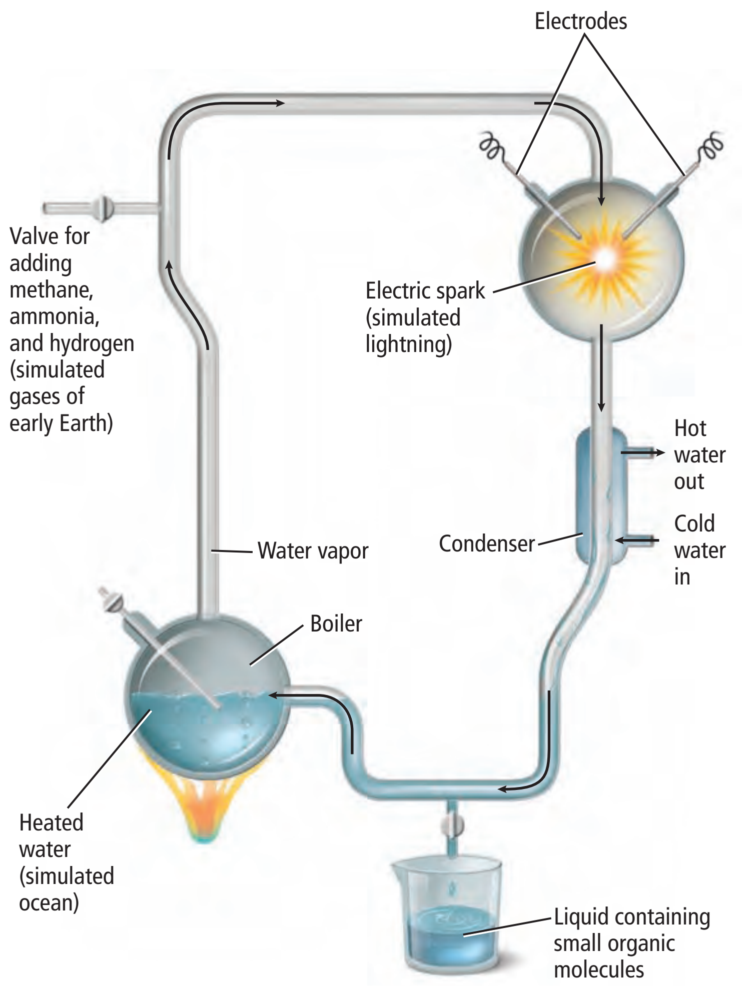
Connection to Chemistry In 1953, American scientists Stanley Miller and Harold Urey were the first to show that simple organic molecules could be made from inorganic compounds, as proposed by Oparin and Haldane. Miller and Urey built a glass apparatus, illustrated in **Figure 13,** to simulate the early Earth conditions hypothesized by Oparin. They filled the apparatus with water and the gases that they thought had made up the early atmosphere. The water was boiled and electric discharges were used to simulate lightning as an energy source. Upon examination, the resulting mixture contained a variety of organic compounds including amino acids. Because amino acids are the building blocks of proteins, this discovery supported the primordial soup hypothesis.

Later, other scientists found that hydrogen cyanide could be formed from even simpler molecules in simulated early Earth environments. Hydrogen cyanide can react with itself to eventually form adenine, one of the nucleotide bases in the genetic code. Many other experiments have since been carried out under conditions that probably reflect the atmosphere of early Earth more accurately. The final reaction products in these experiments were amino acids and sugars as well as nucleotides.

Some scientists suggest that the organic reactions that preceded life's emergence began in the hydrothermal volcanic vents of the deep sea, where sulfur forms the base of a unique food chain. Still others think that meteorites brought the first organic molecules to Earth.

CAREERS IN BIOLOGY

Evolutionary Biochemist Scientists who study chemistry and how it relates to life are biochemists. Evolutionary biochemists specifically study the structure and function of molecules from Earth's early history.



Concepts in Motion

Animation

■ **Figure 13** The Miller-Urey experiment showed for the first time that organic molecules could be produced from gases proposed to have made up the atmosphere of early Earth .

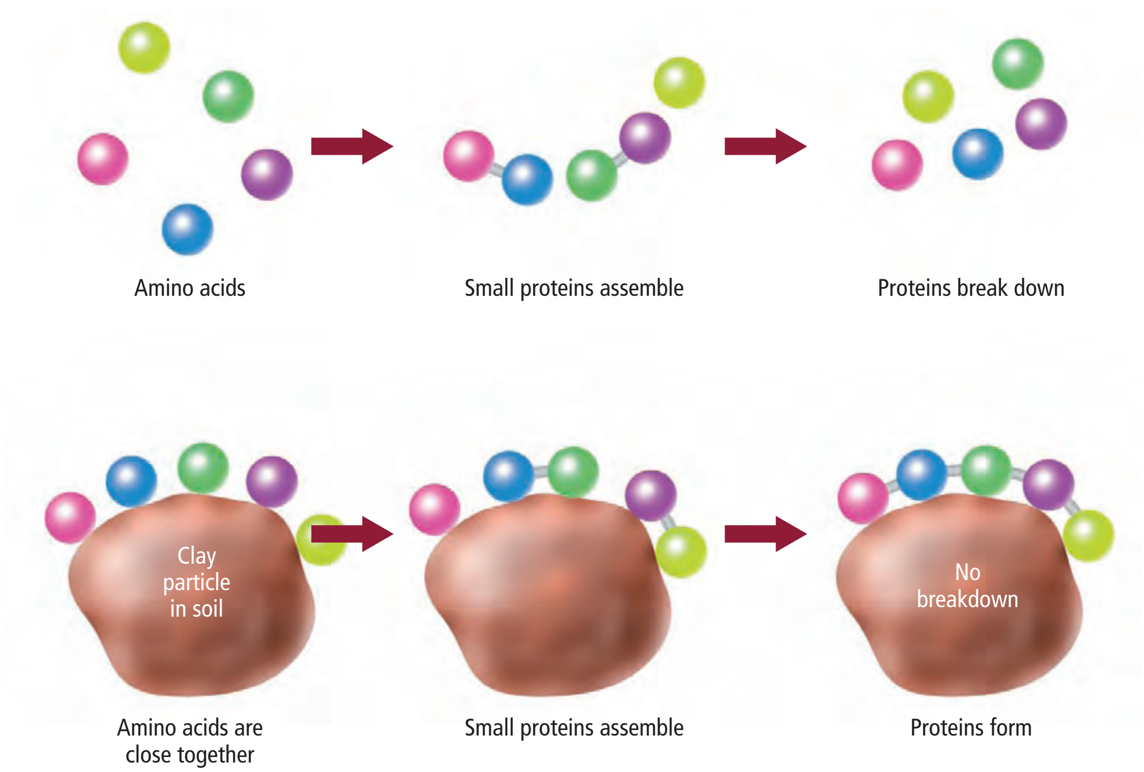


Figure 14 Without clay, amino acids could have formed small, unstable proteins. In the presence of clay, amino acids might have come together in a more stable manner.

Review Personal Tutor

Making proteins Wherever the first organic molecules originated, it is clear that the next critical step was the formation of proteins. Amino acids alone are not sufficient for life. Life requires proteins, which are chains of amino acids. In the Miller-Urey experiment, amino acids could bond to one another, but they could separate just as quickly. One possible mechanism for the formation of proteins would be if amino acids were bound to a clay particle, as illustrated in **Figure 14.** Clay would have been a common sediment in early oceans, and it could have provided a framework for protein assembly.

Genetic code Another requirement for life is a coding system for protein production. All modern life has such a system, based on either RNA or DNA. Because all DNA-based life-forms also contain RNA, and because some RNA sequences appear to have changed very little through time, many biologists consider RNA to have been life's first coding system. Researchers have been able to demonstrate that RNA systems are capable of evolution by natural selection. Some RNAs also can behave like enzymes. These RNA molecules, called ribozymes, could have carried out some early life processes. Other researchers have proposed that clay crystals could have provided an initial template for RNA replication, and that eventually the resulting molecules developed their own replication mechanism.

Molecules to cells Another important step in the evolution of life was the formation of membranes. Researchers have tested ways of enclosing molecules in membranes, allowing early metabolic and replication pathways to develop. In these studies, as in other origin-of-life research, the connection between the various chemical events and the overall path from molecules to cells remains unresolved. However, scientists continue to search for the connection.

VOCABULARY

ACADEMIC VOCABULARY

Mechanism
an instrument or process by which something is done or comes into being
The mechanism for protein synthesis was unknown for a long time.

Cellular Evolution

What were the earliest cells like? Scientists don't know because the first life left no fossils. The earliest fossils are 3.5 billion years old. Chemical markings in rocks as old as 3.8 billion years suggest that life was present at that time even though no fossils remain. Scientists recently announced the discovery of what appeared to be fossilized microbes in rock that is 3.5 billion years old. This suggests that cellular activity had become established very early in Earth's history.

The first cells Scientists hypothesize that the first cells were prokaryotes. Recall that prokaryotic cells are much smaller than eukaryotic cells, and they lack a defined nucleus and most other organelles. Many scientists think that modern prokaryotes called archaea (ar KEE uh) are the closest relatives of Earth's first cells. These organisms often live in extreme environments, such as the hot springs of Yellowstone Park or the volcanic vents in the deep sea, such as the one shown in **Figure 15.** These are environments similar to the environment that might have existed on early Earth.

Photosynthesizing prokaryotes Scientists think that oxygen was absent from Earth's earliest atmosphere until about 1.8 billion years ago. Any oxygen that appeared earlier than 1.8 billion years ago likely bonded with free ions of iron as oxygen does today. Evidence that iron oxide was formed by oxygen generated by early life is found in unique sedimentary rock formations, such as those shown in **Figure 16,** that are between about 1.8 billion and 2.5 billion years old. Scientists hypothesize that after 1.8 billion years ago, the early Earth's free iron was saturated with oxygen, and oxygen instead began accumulating in the atmosphere.

Many scientists think that photosynthesizing prokaryotes evolved not long after the archaea—very early in life's history. Fossil evidence of these primitive prokaryotes, called cyanobacteria, has been found in rocks as old as 3.5 billion years. Cyanobacteria eventually produced enough oxygen to support the formation of an ozone layer. Once an ozone shield was established, conditions would be right for the appearance of eukaryotic cells.

Reading Check **Create** a list of the steps that led to the formation of the ozone layer in Earth's atmosphere.

Figure 15 Some archaea live near deep-sea hydrothermal vents. They use energy from inorganic molecules to form the base of the vent food web.

Infer ***why some scientists think archaea most resemble the first cells.***

Figure 16 These rock formations, called banded iron formations, or BIFs, are unique sedimentary deposits. These rocks formed as a result of free oxygen production by photosynthetic bacteria billions of years ago. Because this deposit is a result of an organism, BIFs are considered trace fossils.

The endosymbiont theory Eukaryotic cells appeared in the fossil record about 1.8 billion years ago, around two billion years after life first formed. Eukaryotic cells have complex internal membranes, which enclose various organelles, including mitochondria and, in plant cells, chloroplasts. Mitochondria metabolize food through cellular respiration, and chloroplasts are the site of photosynthesis. Both mitochondria and chloroplasts are about the size of prokaryotic cells and contain similar prokaryote features. This led some scientists to speculate that prokaryotic cells were involved in the evolution of eukaryotic cells.

In 1966, biologist Lynn Margulis proposed the endosymbiont theory. According to the **endosymbiont theory,** the ancestors of eukaryotic cells lived in association with prokaryotic cells. In some cases, prokaryotes even might have lived inside eukaryotes. Prokaryotes could have entered a host cell as undigested prey, or they could have been internal parasites. Eventually, the relationship between the cells became mutually beneficial, and the prokaryotic symbionts became organelles in eukaryotic cells. This theory explains the origin of chloroplasts and mitochondria, as illustrated in **Figure 17.**

Evidence for the endosymbiont theory When Margulis first proposed the endosymbiont theory, many scientists were hesitant to accept it. There is evidence, however, that at least mitochondria and chloroplasts formed by endosymbiosis. For example, mitochondria and chloroplasts contain their own DNA. It is arranged in a circular pattern, just as it is in prokaryotic cells. Mitochondria and chloroplasts also have ribosomes that more closely resemble those in prokaryotic cells than those in eukaryotic cells. Finally, like prokaryotic cells, mitochondria and chloroplasts reproduce by fission, independent from the rest of the cell.

DATA ANALYSIS LAB 1

Based on Real Data*

Analyze Scientific Illustrations

How did plastids evolve?
Chloroplasts belong to a group of organelles called plastids, which are found in plants and algae. Chloroplasts perform photosynthesis. Other plastids store starch and make substances needed as cellular building blocks or for plant function.

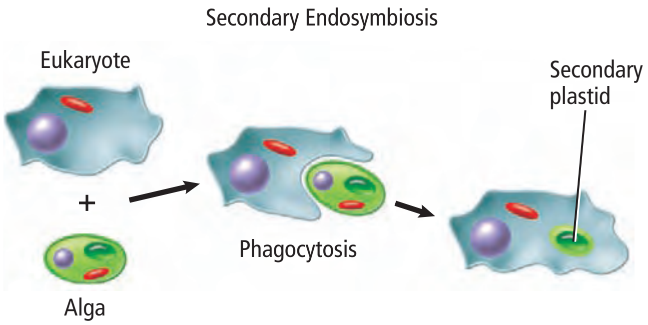
Think Critically

1. **Summarize** the process described in the diagram. Include the definition of phagocytosis in your description.
2. **Compare** secondary endosymbiosis to the endosymbiont theory described in **Figure 17.**

Data and Observations

The illustration shows a way these plastids might have evolved.

Plastid origin



*Data obtained from: Dyall, S.D., et al. 2004. Ancient invasions: from endosymbionts to organelles. *Science* 304: 253–257.

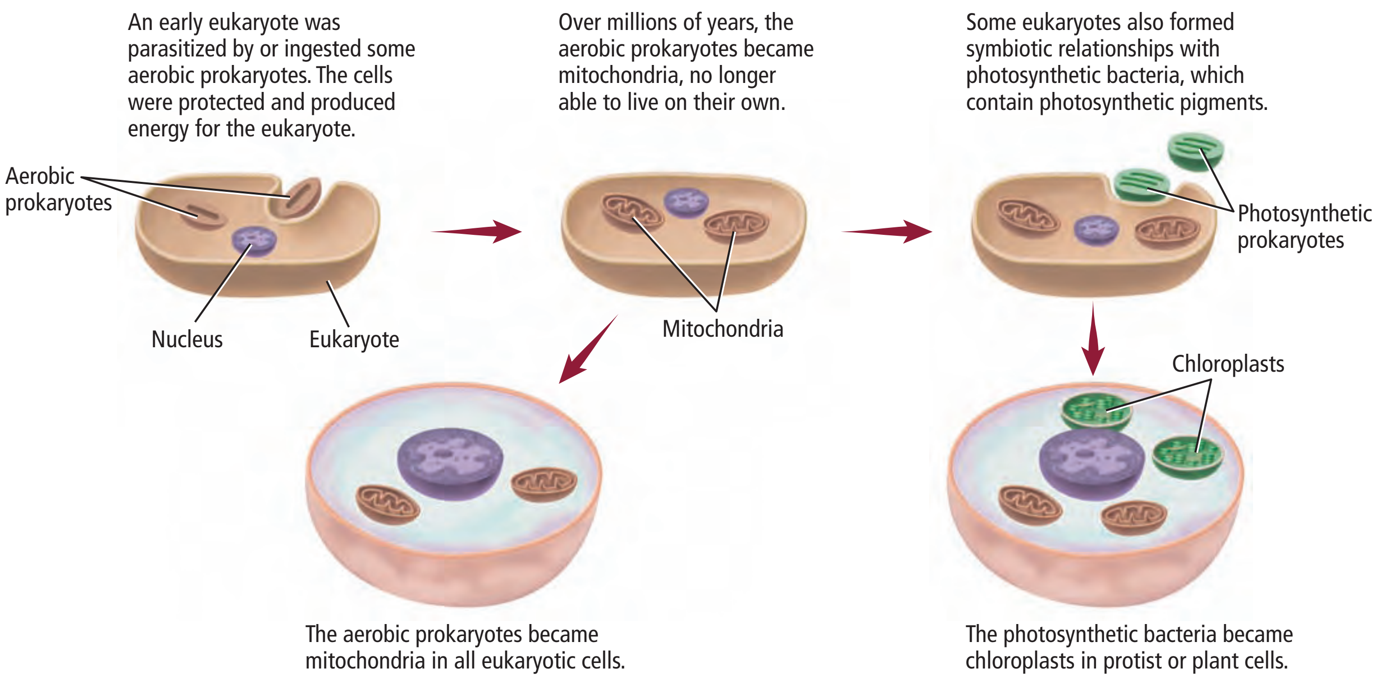


Figure 17 This illustration shows how Margulis hypothesized that eukaryotic cells and their organelles evolved.

Concepts in Motion

Animation

Though the endosymbiont theory is widely endorsed, it is important to understand that scientists do not know the early steps that led to the emergence of life or to its early evolution. It is unlikely that any traces of the first life will ever be found. What scientists do know is that the conditions on Earth shortly after it took shape allowed the precursors of life to form.

The evolution of life is better understood than how the first life appeared. Fossil, geologic, and biochemical evidence supports many of the proposed steps in life's subsequent evolution. However, future discoveries might alter any or all of these steps. Scientists will continue to evaluate new evidence and test new theories in years to come.

Section 2 Assessment

Section Summary

- Spontaneous generation was disproved in favor of biogenesis.
- The origin of life is hypothesized to be a series of chemical events.
- Organic molecules, such as amino acids, might have been formed from simpler molecules on early Earth.
- The first cells probably were autotrophic and prokaryotic.
- The endosymbiont theory explains how eukaryotic cells might have evolved from prokaryotic cells.

Understand Main Ideas

1. MAIN Idea **Infer** why scientists hypothesize that chemical events preceded the origin of life on Earth.
2. **Compare and contrast** spontaneous generation and biogenesis.
3. **Discuss** why prokaryotic cells probably appeared before eukaryotic cells.
4. **Hypothesize** whether prokaryotic cells might have been symbiotic before the evolution of eukaryotic cells.

Think Critically

5. **Describe** the hypothesized sequence of chemical and biological events that preceded the origin of eukaryotic cells.

WRITING in **Biology**

6. Write a persuasive paragraph that explains why many scientists accept the endosymbiont theory.

Assessment **Online Quiz**

In the Field

Career: Paleontologist

Paleontologists Debate the Evolution of Birds

Along lakeshores in northeastern China 130 million years ago, volcanic eruptions sealed the fate of millions of organisms. Ash rains buried dinosaurs, mammals, fish, insects, and amphibians. Entombed for tens of millions of years, their bodies fossilized, sometimes leaving impressions of feathers, fur, and even stomach contents! Today, in the fossil-rich area of the Laioning Province in China, paleontologists are making important discoveries about life in the early Cretaceous period.

A feathered dinosaur Organisms like the fossil specimen *Caudipteryx zoui* in the figure cause excitement in the paleontology community. In the fossil of *C. zoui,* there are clear traces of feathers from head to tail on the roughly one-meter long dinosaur. These feathers were not used for flight, but might have provided more stability for bipedal running.

An early bird A 130 million year old fossil of a new bird species, *Confuciusornis dui,* was discovered in the same general area as *C. zoui. C. dui* appears to have been a well-developed, tree-dwelling bird, not a feathered dinosaur that lived on the ground. *C. dui* and *C. zoui* lived during roughly the same time in history—between 120–150 mya. The coexistence of *C. dui* and *C. zoui* in this region provides an example of ancestral and derived species living together.

Caudipteryx zoui is an important fossil that shows that some dinosaurs had feathers.

Link to the past Paleontologists often interpret fossil evidence to make evolutionary connections between organisms. Paleontologists agree that an evolutionary link exists between birds and dinosaurs. They share many anatomical features, including hollow, thin-walled bones, flexible wrists, clawed hands, and a fused collarbone that forms a wishbone. Paleontologists think that birds came from dinosaurs, but they continue to debate about when the divergence took place. Fossil finds like those in China help to provide evidence and insight into the evolution of birds.

CAREERS IN BIOLOGY

Interview a Paleontologist
Work with a team to create a list of questions you would like to ask a paleontologist. Conduct an interview with a paleontologist at a local college or university. Use the information you gather to write an article which describes what you learned from the conversation.

WebQuest

BIOLAB

IS SPONTANEOUS GENERATION POSSIBLE?

Background: **In the mid-1800s, Louis Pasteur conducted an experiment that showed that living organisms come from other living organisms—not from nonliving material. Pasteur's classic experiment, which disproved the notion of spontaneous generation, laid an essential foundation for modern biology by supporting the concept of biogenesis. In this lab, you will carry out an experiment based on Pasteur's work.**

Question: *How can the idea of spontaneous generation be disproved?*

Materials

beef broth	string
graduated cylinder	rubber stopper (2)
Erlenmeyer flask (2)	Bunsen burner (2)
ring stand (2)	5 cm of plastic tubing
wire gauze (2)	30 cm of plastic tubing

Safety Precautions

Procedure

1. Read and complete the lab safety form.
2. Study the description of Louis Pasteur's classic experiment that disproved spontaneous generation.
3. Design and construct a data table to record changes in color, smell, and the presence of sediments.
4. Label the flasks "A" and "B." Flask A will be capped with a stopper holding a 5-cm piece of tubing. Flask B will be capped with a stopper holding a 30-cm piece of tubing.
5. Place 50 mL of beef broth in each flask. Cap each flask with the appropriate stopper.
6. Put each flask on a wire gauze on a ring stand over a Bunsen burner.
7. Bend the tubing on Flask B until it forms a U-shape. The bottom of the U should be near the base of the flask. Tie the end of the tubing to the ring stand to hold the U-shape.
8. Boil the broth in each flask for 30 min.
9. After the equipment and broth cool, move the apparatuses to an area of the lab where they will not be disturbed.
10. Observe the flasks over the next two weeks. Record your observations in your data table.
11. **Cleanup and Disposal** Dispose of beef broth according to your teacher's instructions. Clean and return all equipment to the appropriate location.

Analyze and Conclude

1. **Describe** the experimental procedure you followed. How does it compare to the steps followed by Louis Pasteur?
2. **Compare** your findings to Pasteur's findings.
3. **Describe** why it is important for scientists to verify one another's data.
4. **Think Critically** Explain how Pasteur's findings disprove spontaneous generation.
5. **Error Analysis** If your results did not match Pasteur's results, explain a possible reason for the difference.

WRITING in Biology

Pasteur's experiment resulted in wide acceptance of biogenesis by the scientific community. Write an essay explaining how Pasteur's work contributed to some of the central ideas of biology.

Chapter 14 Study Guide

THEME FOCUS Change Scientists study the fossil record and perform experiments to learn about the changes that lead to the origin and diversity of life on Earth.

BIG Idea Fossils provide key evidence for understanding the origin and the history of life on Earth.

Section 1 Fossil Evidence of Change

fossil (p. 393)
paleontologist (p. 394)
relative dating (p. 394)
law of superposition (p. 394)
radiometric dating (p. 395)
half-life (p. 395)
geologic time scale (p. 396)
epoch (p. 396)
period (p. 396)
era (p. 396)
eon (p. 396)
Cambrian explosion (p. 398)
K-T boundary (p. 399)
plate tectonics (p. 400)

MAIN Idea Fossils provide evidence of the change in organisms over time.

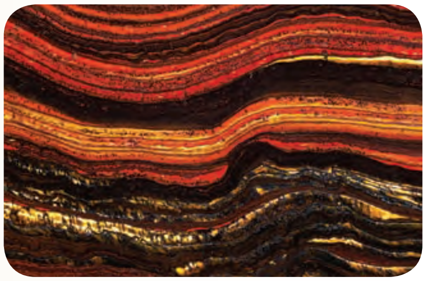
- Fossils provide evidence of past life.
- Relative dating and radiometric dating are two methods used to determine the age of fossils.
- The geologic time scale is divided into eras, periods, and epochs.
- Major events in the geologic time scale include both biological and geological changes.

Section 2 The Origin of Life

spontaneous generation (p. 401)
theory of biogenesis (p. 402)
endosymbiont theory (p. 406)

MAIN Idea Evidence indicates that a sequence of chemical events preceded the origin of life on Earth and that life has evolved continuously since that time.

- Spontaneous generation was disproved in favor of biogenesis.
- The origin of life is hypothesized to be a series of chemical events.
- Organic molecules, such as amino acids, might have been formed from simpler molecules on early Earth.
- The first cells probably were autotrophic and prokaryotic.
- The endosymbiont theory explains how eukaryotic cells might have evolved from prokaryotic cells.



Review Vocabulary eGames

Chapter 14 Assessment

Section 1

Vocabulary Review

Choose the vocabulary term from the Study Guide page that best describes each of the following phrases.

1. determining the age of a fossil by radioactive elements
2. the remains or evidence of an organism
3. scientist who studies fossils

Understand Main Ideas

Use the table below to answer questions 4 and 5.

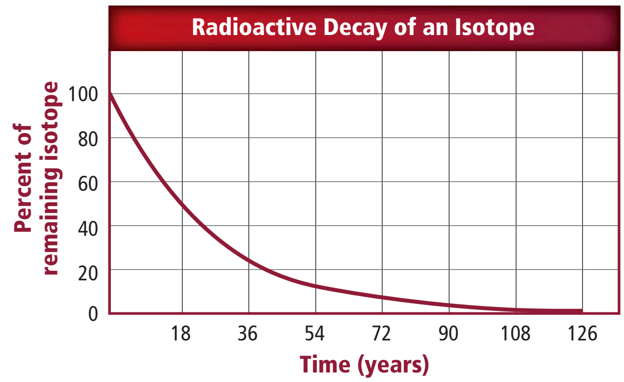
Radioactive Isotope	Product of Decay	Half-Life (Years)
Carbon-14	Nitrogen-14	5730
Chlorine-36	Argon-36	300,000
Beryllium-10	Boron-10	1.52 million
Uranium-235	Lead-207	700 million

4. According to the table above, if one-fourth of the original radioactive carbon is present in a fossil, what is the fossil's age?
   A. 2857.5 years old
   B. 5730 years old
   C. 11,460 years old
   D. 17,145 years old

5. Which isotope would be best for measuring the age of a rock layer estimated to be about one million years old?
   A. beryllium-10
   B. carbon-14
   C. chlorine-36
   D. uranium-235

6. Which fossil type provides the most anatomical information to paleontologists?
   A. trace
   B. molds
   C. replacement
   D. amber

Use the graph below to answer questions 7 and 8.



7. Which is the half-life of the radioactive isotope shown in the graph?
   A. 18 years **C.** 54 years
   B. 36 years **D.** 72 years

8. Assuming that you can only date material that has at least one percent of the radioisotope remaining, which age would be too old to date with this isotope?
   A. 35 years **C.** 75 years
   B. 50 years **D.** 125 years

9. What era followed the mass extinction at the end of the Permian period?
   A. Cambrian
   B. Mesozoic
   C. Paleozoic
   D. Neogene

10. Nearly all fossils occur in what kind of rocks?
    A. batholithic
    B. igneous
    C. metamorphic
    D. sedimentary

Constructed Response

11. **Short Answer** How does the law of superposition help paleontologists?
12. **Open Ended** Explain the geologic time scale using an analogy other than a ribbon of time.
13. **Short Answer** Calculate the percentage of Earth's existence occupied by the Cenozoic era (65 million years). Show your work.

Assessment Online Test Practice

Think Critically

14. **Infer** Imagine that you found a piece of amber in a sedimentary rock layer. What environment likely was present at the time of the fossil's formation?

15. **Describe** a fossil type and how it helps paleontologists understand an organism's anatomy.

Use the photo below to answer question 16.

16. MAIN Idea If you found the above fossil of a flowering plant in a layer of rock, what would you conclude about the age of the layer? Would you look in layers above or below the layer with the flower to learn about the Permian mass extinction?

Section 2

Vocabulary Review

Replace the underlined words with the correct vocabulary term from the Study Guide page.

17. The belief that organisms originate from nonliving matter was disproven by Redi and Pasteur.

18. The explanation that bacteria might have lived inside prokaryotes and eventually became organelles was proposed by Lynn Margulis.

Understand Main Ideas

19. Pasteur's experiments led to which theory?
    A. biogenesis theory
    B. endosymbiont theory
    C. evolution theory
    D. spontaneous generation theory

Use the illustration below to answer questions 20 and 21.

20. The organisms represented in the photo above had which effect on early Earth?
    A. produced the first amino acids
    B. increased oxygen in the atmosphere
    C. became the first mitochondria
    D. consumed the first heterotrophs

21. When did the fossils of organisms like those in the photo first appear in the fossil record?
    A. 1.0 million years ago
    B. 2.0 million years ago
    C. 3.5 billion years ago
    D. 4.5 billion years ago

22. Clay most likely was involved in which process?
    A. producing the first oxygen in the atmosphere
    B. forming the first plasma membranes
    C. providing a framework for amino acid chains
    D. capturing prokaryotes for chloroplast evolution

23. Scientists have fossil evidence for which idea for the origin of life?
    A. first amino acids
    B. first RNA
    C. first cells
    D. first autotrophs

24. Banded iron formations are important evidence for which idea in the early evolution of life?
    A. photosynthetic autotrophs
    B. endosymbiont organelles
    C. heterotrophic prokaryotes
    D. heterotrophic eukaryotes

Assessment Online Test Practice

Constructed Response

25. **Open Ended** What would you expect the first step to be in the emergence of life from nonliving matter?

26. MAIN Idea Explain the significance of the Miller-Urey experiment for understanding the origin of cells.

27. **Open Ended** Which evidence do you think is most important for the endosymbiont hypothesis? Why?

Think Critically

28. **Sequence** the hypothesized events that led from a lifeless Earth to the presence of eukaryotic cells.

29. **Compare** the contributions of Redi and Pasteur in disproving spontaneous generation.

Use the photo below to answer question 30.

30. **THEME FOCUS Change** How is the hot spring shown above similar to conditions on early Earth? What kind of organisms can survive in this type of environment?

31. **Infer** How was evolution affected by the increase in oxygen caused by the first photosynthetic organisms?

32. **CAREERS IN BIOLOGY** How could a biochemist studying DNA sequences provide evidence for the endosymbiont theory?

33. **Analyze** and critique the endosymbiont theory. What are its strengths and weaknesses?

Summative Assessment

34. BIG Idea There are six major fossil types discussed in **Table 1**. Create a hierarchy of the fossil types in **Table 1** based on the amount and type of information obtained from the fossil. Write a paragraph supporting your hierarchy.

35. WRITING in Biology Assume that you are a scientist searching for the cause of a mass extinction. Several causes have been hypothesized. Write a paragraph that explains how you could use dating methods to accept or reject them.

36. WRITING in Biology Explain the importance of a particular fossil being found in both South America and Africa.

37. Make a list of requirements for the existence of life. Put them in the order in which you think that they had to occur in order for life to begin successfully.

38. Explain why paleontologists find radiometric dating important.

39. Based on what you know about laws and theories, could the endosymbiont theory become a law? Explain your answer.

DBQ Document-Based Questions

"Probably all of the organic beings which have ever lived on this Earth have descended from some one primordial form."
Charles Darwin in *The Origin of Species,* 1859.

40. If Darwin was alive today, do you think he would include proteins among "organic beings"? Why or why not?

41. Use the quote above to support why you think Darwin would or would not have supported the endosymbiont theory.

42. Discuss what Darwin might have meant by the phrase, "…descended from some one primordial form."

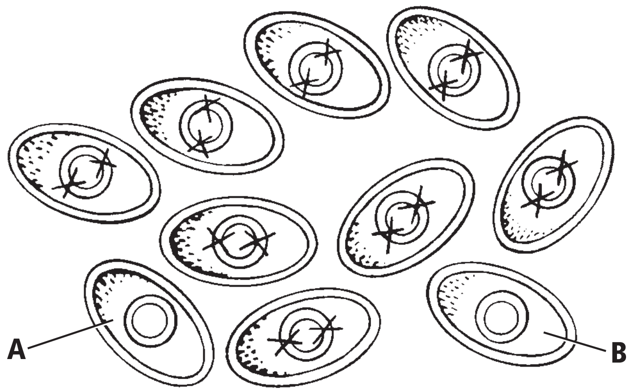
Standardized Test Practice

Cumulative

Multiple Choice

1. Which is associated with gene regulation in prokaryotic cells?
   A. DNA pairing
   B. repressor proteins
   C. RNA interference
   D. transcription factor

Use the illustration below to answer questions 2 and 3.

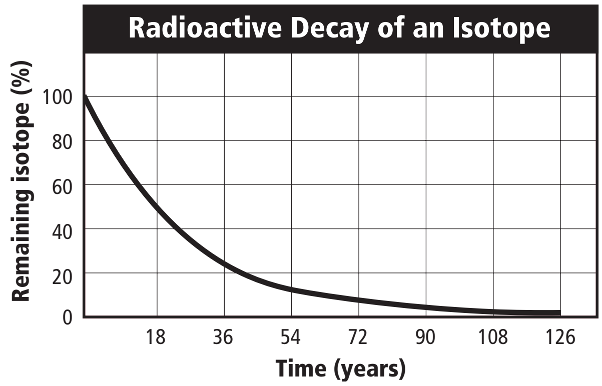


2. The bacterial cells in the figure above were transformed after they were mixed with recombinant DNA—represented by "XX" in the diagram. Which is one possible reason that Cells A and B do not have the new recombinant DNA plasmid?
   A. Cells A and B are resistant to antibiotics.
   B. Cells A and B do not have plasma membranes.
   C. Cells A and B did not take up the DNA fragment.
   D. Cells A and B initially had different plasmids.

3. In the figure, which step is likely to happen after the transformation of bacterial cells?
   A. Cells with the new plasmid will die after exposure to an antibiotic.
   B. Cells with the new plasmid will replicate quicker.
   C. Cells without the new plasmid will die after exposure to an antibiotic.
   D. Cells without the new plasmid will replicate more quickly.

4. A piece of DNA has the following sequence: CCCCGAATT. Suppose a mutation causes the following change: CCTCGAATT. Which term describes this mutation?
   A. chromosomal
   B. deletion
   C. duplication
   D. missense

Use the graph below to answer question 5.



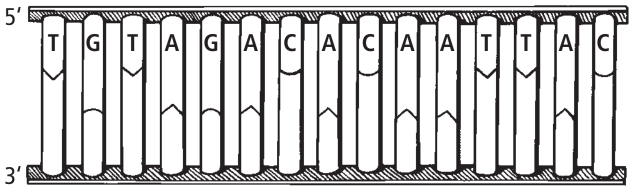
5. How much of the original isotope remains after 10 years?
   A. 50 percent
   B. 75 percent
   C. 10 percent
   D. 30 percent

6. Which causes DNA fragments to separate during gel electrophoresis?
   A. charge on the fragments
   B. DNA extraction of chemicals
   C. gel medium components
   D. source of the DNA

7. Where can Barr bodies be found?
   A. female body cells
   B. female sex cells
   C. male body cells
   D. male sex cells

Short Answer

Use the illustration below to answer questions 8 and 9.



8. The diagram shows a molecule of DNA. What is the complementary DNA strand base code? Be sure to indicate the orientation of the strand.

9. Suppose the adjacent thymine bases in the figure formed a dimer after being exposed to ultraviolet radiation. How would the dimer affect the structure of the DNA molecule?

10. Describe the difference between petrified and replacement fossils.

11. Explain the three steps that take place in a polymerase chain reaction (PCR).

12. Describe why scientists infer that oxygen was absent from the early atmosphere on Earth.

13. Use a chart to show the role that different enzymes play in the replication of DNA. Be sure to put the steps in the correct order.

14. What are restriction enzymes? Assess why they are an important tool for genetic engineering.

15. How does a paleontologist use geologic principles for the relative dating of fossils?

Extended Response

16. How is selective breeding related to genetic engineering?

17. Appraise how your body temperature is related to homeostasis.

Essay Question

Some genes contain instructions for controlling when our cells grow, divide, and die. Certain genes that promote cell division are called oncogenes. Others that slow down cell division, or cause cells to die at the right time, are called tumor suppressor genes. It is known that cancers can be caused by DNA mutations (changes) that "turn on" oncogenes or "turn off" tumor suppressor genes.

The BRCA genes (BRCA1 and BRCA2) are tumor suppressor genes. When they are mutated, they no longer function to suppress abnormal growth and breast cancer is more likely to develop. Certain inherited DNA changes can result in a high risk for the development of breast cancer in people who carry these genes and are responsible for the cancers that run in some families.

Using the information in the paragraph above, answer the following question in essay format.

18. How could oncogenes and tumor suppressor genes play a part in the development of breast cancer? Use what you know about molecular genetics to write an essay explaining how these genes might contribute to the formation of tumors.

NEED EXTRA HELP?																		
If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Review Section . . .	12.4	13.2	13.2	12.4	14.1	13.2	11.2	12.2	12.4	14.1	13.2	14.2	12.3	13.2	14.1	13.2, 12.2	1.1	12.3, 12.4

CHAPTER 15

Evolution

ConnectED

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- Video
- Audio
- Review
- Inquiry
- WebQuest
- Assessment
- Concepts in Motion
- Multilingual eGlossary

Launch Lab

How does selection work?

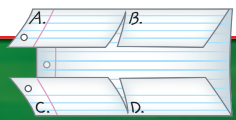
Predators can cause changes in populations by choosing certain organisms as prey. In this lab, you will look at how prey populations might respond to a predator.

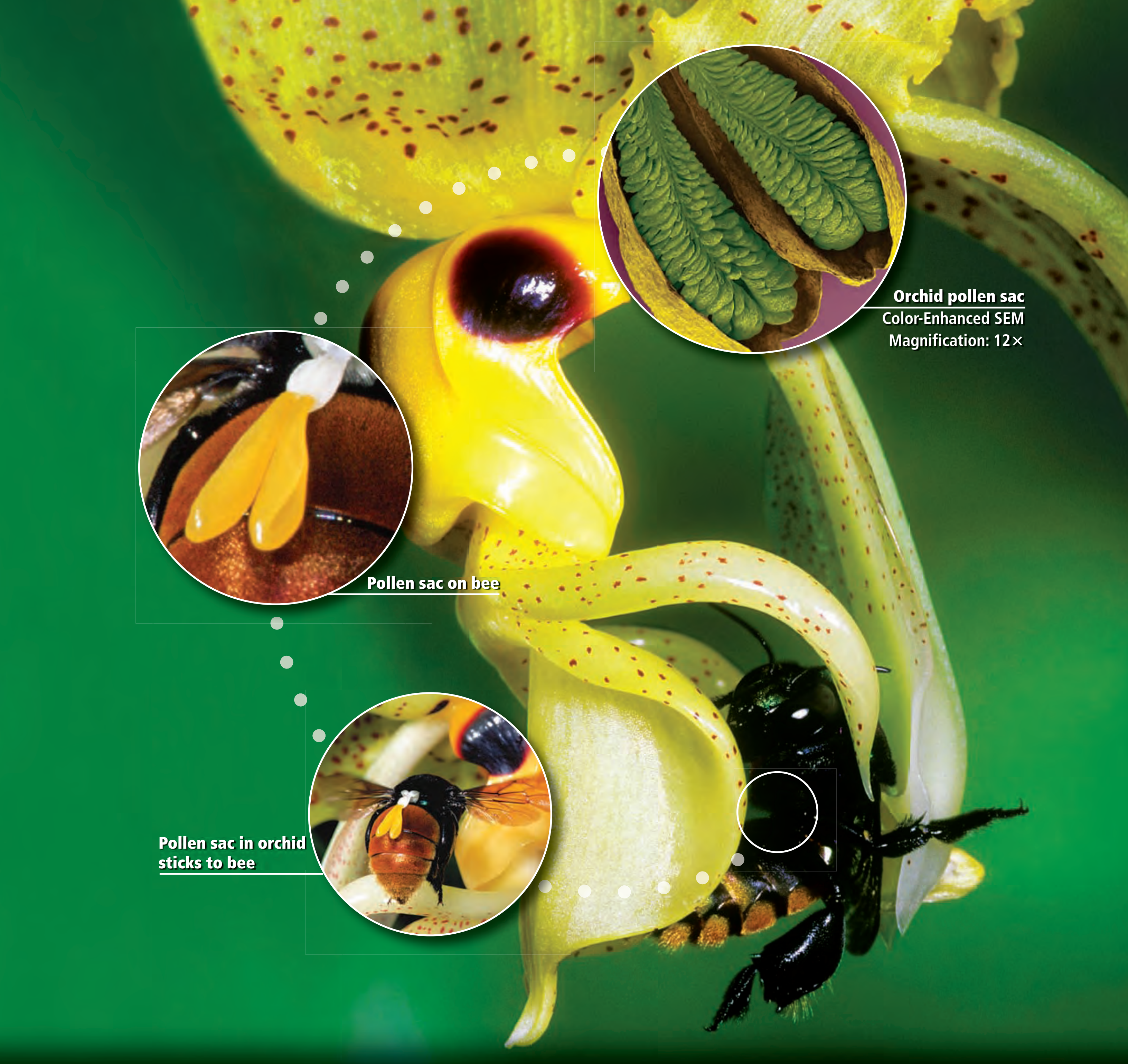
For a lab worksheet, use your StudentWorks™ Plus Online.

Inquiry Launch Lab

FOLDABLES®

Make a four-door book and label each door with one of the four principal ideas of natural selection. Use it to organize your notes on natural selection.





THEME FOCUS **Scientific Inquiry**

The theory of evolution was developed as a result of scientific inquiry.

BIG Idea The theory of evolution is supported by natural selection and explains the diversity of life.

Section 1 • Darwin's Theory of Evolution by Natural Selection

Section 2 • Evidence of Evolution

Section 3 • Shaping Evolutionary Theory

Section 1

Reading Preview

Essential Questions

- What evidence convinced Darwin that species could change over time?
- What are the four principles of natural selection?
- How can natural selection change a population?

Review Vocabulary

selective breeding: the process by which a breeder develops a plant or animal to have certain traits

New Vocabulary

artificial selection
natural selection
evolution

g Multilingual eGlossary

Darwin's Theory of Evolution by Natural Selection

MAIN Idea Charles Darwin developed a theory of evolution based on natural selection.

Real-World Reading Link Today, a jet can travel from London to New York in hours. Imagine how different things were when it took almost five years for Charles Darwin to circle the globe aboard a small, cramped ship.

Developing the Theory of Evolution

When Charles Darwin, shown in **Figure 1,** boarded the HMS *Beagle* in 1831, the average person thought that the world was about 6000 years old. Almost everyone, including the young Darwin, thought that animals and plants were unchanging. The concept of gradual change over time was still years away.

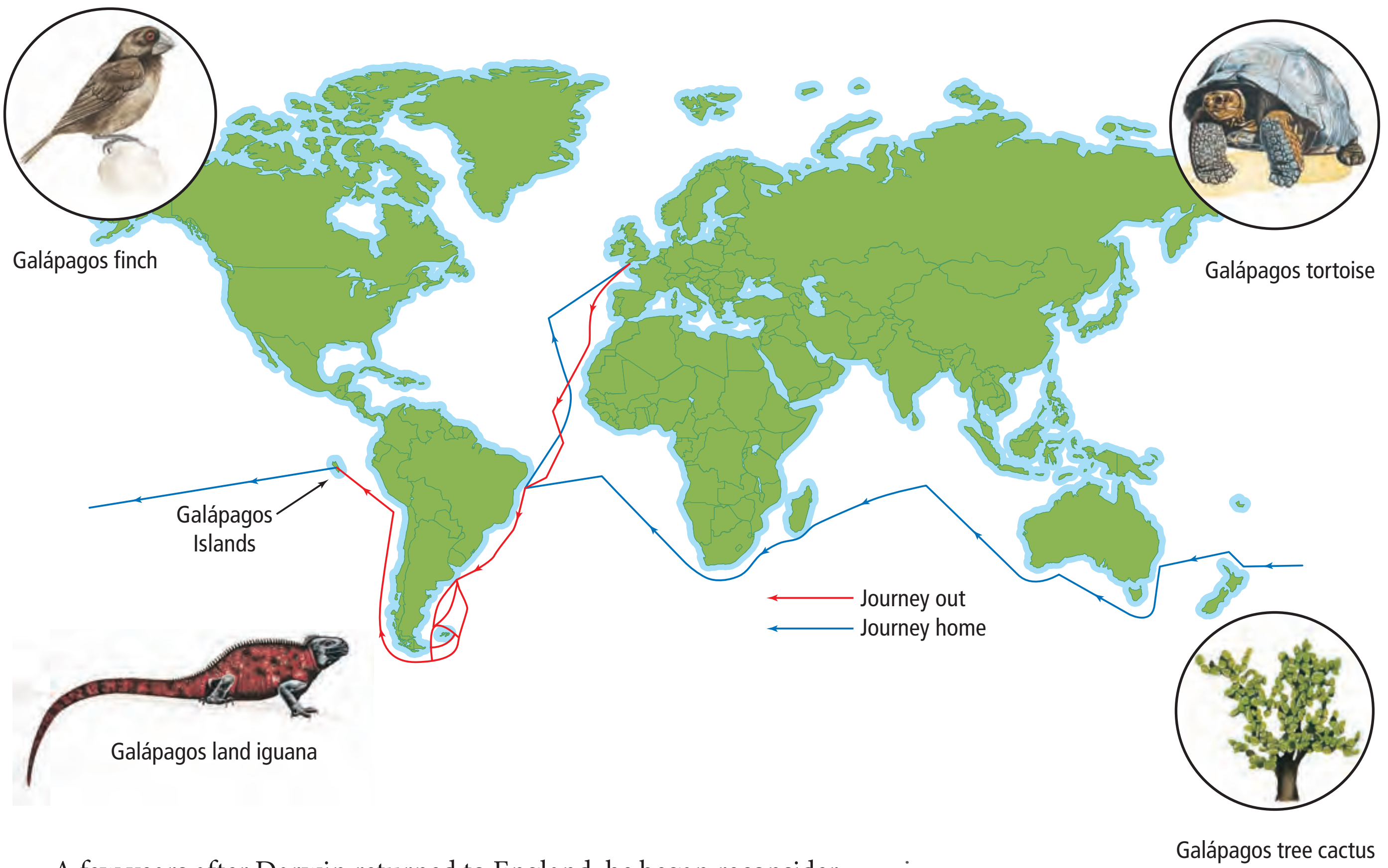
■ **Figure 1** Charles Darwin (1809–1882) posed for this portrait shortly after he returned from his voyage aboard the HMS *Beagle*.

Darwin on the HMS *Beagle* The primary mission of the *Beagle* was to survey the coast of South America. In 1831, the *Beagle* set sail from England for Maderia and then proceeded to South America, as shown on the map in **Figure 2.** Darwin's role on the ship was as a naturalist and companion to the captain. His job was to collect biological and geological specimens during the ship's travels. Darwin had a degree in theology from Christ's College, Cambridge, although he previously had studied medicine and the sciences.

Over the course of the ship's five-year voyage, Darwin made extensive collections of rocks, fossils, plants, and animals. He also read a copy of Charles Lyell's *Principles of Geology*—a book proposing that Earth was millions of years old. This book influenced his thinking as he observed fossils of marine life at high elevations in the Andes, unearthed giant fossil versions of smaller living mammals, and saw how earthquakes could lift rocks great distances very quickly.

The Galápagos Islands In 1835, the *Beagle* arrived in the Galápagos (guh LAH puh gus) Islands off the coast of South America. Darwin was initially disappointed by the stark barrenness of these volcanic islands. However, as he began to collect mockingbirds, finches, and other animals on the four islands that he visited, he noticed that the different islands seemed to have their own, slightly different varieties of animals. These differences, however, only sparked a mere curiosity. He took little notice of the comment from the colony's vice governor that the island origins of the giant tortoises could be identified solely by the appearance of the tortoises' shells.

Reading Check **Summarize** some of the experiences or observations that influenced Darwin during his voyage on the *Beagle.*



■ **Figure 2** The map shows the route of the *Beagle's* voyage. The species shown are all unique to the Galápagos Islands.
Infer ***How did the first organisms reach the Galápagos Islands?***

A few years after Darwin returned to England, he began reconsidering his observations. He took note of the work of John Gould, an ornithologist who was classifying the birds Darwin brought back from the Galápagos. Gould discovered that the Galápagos finches were separate species and determined that the finches of the Galápagos did not live anywhere else in South America. In fact, almost every specimen that Darwin had collected on the islands was new to European scientists. These new species most closely resembled species from mainland South America, although the Galápagos and the mainland had different environments. Island and mainland species should not have resembled one another so closely unless, as Darwin began to suspect, populations from the mainland changed after reaching the Galápagos.

Darwin continued his studies Darwin hypothesized that new species could appear gradually through small changes in ancestral species, but he could not see how such a process would work. To understand it better, he turned to animal breeders—pigeon breeders in particular.

Different breeds of pigeons have certain distinctive traits that also are present in these breeds' offspring. A breeder can promote these traits by selecting and breeding pigeons that have the most exaggerated expressions of those traits. For example, to produce pigeons with fan-shaped tails, the breeder will breed pigeons with the most fan-shaped tails. The process of directed breeding to produce offspring with desired traits, referred to as selective breeding was called **artificial selection** by Darwin.

Artificial selection also occurs when humans develop new breeds of dogs or new strains of crop plants. Darwin inferred that if humans could change species by artificial selection, then perhaps the same process could work in nature. Further, Darwin thought that, given enough time, perhaps this process could produce new species.

Natural selection While thinking about artificial selection, Darwin read an essay by economist Thomas Malthus. The essay suggested that the human population, if unchecked, eventually would outgrow its food supply, leading to a competitive struggle for existence. Darwin realized that Malthus's ideas could be applied to the natural world. He reasoned that some competitors in the struggle for existence would be better equipped for survival than others. Those less equipped would die. This is the process of **natural selection.** Here, finally, was the framework for a new theory about the origin of species.

Darwin's theory of evolution by natural selection has four basic principles that explain how traits of a population can change over time. First, individuals in a population show differences, or variations. Second, variations can be inherited, meaning that they are passed down from parent to offspring. Third, organisms have more offspring than can survive on available resources. The average cardinal, for example, lays nine eggs each summer. If each baby cardinal survived and reproduced just once, it would take only seven years for the first pair to have produced one million birds. Finally, variations that increase reproductive success will have a greater chance of being passed on than those that do not increase reproductive success. If having a fantail helps a pigeon reproduce successfully, future generations would include more pigeons with fan-shaped tails.

FOLDABLES® Incorporate information from this section into your Foldable.

Given enough time, natural selection could modify a population enough to produce a new species. Natural selection is now considered the mechanism by which evolution takes place. **Figure 3** shows how natural selection might modify a population of sunflowers.

Reading Check **Explain** the four principles of natural selection.

DATA ANALYSIS LAB 1

Based on Real Data*

Interpret the Data

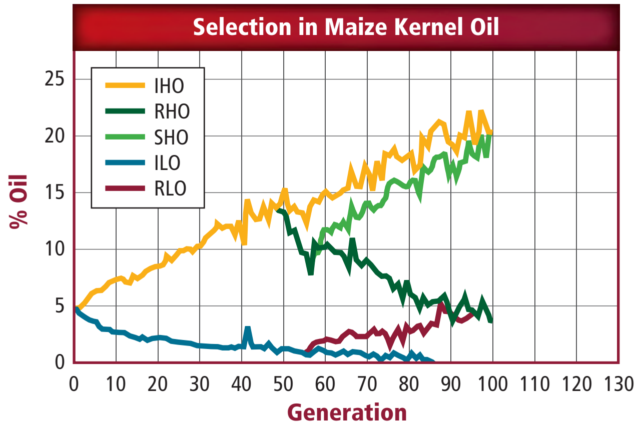
How did artificial selection change corn? Plant breeders have made many changes to crops. In one of the longest experiments ever conducted, scientists selected maize (corn) for oil content in kernels.

Data and Observations

Look at the graph and compare the selection in the different plant lines.

Line IHO was selected for high oil content, and line ILO was selected for low oil content. The direction of selection was reversed in lines RHO (started from IHO) and RLO (started from ILO) at generation 48. In line SHO (derived from RHO), selection was switched back to high oil content at generation 55.

*Data obtained from: Hill, W. G. 2005. A century of corn selection. *Science* 307: 683-684.



Think Critically

1. **Measure** What were the highest and lowest percentages of oil seen in the experiment?
2. **Predict** If the trend continues for line RHO, approximately how many generations will it take until the oil content reaches zero percent?

Visualizing Natural Selection

Figure 3

Natural selection is the mechanism by which, if given enough time, a population—in this case, a population of sunflowers—could be modified to produce a new species. There are four principles of natural selection that explain how this can occur: variation, heritability, overproduction, and reproductive advantage.

Variation Individuals in a population differ from one another. For example, some sunflowers are taller than others.

Heritability Variations are inherited from parents. Tall sunflowers produce tall sunflowers, and short sunflowers produce short sunflowers.

Overproduction Populations produce more offspring than can survive. Each sunflower has hundreds of seeds, most of which will not germinate.

Reproductive Advantage Some variations allow the organism that possesses them to have more offspring than the organism that does not possess them. For example, in this habitat, shorter sunflowers reproduce more successfully.

Over time, the average height of the sunflower population is short if the short sunflowers continue to reproduce more successfully. After many generations, the short sunflowers might become a new species if they are unable to breed with the original sunflowers.

Concepts in Motion **Animation**

Table 1	Basic Principles of Natural Selection	Concepts in Motion Interactive Table

Principle	Example
Individuals in a population show variations among others of the same species.	The students in a classroom all look different.
Variations are inherited.	You look similar to your parents.
Animals have more young than can survive on the available resources.	The average cardinal lays nine eggs per summer. If each cardinal lived only one year and all offspring survived, in seven years there would be a million cardinals.
Variations that increase reproductive success will be more common in the next generation.	If having a fan-shaped tail increases the reproductive success of pigeons, then more pigeons in the next generation will have fan-shaped tails.

The Origin of Species

Darwin had likely formulated his theory of evolution by natural selection by about 1840. Soon after, he began writing a multivolume book compiled of evidence for evolution and explaining how natural selection might provide a mechanism for the origin of species. **Table 1** summarizes the principles of natural selection described in Darwin's work. He continued to compile evidence in support of his theory for many years. For example, he spent eight years studying relationships among barnacles.

In 1858, Alfred Russel Wallace, another English naturalist, proposed a theory that was almost identical to Darwin's theory. Both men's ideas were presented to the Linnean Society of London. One year later, Darwin published *On the Origin of Species by Means of Natural Selection*—a condensed version of the book he had started many years before.

In his book, Darwin used the term *evolution* only on the last page. Today, biologists use the term **evolution** to define cumulative changes in groups of organisms through time. Natural selection is not synonymous with evolution; it is a mechanism by which evolution occurs.

VOCABULARY
WORD ORIGIN
Evolve
comes from the Latin word *evolvere*, meaning *unroll* or *unfold*

Section 1 Assessment

Section Summary

- Darwin drew from his observations on the HMS *Beagle* and later studies to develop his theory of evolution by natural selection.
- Natural selection is based on ideas of variation, inheritance, excess reproduction, and advantages of certain traits in certain environments.
- Darwin reasoned that the process of natural selection eventually could result in the appearance of new species.

Understand Main Ideas

1. MAIN Idea **Describe** the evidence Charles Darwin gathered that led to his theory of evolution.
2. **Explain** how the idea of artificial selection contributed to Darwin's ideas on natural selection.
3. **Identify** the four principles of natural selection and provide examples not used in this section.
4. **Discuss** Wallace's contribution to the theory of evolution by natural selection.

Think Critically

5. **Infer** the consequences for evolution if species did not vary.

WRITING in Biology

6. Write a short story about what it might have been like to visit the Galápagos Islands with Darwin.

Assessment Online Quiz

Section 2

Reading Preview

Essential Questions

- How do fossils provide evidence of evolution?
- How does morphology provide evidence of evolution?
- How does biochemistry provide evidence of evolution?

Review Vocabulary

fossil: remains of an organism or its activities

New Vocabulary

derived trait
ancestral trait
homologous structure
vestigial structure
analogous structure
embryo
biogeography
fitness
camouflage
mimicry

Multilingual eGlossary

Evidence of Evolution

MAIN Idea Multiple lines of evidence support the theory of evolution.

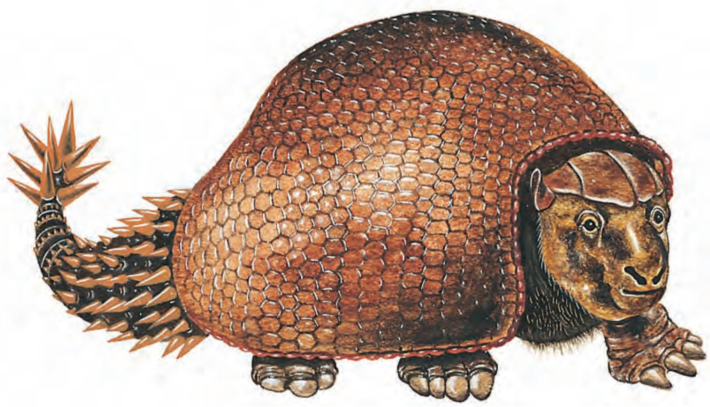
Real-World Reading Link The evidence for evolution is like a set of building blocks. Just as you cannot build something with only one building block, one piece of evidence does not make a theory. The evidence for evolution is more convincing when it is supported by many pieces of evidence, just as a structure is more sturdy when it is built with many blocks.

Support for Evolution

Darwin's book *On the Origin of Species* demonstrated how evolution might happen. The book also provided evidence that evolution has occurred on our planet. The concepts of natural selection and evolution are different, though related. Darwin's theory of evolution by natural selection is part of the larger theory of evolution. Recall that a theory provides an explanation for a natural phenomenon based on observations. Theories explain available data and suggest further areas for experimentation. The theory of evolution states that all organisms on Earth have descended from a common ancestor.

The fossil record Fossils provide a record of species that lived long ago, and they supply some of the most significant evidence of evolutionary change. This record can show how ancient species are similar to current species, as illustrated in **Figure 4.** Fossils also show that some species, such as the horseshoe crab, have remained unchanged for millions of years. The fossil record is an important source of information for determining the ancestry of organisms and patterns of evolution.

Figure 4 The giant armadillo-like glyptodont, *Glyptodon,* is an extinct animal that Darwin thought must have been related to living armadillos.
Observe ***What features of the 2000-kg glyptodont are similar to those of the 4-kg armadillo?***



Glyptodont

Armadillo

■ **Figure 5** This artist's rendering of *Archaeopteryx* shows that it shares many features with modern birds while retaining ancestral dinosaur features.

Connection to Earth Science Although Darwin recognized the limitations of the fossil record, he predicted the existence of fossils intermediate in form between species. Today, scientists studying evolutionary relationships have found hundreds of thousands of transitional fossils that contain features shared by different species. For example, certain dinosaur fossils show feathers of modern birds and teeth and bony tails of reptiles. **Figure 5** shows an artist's rendering of *Archaeopteryx,* one of the first birds. *Archaeopteryx* fossils provide evidence of characteristics that classify it as a bird, and also show that the bird retained several distinct dinosaur features.

Researchers consider two major classes of traits when studying transitional fossils: derived traits and ancestral traits. **Derived traits** are newly evolved features, such as feathers, that do not appear in the fossils of common ancestors. **Ancestral traits,** on the other hand, are more primitive features, such as teeth and tails, that do appear in ancestral forms. Transitional fossils provide detailed patterns of evolutionary change for the ancestors of many modern animals, including mollusks, horses, whales, and humans.

Vocabulary

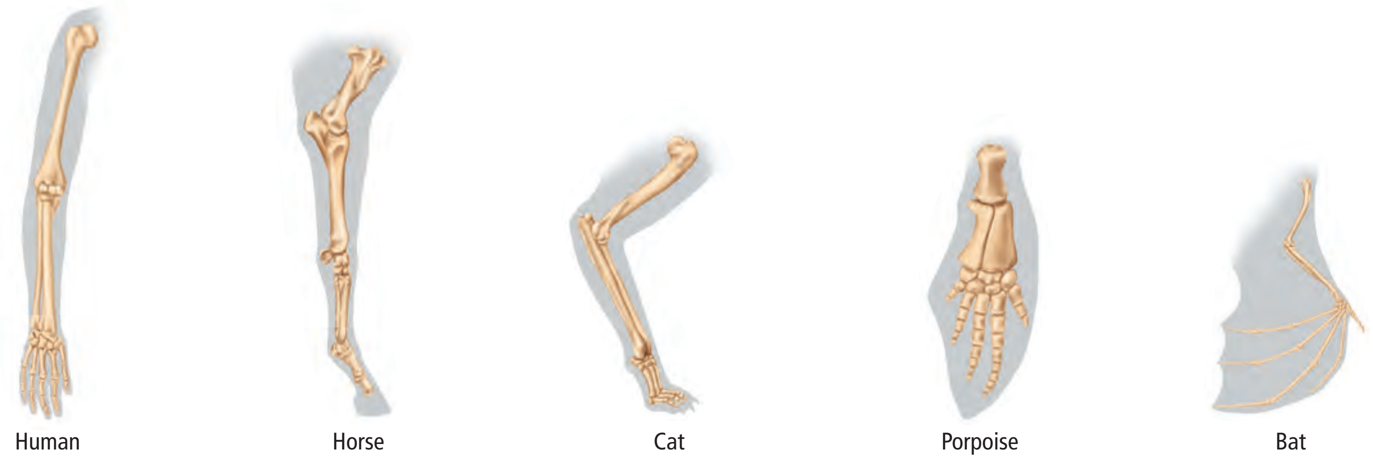
Word origin

Homologous
comes from the Greek words *homos,* meaning *same,* and *logos,* meaning *relation* or *reasoning*

Comparative anatomy

Why do the vertebrate forelimbs shown in **Figure 6** have different functions but appear to be constructed of similar bones in similar ways? Evolutionary theory suggests that the answer lies in shared ancestry.

Homologous structures Anatomically similar structures inherited from a common ancestor are called **homologous structures.** Evolution predicts that an organism's body parts are more likely to be modifications of ancestral body parts than they are to be entirely new features. The limbs illustrated in **Figure 6** move animals in different ways, yet they share similar construction. Bird wings and reptile limbs are another example. Although birds use their wings to fly and reptiles use their limbs to walk, bird wings and reptile forelimbs are similar in shape and construction, which indicates that they were inherited from a common ancestor. While homologous structures alone are not evidence of evolution, they are an example for which evolution is the best available explanation for the biological data.

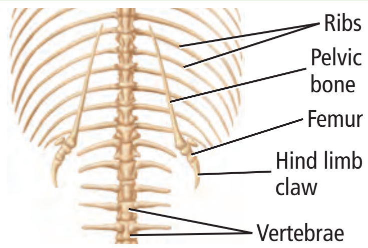
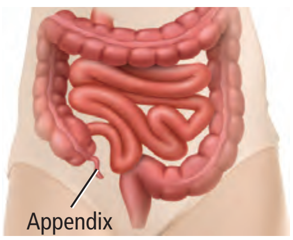


Vestigial structures In some cases, a functioning structure in one species is smaller or less functional in a closely related species. For example, most birds have wings developed for flight. Kiwis, however, have very small wings that cannot be used for flying. The kiwi wing is a kind of homologous structure called a vestigial structure. **Vestigial structures** are structures that are the reduced forms of functional structures in other organisms. **Table 2** illustrates some vestigial structures in different species. Evolutionary theory predicts that features of ancestors that no longer have a function for that species will become smaller over time until they are lost.

■ **Figure 6** The forelimbs of vertebrates illustrate homologous structures. Each limb is adapted for different uses, but they all have similar bones.
Infer ***which of the forelimbs shown would most likely resemble a whale's pectoral fin.***

Table 2 Vestigial Structures

Concepts in Motion
Interactive Table

Trait	Example	Description
Snake pelvis		The pelvis is the attachment point for legs and is therefore nonfunctional in an animal without legs.
Kiwi wings		The wings of kiwis are too small to be of any use in flight.
Human appendix		This is a 5- to 15-cm-long structure that is important for digestion in many mammals, but is of limited use in humans and some apes.

■ **Figure 7** Eagles and beetles use their wings to fly, but their wing structures are different.
Explain ***how scientists know that the wings of eagles and beetles are analogous structures.***

Bald eagle

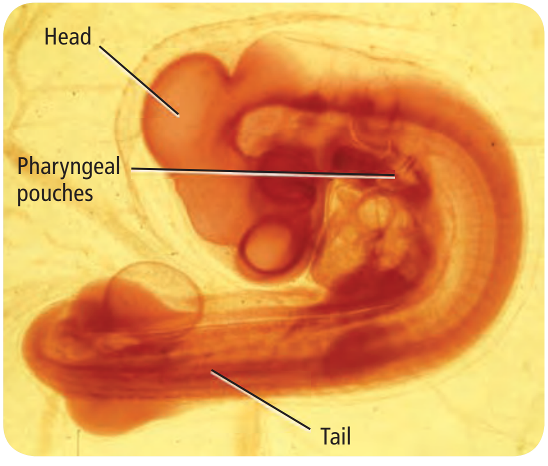
May beetle

Not all anatomically similar features are evidence of common ancestry. **Analogous structures** can be used for the same purpose and can be superficially similar in construction but are not inherited from a common ancestor. As shown in **Figure 7,** the wings of an eagle and the wings of a beetle have the same function. They both enable the organism to fly. However, the wings are constructed in different ways and from different materials. While analogous structures do not indicate close evolutionary relationships, they do show that functionally similar features can evolve independently in similar environments.

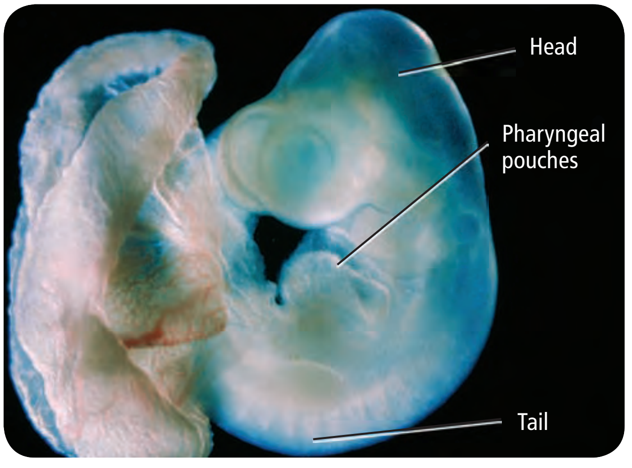
Reading Check **Explain** why vestigial structures are considered examples of homologous structures.

Comparative embryology Vertebrate embryos provide more glimpses into evolutionary relationships. An **embryo** is an early, prebirth stage of an organism's development. Scientists have found that vertebrate embryos exhibit homologous structures during certain phases of development but become totally different structures in the adult forms. The embryos shown in **Figure 8,** like all vertebrate embryos, have a tail and paired structures called pharyngeal pouches. In fish, the pouches develop into gills. In reptiles, birds, and mammals, these structures become parts of the ears, jaws, and throats. Although the adult forms differ, the shared features in the embryos suggest that vertebrates evolved from a shared ancestor.

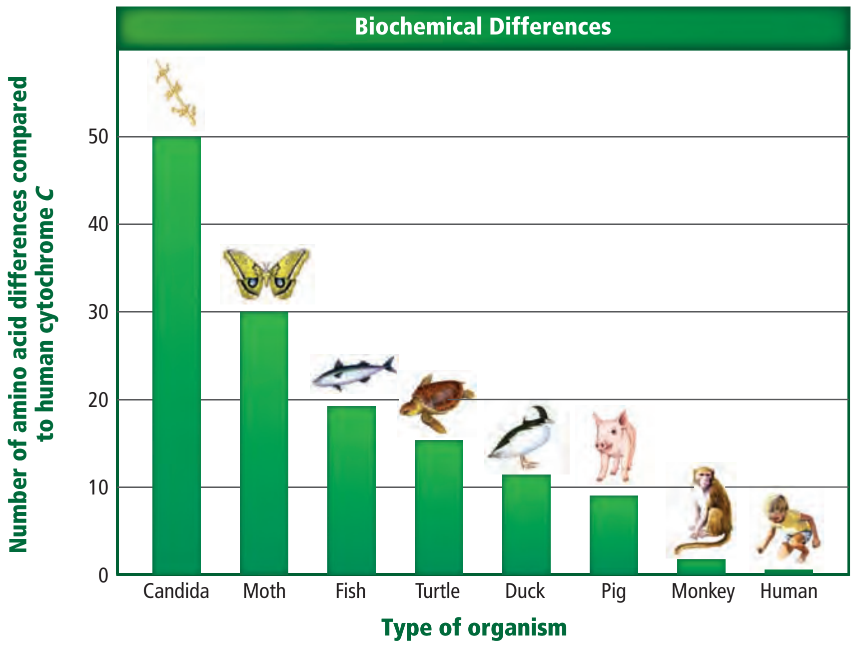
■ **Figure 8** Embryos reveal evolutionary history. Bird and mammal embryos share several developmental features.



Bird embryo



Mammal embryo



■ **Figure 9** This illustration compares amino acid sequences of cytochrome *c* in humans and other organisms.
Infer ***Would the cytochrome c of a reptile or a bird be expected to have more amino acid differences when compared with that of a human? Explain.***

Comparative biochemistry Scientific data also show that common ancestry can be seen in the complex metabolic molecules that many different organisms share. Cytochrome *c* is an enzyme that is essential for respiration and is highly conserved in animals. This means that despite slight variations in its amino acid sequence, the molecule has changed very little over time.

Evolutionary theory predicts that molecules in species with a recent common ancestor should share certain ancient amino acid sequences. The more closely related the species are, the greater the number of sequences that will be shared. This predicted pattern is what scientists find to be true in cytochrome *c*. For example, as illustrated in **Figure 9,** the cytochrome *c* in the pig and in the monkey share more amino acid sequences with humans than the cytochrome *c* in the duck shares with humans.

Connection to Chemistry Scientists have found similar biochemical patterns in other proteins, as well as in DNA and RNA. DNA and RNA form the molecular basis of heredity in all living organisms. The fact that many organisms have the same complex molecules suggests that these molecules evolved early in the history of life and were passed on through the life-forms that have lived on Earth. Comparisons of the similarities in these molecules across species reflect evolutionary patterns seen in comparative anatomy and in the fossil record. Organisms with closely related morphological features have more closely related molecular features.

Geographic distribution The distribution of plants and animals that Darwin saw during his South American travels first suggested evolution to Darwin. He observed that animals on the South American mainland were more similar to other South American animals than they were to animals living in similar environments in Europe. The South American mara, for example, inhabited a niche that was occupied by the English rabbit. You can compare a mara and an English rabbit in **Figure 10.** Darwin realized that the mara was more similar to other South American species than it was to the English rabbit because it shared a closer ancestor with the South American animals.

■ **Figure 10** The mara *(Dolichotis patagonum)* exists in a niche similar to that of the English rabbit *(Oryctolagus cuniculus).*

Mara

English rabbit

Patterns of migration were critical to Darwin when he was developing his theory. Migration patterns explained why, for example, islands often have more plant diversity than animal diversity: the plants are more able to migrate from the closest mainland as seeds, either by wind or on the backs of birds. Since Darwin's time, scientists have confirmed and expanded Darwin's study of the distribution of plants and animals around the world in a field of study now called **biogeography.** Evolution is intimately linked with climate and geological forces, especially plate tectonics, which helps explain many ancestral relationships and geographic distributions seen in fossils and living organisms today.

Adaptation

The five categories discussed in the previous section—the fossil record, comparative anatomy, comparative embryology, comparative biochemistry, and geographic distribution—offer evidence for evolution. Darwin drew on all of these except biochemistry—which was not well developed in his time—to develop his own theory of evolution by natural selection. At the heart of his theory lies the concept of adaptation.

Types of adaptation An adaptation is a trait shaped by natural selection that increases an organism's reproductive success. One way to determine how effectively a trait contributes to reproductive success is to measure fitness. **Fitness** is a measure of the relative contribution that an individual trait makes to the next generation. It often is measured as the number of reproductively viable offspring that an organism produces in the next generation.

The better an organism is adapted to its environment, the greater its chances of survival and reproductive success. This concept explains the variations Darwin observed in the finches' beaks on the Galápagos Islands. Because the environments differed on each island, different beak characteristics were selected for.

Vocabulary

Science usage v. Common usage

Adaptation

Science usage: a trait shaped by natural selection to increase the survival or reproductive success of an organism

The prehensile tail of monkeys is an adaptation for life in trees.

Common usage: adjustment or change

The movie script is an adaptation of the original play.

Camouflage Some species have evolved morphological adaptations that allow them to blend in with their environments. This is called **camouflage** (KA muh flahj). Camouflage allows organisms to become almost invisible to predators, as shown in **Figure 11.** As a result, more of the camouflaged individuals survive and reproduce.

Figure 11 It would be easy for a predator to overlook a leafy sea dragon, *Phycodurus eques,* in a sea grass habitat because of the animal's effective camouflage.

California kingsnake

Western coral snake

■ **Figure 12** Predators avoid the harmless California kingsnake because it has color patterns similar to those of the poisonous western coral snake.

Mimicry Another type of morphological adaptation is mimicry. In **mimicry,** one species evolves to resemble another species. You might expect that mimicry would make it difficult for individuals in one species to find and breed with other members of their species, thus decreasing reproductive success. However, mimicry often increases an organism's fitness. Mimicry can occur in a harmless species that has evolved to resemble a harmful species, such as the example shown in **Figure 12.** Sometimes mimicry benefits two harmful species. In both cases, the mimics are protected because predators can't always tell the mimic from the animal that it is mimicking, so they learn to avoid them both.

Reading Check **Compare** mimicry and camouflage.

Antimicrobial resistance Species of bacteria that originally were killed by penicillin and other antibiotics have developed drug resistance. For almost every antibiotic, at least one species of resistant bacteria exists. One unintended consequence of the continued development of antibiotics is that some diseases, which were once thought to be contained, such as tuberculosis, have re-emerged in more harmful forms.

MiniLab 1

Investigate Mimicry

Inquiry MiniLab

Why do some species mimic the features of other species? Mimicry is the process of natural selection that shapes one species of organism to look similar to another species. Natural selection has shaped the nontoxic viceroy butterfly to look like the toxic monarch butterfly. Investigate the mimicry displayed during this lab.

Procedure

1. Read and complete the lab safety form.
2. Create a data table for recording your observations and measurements of the **monarch** and **viceroy butterflies.**
3. Observe the physical characteristics of both butterfly species and record your observations in your data table.

Analysis

1. **Compare and contrast** the physical characteristics of the two butterfly species.
2. **Hypothesize** why the viceroy butterflies have bright colors that are highly visible.

Figure 13 Spaces between arches set in a square to support a dome are called spandrels and are often decorative. Some features in organisms might be like spandrels, a consequence of another adaptation.

Consequences of adaptations Not all features of an organism are necessarily adaptive. Some features might be consequences of other evolved characteristics. Biologists Stephen Jay Gould and Richard Lewontin made this point in 1979 in a paper claiming that biologists tended to overemphasize the importance of adaptations in evolution.

Spandrel example To illustrate this concept, they used an example from architecture. Building a set of four arches in a square to support a dome means that spaces called spandrels will appear between the arches, as illustrated in **Figure 13.** Because spandrels are often decorative, one might think that spandrels exist for decoration. In reality, they are an unavoidable consequence of arch construction. Gould and Lewontin argued that some features in organisms are like spandrels because even though they are prominent, they do not increase reproductive success. Instead, they likely arose as an unavoidable consequence of prior evolutionary change.

Human example A biological example of a spandrel is the helplessness of human babies. Humans give birth at a much earlier developmental stage than other primates do. This causes them to need increased care early in their lives. Many scientists think that the helplessness of human babies is a consequence of the evolution of big brains and upright posture. To walk upright, humans need narrow pelvises, which means that babies' heads must be small enough to fit through the pelvic opening at birth. In contrast, scientists previously thought that the helplessness of human infants provided an adaptive advantage, such as increased attention from parents and more learning.

Section 2 Assessment

Section Summary

- Fossils provide strong direct evidence to support evolution.
- Homologous and vestigial structures indicate shared ancestry.
- Examples of embryological and biochemical traits provide insight into the evolution of species.
- Biogeography can explain why certain species live in certain locations.
- Natural selection gives rise to features that increase reproductive success.

Understand Main Ideas

1. MAIN Idea **Describe** how fossils provide evidence of evolution.
2. **Explain** what natural selection predicts about mimicry, camouflage, homologous structures, and vestigial structures.
3. **Indicate** how biochemistry provides evidence of evolution.
4. **Compare** the morphological evidence and the biochemical evidence supporting evolution.

Think Critically

5. **Hypothesize** Evidence suggests that the bones in bird wings share a number of features with the bones of dinosaur arms. Based on this evidence, what hypothesis could you make about the evolutionary relationship between birds and dinosaurs?
6. **Apply** Research has shown that if a prescribed dose of an antibiotic is not taken completely, some bacteria might not be killed and the disease might return. How does natural selection explain this phenomenon?

Assessment Online Quiz

Section 3

Reading Preview

Essential Questions

- What are the conditions of the Hardy-Weinberg principle?
- What patterns can be observed in evolution?
- What factors influence speciation?

Review Vocabulary

allele: alternate forms of a character trait that can be inherited

New Vocabulary

Hardy-Weinberg principle
genetic drift
founder effect
bottleneck
stabilizing selection
directional selection
disruptive selection
sexual selection
prezygotic isolating mechanism
postzygotic isolating mechanism
allopatric speciation
sympatric speciation
adaptive radiation
gradualism
punctuated equilibrium

g Multilingual eGlossary

Shaping Evolutionary Theory

MAIN Idea The theory of evolution continues to be refined as scientists learn new information.

Real-World Reading Link The longer you operate a complicated piece of electronics, the better you understand how it works. The device does not change, but you become more familiar with its functions. Scientists have been studying evolution for almost 150 years, yet they are still learning new ways in which evolution leads to changes in species.

Mechanisms of Evolution

Natural selection remains a central theme in evolution. It explains how organisms adapt to their environments and how variations can give rise to adaptations within species. Scientists now know that natural selection is not the only mechanism of evolution. Studies in population genetics and molecular biology led to the development of evolutionary theory. At the center is the understanding that evolution occurs at the population level, with genes as the raw material.

Population genetics At the turn of the twentieth century, genes had not been discovered. However, the allele was understood to be one form of an inherited character trait, such as eye color, that gets passed down from parent to offspring. Scientists did not understand why dominant alleles would not simply overpower recessive alleles in a population.

In 1908, English mathematician Godfrey Hardy and German physician Wilhelm Weinberg independently came up with the same solution to this problem. They showed mathematically that evolution will not occur in a population unless allelic frequencies are acted upon by forces that cause change. In the absence of these forces, the allelic frequency remains the same and evolution doesn't occur. According to this idea, which is now known as the **Hardy-Weinberg principle,** when allelic frequencies remain constant, a population is in genetic equilibrium. This concept is illustrated in **Figure 14.**

Figure 14 According to the Hardy-Weinberg principle, even though the number of owls doubled, the ratio of gray to red owls remained the same.

CAREERS IN BIOLOGY

Biometrician Almost all scientific research papers include some statistics. Many researchers consult biometricians—people who specialize in statistics related to biology—to help design studies and analyze study results.

Connection to Math To illustrate the Hardy-Weinberg principle, consider a population of 100 humans. Forty people are homozygous dominant for earlobe attachment *(EE)*. Another 40 people are heterozygous *(Ee)*. Twenty people are homozygous recessive *(ee)*. In the 40 homozygous dominant people, there are 80 *E* alleles (2 *E* alleles × 40); and in the 20 homozygous recessive people, there are 40 *e* alleles (2 *e* alleles × 20). The heterozygous people have 40 *E* alleles and 40 *e* alleles. Summing the alleles, we have 120 *E* alleles and 80 *e* alleles for a total of 200 alleles. The *E* allele frequency is 120/200, or 0.6. The *e* allele frequency is 80/200, or 0.4.

The Hardy-Weinberg principle states that the allele frequencies in populations should be constant. This often is expressed as $p + q = 1$. For our example, p can represent the *E* allele frequency and q can represent the *e* allele frequency.

Squaring both sides of the equation yields the new equation $p^2 + 2pq + q^2 = 1$. This equation allows us to determine the equilibrium frequency of each genotype in the population: homozygous dominant (p^2), heterozygous (2pq), and homozygous recessive (q^2). From the above example, $p = 0.6$, and $q = 0.4$, so $(0.6)(0.6) + 2(0.6)(0.4) + (0.4)(0.4) = 1$. In the example population, the equilibrium frequency for homozygous dominant will be 0.36, the equilibrium frequency of heterozygous will be 0.48, and the equilibrium frequency of homozygous recessive will be 0.16. Note that the sum of these frequencies equals one.

Reading Check **Determine** when a population is in equilibrium.

Conditions According to the Hardy-Weinberg principle, a population in genetic equilibrium must meet five conditions: there must be no genetic drift, no gene flow, no mutation, mating must be random, and there must be no natural selection. Populations in nature might meet some of these requirements, but hardly any population meets all five conditions for long periods of time. If a population is not in genetic equilibrium, at least one of the five conditions has been violated. These five conditions, listed in **Table 3,** are known mechanisms of evolutionary change.

Table 3 **The Hardy-Weinberg Principle** Concepts in Motion Interactive Table

Condition	Violation	Consequence
The population is very large.	Many populations are small.	Chance events can lead to changes in population traits.
There is no immigration or emigration.	Organisms move in and out of the population.	The population can lose or gain traits with movement of organisms.
Mating is random.	Mating is not random.	New traits do not pass as quickly to the rest of the population.
Mutations do not occur.	Mutations occur.	New variations appear in the population with each new generation.
Natural selection does not occur.	Natural selection occurs.	Traits in a population change from one generation to the next.

Genetic drift Any change in the allelic frequencies in a population that results from chance is called **genetic drift.** Recall that for simple traits, only one of a parent's two alleles passes to the offspring, and that this allele is selected randomly through independent assortment. In large populations, enough alleles "drift" to ensure that the allelic frequency of the entire population remains relatively constant from one generation to the next. In smaller populations, however, the effects of genetic drift become more pronounced, and the chance of losing an allele becomes greater.

Founder effect The founder effect is an extreme example of genetic drift. The **founder effect** can occur when a small sample of a population settles in a location separated from the rest of the population. Because this sample is a random subset of the original population, the sample population carries a random subset of the population's genes. Alleles that were uncommon in the original population might be common in the new population, and the offspring in the new population will carry those alleles. Such an event can result in large genetic variations in the separated populations.

The founder effect is evident in the Amish and Mennonite communities in the United States, in which the people rarely marry outside their own communities. The Old Order Amish have a high frequency of six-finger dwarfism. All affected individuals can trace their ancestry back to one of the founders of the Order.

Bottleneck Another extreme example of genetic drift is a **bottleneck,** which occurs when a population declines to a very low number and then rebounds. The gene pool of the rebound population often is genetically similar to that of the population at its lowest level, that is, it has reduced diversity. Researchers think that cheetahs in Africa experienced a bottleneck 10,000 years ago, and then another one about 100 years ago. Throughout their current range, shown in **Figure 15,** cheetahs are so genetically similar that they appear inbred. Inbreeding decreases fertility, and might be a factor in the potential extinction of this endangered species.

Reading Check **Explain** how genetic drift affects populations.

Study Tip

Concept Map Make a concept map, placing the term *evolution* in the top oval. The second row of ovals should contain the following terms: *genetic drift, gene flow, nonrandom mating, mutation,* and *natural selection.* As you read the chapter, fill in definitions and write examples that illustrate each term.

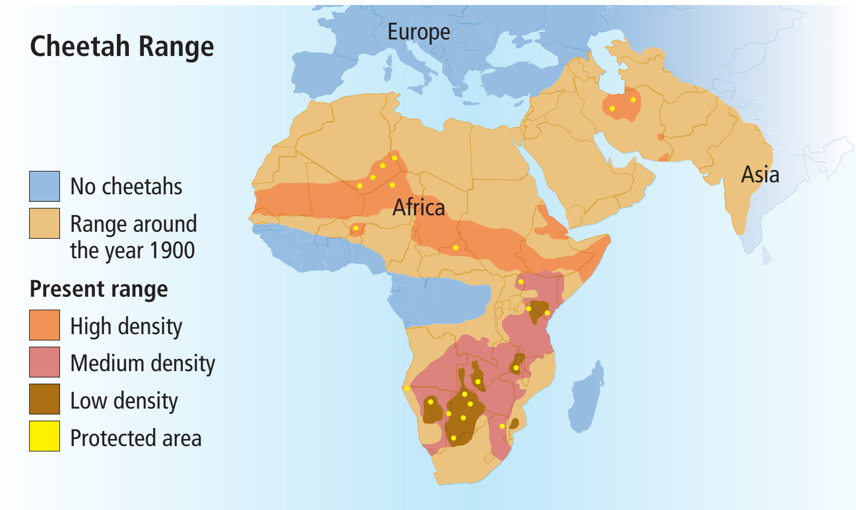
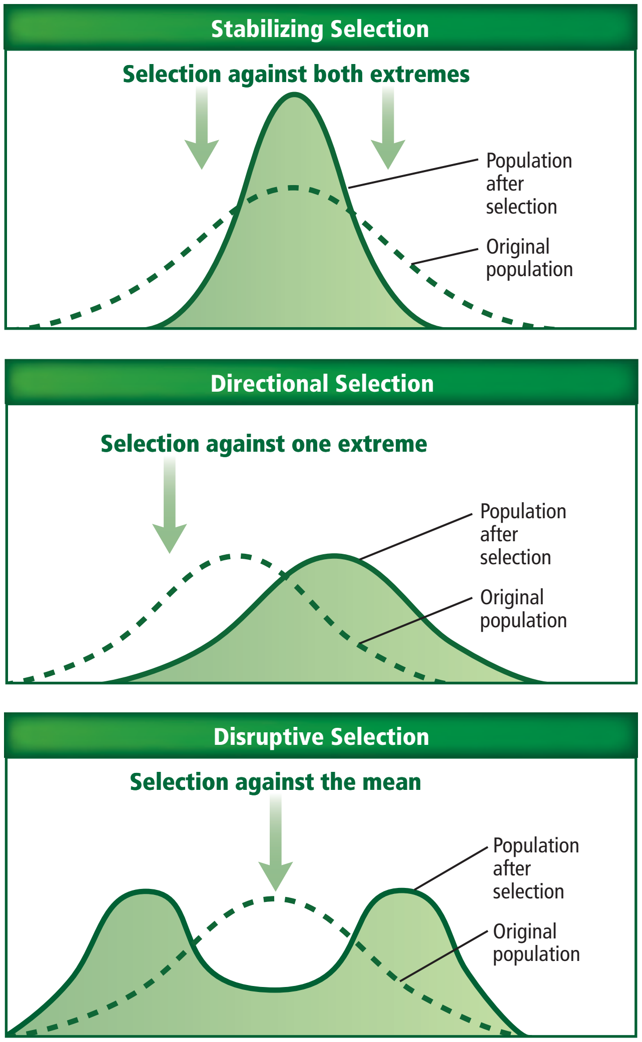


Figure 15 The map shows the present range of cheetahs in Africa. It is believed that cheetahs had a much larger population until a bottleneck occurred.

Apply Concepts ***What effect has the bottleneck had on the reproductive rate of cheetahs?***

Review **Personal Tutor**

■ **Figure 16** Natural selection can alter allele frequencies of a population in three ways. The bell-shaped curve shown as a dotted line in each graph indicates the trait's original variation in a population. The solid line indicates the outcome of each type of selection pressure.



Gene flow A population in genetic equilibrium experiences no gene flow. It is a closed system, with no new genes entering the population and no genes leaving the population. In reality, few populations are isolated. The random movement of individuals between populations, or migration, increases genetic variation within a population and reduces differences between populations.

Nonrandom mating Rarely is mating completely random in a population. Usually, organisms mate with individuals in close proximity. This promotes inbreeding and could lead to a change in allelic proportions favoring individuals that are homozygous for particular traits.

Mutation Recall that a mutation is a random change in genetic material. The cumulative effect of mutations in a population might cause a change in allelic frequencies and thus violate genetic equilibrium. Although many mutations cause harm or are lethal, occasionally a mutation provides an advantage to an organism. This mutation will then be selected for and become more common in subsequent generations. In this way, mutations provide the raw material upon which natural selection works.

Reading Check **Summarize** how mutation violates the Hardy-Weinberg principle.

Natural selection The Hardy-Weinberg principle requires that all individuals in a population be equally adapted to their environment and thus contribute equally to the next generation. As you have learned, this rarely happens. Natural selection acts to select the individuals that are best adapted for survival and reproduction. Natural selection acts on an organism's phenotype and changes allelic frequencies. **Figure 16** shows three main ways in which natural selection alters phenotypes: through stabilizing selection, directional selection, and disruptive selection. A fourth type of selection, sexual selection, also is considered a type of natural selection.

Stabilizing selection The most common form of natural selection is **stabilizing selection.** It operates to eliminate extreme expressions of a trait when the average expression leads to higher fitness. For example, human babies born with below-normal and above-normal birth weights have lower chances of survival than babies born with average weights. Therefore, birth weight varies little in human populations.

Directional selection If an extreme version of a trait makes an organism more fit, **directional selection** might occur. This form of selection increases the expression of the extreme versions of a trait in a population. One example is the evolution of moths in industrial England. The peppered moth has two color forms, or morphs, as shown in **Figure 17.** Until the mid-1850s, nearly all peppered moths in England had light-colored bodies and wings. Beginning around 1850, however, dark moths began appearing. By the early 1900s, nearly all peppered moths were dark. Why? Industrial pollution favored the dark-colored moths at the expense of the light-colored moths. The darker the moth, the more it matched the sooty background of its tree habitat, and the harder it was for predators to see. Thus, more dark moths survived, adding more genes for dark color to the population. This conclusion was reinforced in the mid-1900s, when the passage of air pollution laws led to the resurgence of light-colored moths. This phenomenon is called industrial melanism.

Directional selection also can be seen in Galápagos finches. For three decades in the latter part of the twentieth century, Peter and Rosemary Grant studied populations of these finches. The Grants found that during drought years, food supplies dwindled and the birds had to eat the hard seeds that they normally ignored. Birds with the largest beaks were more successful in cracking the tough seed coatings than were birds with smaller beaks. As a result, over the duration of the drought, birds with larger beaks came to dominate the population. In rainy years, however, the directional trend was reversed, and the population's average beak size decreased.

Figure 17 The peppered moth exists in two forms: light-colored and dark-colored.
Infer *how natural selection might have caused a change in the frequencies of the two forms.*

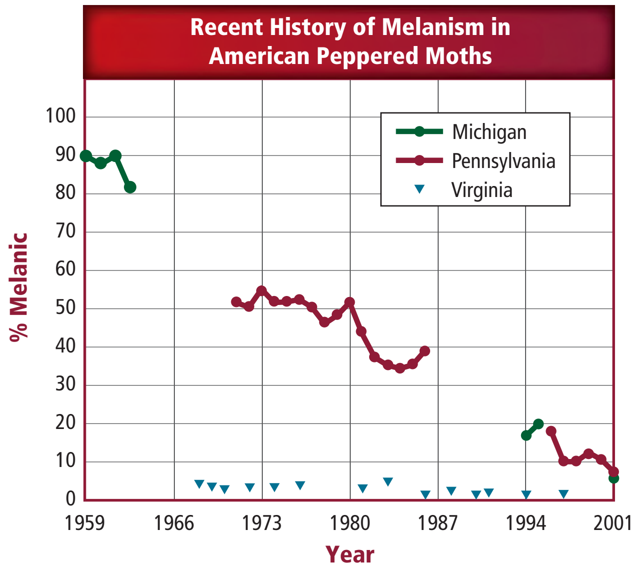
DATA ANALYSIS LAB 2

Based on Real Data*

Interpret the Graph

How does pollution affect melanism in moths? The changing frequencies of light-colored and dark-colored moths have been studied for decades in the United States. The percentage of the melanic, or dark, form of the moth was low prior to the Industrial Revolution. It increased until it made up nearly the entire population in the early 1900s. After antipollution laws were passed, the percentage of melanic moths declined, as shown in the graph.

Data and Observations



Think Critically

1. **Interpret** the percent decrease in Pennsylvania melanic moth population.
2. **Hypothesize** why the percentage of melanic moths might have remained at a relatively low level in Virginia.

*Data obtained from: Grant, B. S. and L. L. Wiseman. 2002. Recent history of melanism in American peppered moths. *Journal of Heredity* 93: 86-90.

■ **Figure 18** Northern water snakes have two different color patterns, depending on their habitats. Intermediate color patterns would make them more visible to predators.

Disruptive selection Another type of natural selection, **disruptive selection,** is a process that splits a population into two groups. It tends to remove individuals with average traits but retain individuals expressing extreme traits at both ends of a continuum. Northern water snakes, illustrated in **Figure 18,** are an example. Snakes living on the mainland shores inhabit grasslands and have mottled brown skin. Snakes inhabiting rocky island shores have gray skin. Each is adapted to its particular environment. A snake with intermediate coloring would be disadvantaged because it would be more visible to predators.

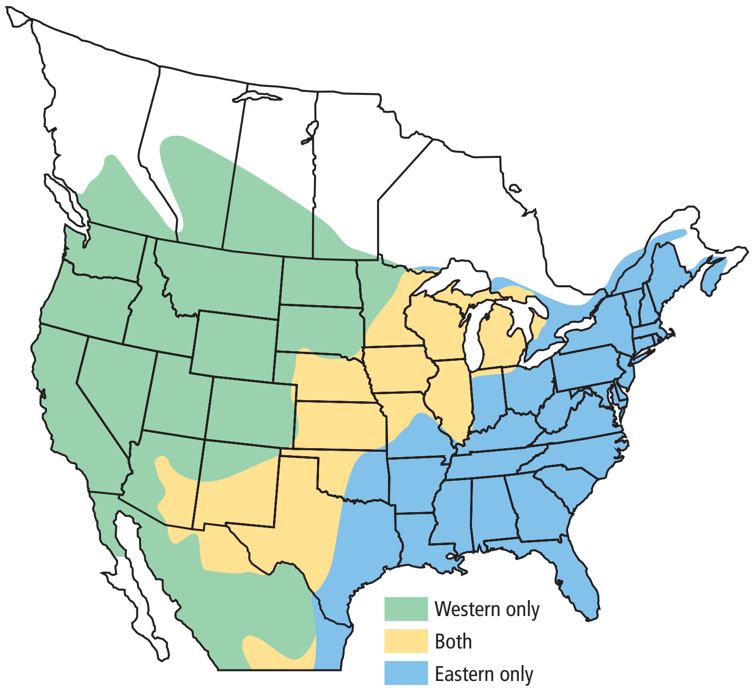
Inquiry **Launch Lab**

Review **Based on what you have learned about adaptation, how would you now answer the analysis questions?**

Sexual selection Another type of natural selection, in which change in frequency of a trait is based on the ability to attract a mate is called **sexual selection.** This type of selection often operates in populations in which males and females differ significantly in appearance. Usually in these populations, males are the largest and most colorful of the group. The bigger the tail of a male peacock, as shown in **Figure 19,** the more attractive the bird is to females. Males also evolve threatening characteristics that intimidate other males; this is common in species, such as elk and deer, where the male keeps a harem of females.

Darwin wondered why some qualities of sexual attractiveness appeared to be the opposite of qualities that might enhance survival. For example, the peacock's tail, while attracting females, is large and cumbersome, and it might make the peacock a more likely target for predators. Although some modern scientists think that sexual selection is not a form of natural selection, others think that sexual selection follows the same general principle: brighter colors and bigger bodies enhance reproductive success, whatever the chances are for long-term survival.

■ **Figure 19** Peacocks that have the largest tails tend to attract more peahens. The frequency of this trait increases because of sexual selection.



■ **Figure 20** The map shows the overlapping ranges of the Eastern meadowlark and Western meadowlark. While the two are similar in appearance, their songs separate them behaviorally.
Infer ***how different songs prevent the meadowlarks from breeding.***

Reproductive Isolation

Mechanisms of evolution—genetic drift, gene flow, nonrandom mating, mutation, and natural selection—violate the Hardy-Weinberg principle. To what extent each mechanism contributes to the origin of new species is a major topic of debate in evolutionary science today. Most scientists define speciation as the process whereby some members of a sexually reproducing population change so much that they can no longer produce fertile offspring with members of the original population. Two types of reproductive isolating mechanisms prevent gene flow among populations. **Prezygotic isolating mechanisms** operate before fertilization occurs. **Postzygotic isolating mechanisms** operate after fertilization has occurred to ensure that the resulting hybrid remains infertile.

Prezygotic isolation Prezygotic isolating mechanisms prevent reproduction by making fertilization unlikely. These mechanisms prevent genotypes from entering a population's gene pool through geographic, ecological, behavioral, or other differences. For example, the Eastern meadowlark and the Western meadowlark, pictured in **Figure 20,** have overlapping ranges and are similar in appearance. These two species, however, use different mating songs and do not interbreed. Time is another factor in maintaining a reproductive barrier. Closely related species of fireflies mate at different times of night, just as different species of trout live in the same stream but breed at different times of the year.

Postzygotic isolation When fertilization has occurred but a hybrid offspring cannot develop or reproduce, postzygotic isolation has occurred. Postzygotic isolating mechanisms prevent offspring survival or reproduction. A lion and a tiger are considered separate species because even though they can mate, the offspring—a liger, shown in **Figure 21**—is sterile.

? Inquiry **Virtual Lab**

■ **Figure 21** The offspring of a male lion and a female tiger is a liger. Ligers are sterile.

Speciation

For speciation to occur, a population must diverge and then be reproductively isolated. Biologists usually recognize two types of speciation: allopatric and sympatric.

Allopatric speciation In **allopatric speciation,** a physical barrier divides one population into two or more populations. The separate populations eventually will contain organisms that, if enough time has passed, will no longer be able to breed successfully with one another. Most scientists think that allopatric speciation is the most common form of speciation. Small subpopulations isolated from the main population have a better chance of diverging than those living within it. This was the conclusion of biologist Ernst Mayr, who argued as early as the 1940s that geographic isolation was not only important but also was required for speciation.

Geographic barriers can include mountain ranges, channels between islands, wide rivers, and lava flows. The Grand Canyon, pictured in **Figure 22,** is an example of a geographic barrier. The Kaibab squirrel is found on the canyon's north rim, while the Abert squirrel lives on the south rim. Scientists think that the two types of squirrels diverged from an ancestral species and today are reproductively isolated by the width of the canyon. While these animals officially belong to the same species, they demonstrate distinct differences and, in time, they might diverge enough to be classified as separate species.

Sympatric speciation In **sympatric speciation,** a species evolves into a new species without a physical barrier. The ancestor species and the new species live side-by-side during the speciation process. Evidence of sympatric evolution can be seen in several insect species, including apple maggot flies, which appear to be diverging based on the type of fruit they eat. Scientists think that sympatric speciation happens fairly frequently in plants, especially through polyploidy. Recall that polyploidy is a mutation that increases a plant's chromosome number. As a result, the plant is no longer able to interbreed with the main population.

VOCABULARY

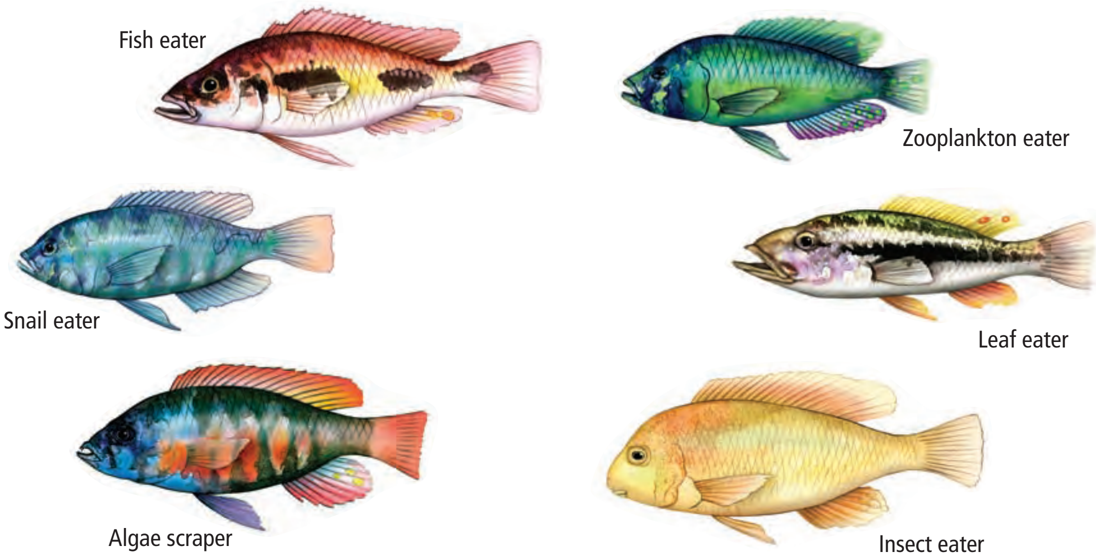
ACADEMIC VOCABULARY

Isolation
the condition of being separated from others
After infection, a patient is kept in isolation from other patients to prevent the infection from spreading.

Figure 22 The Grand Canyon is a geographic barrier separating the Abert and Kaibab squirrels.

Abert squirrel

Kaibab squirrel



■ **Figure 23** More than 300 species of cichlid fishes once lived in Lake Victoria. Their adaptive radiation is remarkable because it is thought to have occurred in less than 14,000 years.

Patterns of Evolution

Many details of the speciation process remain unresolved. Relative to the human life span, speciation is a long process, and first-hand accounts of speciation are expected to be rare. However, evidence of speciation is visible in patterns of evolution.

Adaptive radiation More than 300 species of cichlid fish, six of which are illustrated in **Figure 23,** once lived in Africa's Lake Victoria. Data show that these species diverged from a single ancestor within the last 14,000 years. This is a dramatic example of a type of speciation called **adaptive radiation.** Adaptive radiation, also called divergent evolution, can occur in a relatively short time when one species gives rise to many species in response to the creation of a new habitat or another ecological opportunity. Likely, a combination of factors caused the explosive radiation of the cichlids, including the appearance of a unique double jaw, which allowed these fish to exploit various food sources. Adaptive radiation often follows large-scale extinctions. Adaptive radiation of mammals at the beginning of the Cenozoic era following the extinction of dinosaurs likely produced the diversity of mammals visible today.

Coevolution Many species evolve in close relationship with other species. The relationship might be so close that the evolution of one species affects the evolution of other species. This is called coevolution. Mutualism is one form of coevolution. Mutualism occurs when two species benefit each other. For example, comet orchids and the moths that pollinate them have coevolved an intimate dependency: the foot-long flowers of this plant perfectly match the foot-long tongue of the moth, shown in **Figure 24.**

In another form of coevolution, one species can evolve a parasitic dependency on another species. This type of relationship is often called a coevolutionary arms race. The classic example is a plant and an insect pathogen that is dependent on the plant for food. The plant population evolves a chemical defense against the insect population. The insects, in turn, evolve the biochemistry to resist the defense. The plant then steps up the race by evolving new defenses, the insect escalates its response, and the race goes on. Complex coevolutionary relationships like these might reflect thousands of years of evolutionary interaction.

■ **Figure 24** By coevolving, this moth and the comet orchid it pollinates exist in a mutualistic relationship.

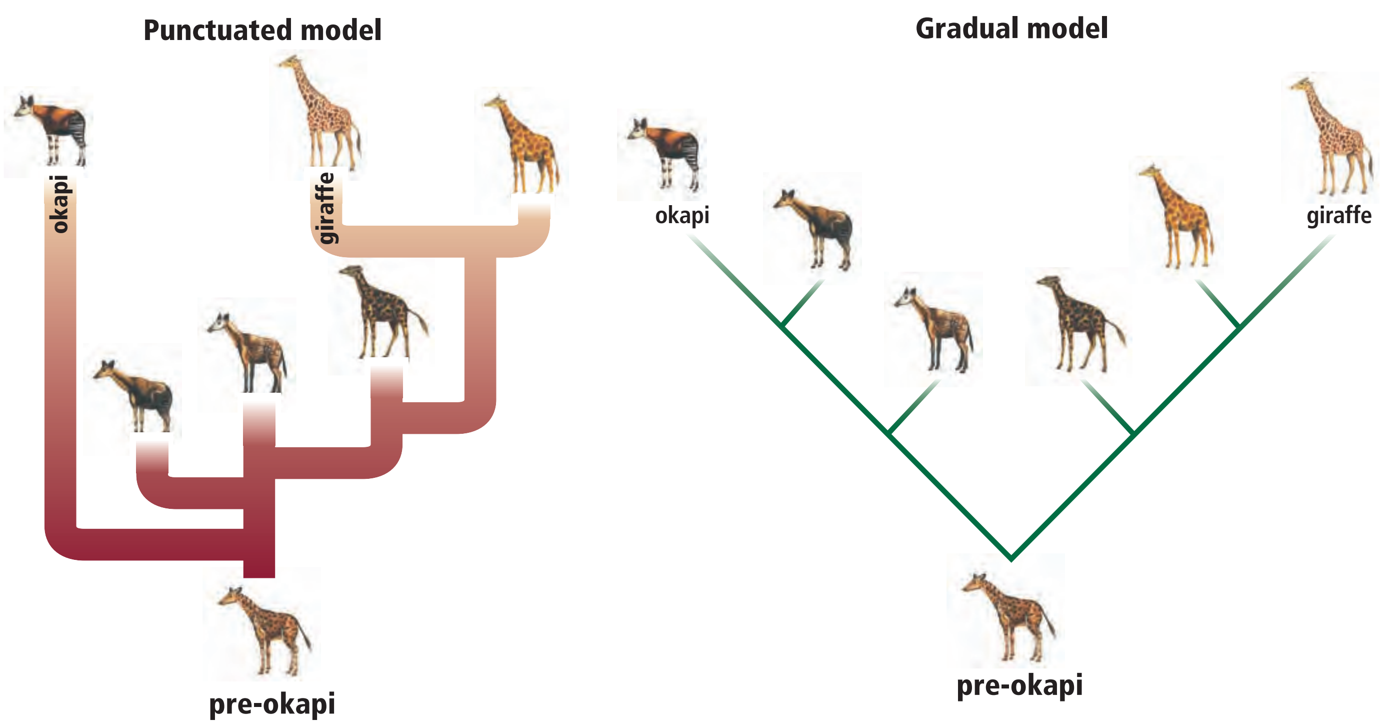
Table 4 **Convergent Evolution**

Concepts in Motion
Interactive Table

Niche	Placental Mammals	Australian Marsupials
Burrower	 **Mole**	 **Marsupial mole**
Anteater	 **Lesser anteater**	 **Numbat (anteater)**
Mouse	 **Mouse**	 **Marsupial mouse**
Glider	 **Flying squirrel**	 **Flying phalanger**
Wolf	 **Wolf**	 **Tasmanian wolf**

Convergent evolution Sometimes unrelated species evolve similar traits even though they live in different parts of the world. This is called convergent evolution. Convergent evolution occurs in environments that are geographically far apart but have similar ecology and climate. The mara and rabbit discussed in Section 2 provide an example of convergent evolution. The mara and the rabbit are unrelated, but because they inhabit similar niches, they have evolved similarities in morphology, physiology, and behavior. **Table 4** shows examples of convergent evolution between Australian marsupials and the placental mammals on other continents.

Rate of speciation Evolution is a dynamic process. In some cases, as in a coevolutionary arms race, traits might change rapidly. In other cases, traits might remain unchanged for millions of years. Most scientists think that evolution proceeds in small, gradual steps. This is a theory called **gradualism.** A great deal of evidence favors this theory. However, the fossil record contains instances of abrupt transitions. For example, certain species of fossil snails looked the same for millions of years, and then the shell shape changed dramatically in only a few thousand years. The theory of **punctuated equilibrium** attempts to explain such abrupt transitions in the fossil record. According to this theory, rapid spurts of genetic change cause species to diverge quickly; these periods punctuate much longer periods when the species exhibit little change.



■ **Figure 25** Gradualism and punctuated equilibrium are two competing models describing the tempo of evolution.

Concepts in Motion

Animation

The two theories for the tempo of evolution are illustrated in **Figure 25.** The tempo of evolution is an active area of research in evolutionary theory today. Does most evolution occur gradually or in short bursts? Fossils can show only morphological structures. Changes in internal anatomy and function go unnoticed. How, then, does one examine the past for evidence?

The question of the tempo of evolution is an excellent illustration of how science works. Solving this puzzle requires insights from a variety of disciplines using a variety of methods. Like many areas of scientific endeavor, evolution offers a complex collection of evidence, and it does not yield easily to simple analysis.

Section 3 Assessment

Section Summary

- The Hardy-Weinberg principle describes the conditions within which evolution does not occur.
- Speciation often begins in small, isolated populations.
- Selection can operate by favoring average or extreme traits.
- Punctuated equilibrium and gradualism are two models that explain the tempo of evolution.

Understand Main Ideas

1. MAIN Idea **Describe** one new mechanism of evolution that scientists learned after Darwin's book was published.
2. **Identify** three of the conditions of the Hardy-Weinberg principle.
3. **Discuss** factors that can lead to speciation.
4. **Indicate** which pattern of evolution is shown by the many species of finches on the Galápagos Islands.

Think Critically

5. **Design an Experiment** Biologists discovered two populations of frogs separated by the Amazon River. What experiment could be designed to test whether the two populations are one species or two?

MATH in Biology

6. What type of mathematical results would you expect from the experiment you designed above if the two populations diverged only recently?

Assessment Online Quiz

BioDiscoveries

Madagascar: Island of Biodiversity

Move over, Galapagos Islands—another island is emerging as a prime example of biodiversity. Thousands of species of rare plants and animals live on Madagascar, including lemurs, frogs, geckos, chameleons, butterflies, and orchids. Scientists estimate that 80 percent of Madagascar's plants and animals are endemic, that is, they do not live anywhere else in the world. A scientific study published in 2009 reported that up to 221 new species of frogs had been found on Madagascar, which nearly doubles the number of amphibians found on the island so far.

Giant leaf-tailed gecko One of the reptile species is the giant leaf-tailed gecko (*Uroplatus fimbriatus*). As the name indicates, the tails of these nocturnal geckos are shaped like leaves, which helps camouflage them from predators. If a predator grabs a gecko's tail, it breaks off so the gecko can escape. The tail will grow back, but it might have a different appearance. These geckos' colorings also help them blend with their rainforest home, as they have some ability to change color to better blend with the trees.

Giant leaf-tailed geckos have other fascinating characteristics. They do not have eyelids, so they use their tongues to lick their eyeballs clean. Their toes are equipped with tiny bristles that allow them to run up smooth, vertical surfaces. And when these geckos are startled, they lift their heads and tails, open their mouths, and bark or scream.

Pygmy mouse lemur Lemurs are a group of primates that are endemic to Madagascar. There are 88 species of lemurs on the island, and the smallest is the pygmy mouse lemur (*Microcebus myoxinus*), the tiniest primate in the world.

The gaint leaf-tailed gecko (above) and the pygmy mouse lemur (right) are both species that live only on Madagascar.

The pygmy mouse lemur is just 6 centimeters long with a 13 centimeter tail. It weighs only 30 grams. These nocturnal animals live mainly in trees and eat insects and fruit. The pygmy mouse lemur has large ears that it uses to listen for predators.

New species are discovered on Madagascar every year. As larger numbers of scientists turn their attention to this island, its status as one of the most important areas of biodiversity on the planet is likely to grow.

PUBLIC SPEAKING AND SOCIAL NETWORKING

Scavenger Hunt Your teacher will divide your class into several groups, giving each group a list of five species that are endemic to Madagascar. With your group, research the species. Present your findings to the class.

WebQuest

BIOLAB

CAN SCIENTISTS MODEL NATURAL SELECTION?

Background: **Natural selection is the mechanism that Darwin proposed to explain evolution. Through natural selection, traits that allow individuals to have the most offspring in a given environment tend to increase in the population over time.**

Question: *How can natural selection be modeled in a laboratory setting?*

Materials

small, medium, and large beads
forceps
short-nosed pliers
tray or pan
stopwatch

Safety Precautions

Procedure

1. Read and complete the lab safety form.
2. Divide into groups of three. One student will use forceps to represent one adult member of a predator population, one will use pliers to represent another adult member of the predator population, and the third will keep time and score.
3. Mix prey items (beads) on a tray or pan.
4. In 20 seconds, try to pick up all possible beads using forceps or pliers.
5. After 20 seconds, assign three points for each large bead, two points for each medium bead, and one point for each small bead.
6. Add up the points and use the following rules: survival requires 18 points, and the ability to produce a new offspring requires an additional 10 points.
7. Determine the number of survivors and the number of offspring.
8. Repeat the procedure 10 times and combine your data with the other groups.

Analyze and Conclude

1. **Calculate** Combining all of the trials of all of the groups, determine the percentage of forceps and pliers that survived.
2. **Evaluate** Using data from the entire class, determine the total number of offspring produced by the forceps adult and the plier adult.
3. **Summarize** The original population was divided evenly between the forceps adult and the plier adult. If all of the adults left, what would be the new population ratio? Use the results from the entire class.
4. **Infer** Given the survival and reproduction data, predict what will happen to the two organisms in the study. Which adult—the forceps or the pliers—is better adapted to produce more offspring?
5. **Conclude** Using the principles of natural selection, how is this population changing?

APPLY YOUR SKILL

Make Inferences Given the results of the experiment, how will the prey populations (beads) change as the predator population changes? Explain your inference.

Chapter 15 Study Guide

THEME FOCUS Scientific Inquiry Extensive collections of rocks, fossils, plants, and animals, as well as the study of selective breeding contributed to the development of the theory of evolution.

BIG Idea The theory of evolution is supported by natural selection and explains the diversity of life.

Section 1 Darwin's Theory of Evolution by Natural Selection

artificial selection (p. 419)
natural selection (p. 420)
evolution (p. 422)

MAIN Idea Charles Darwin developed a theory of evolution based on natural selection.

- Darwin drew from his observations on the HMS *Beagle* and later studies to develop his theory of evolution by natural selection.
- Natural selection is based on ideas of excess reproduction, variation, inheritance, and advantages of certain traits in certain environments.
- Darwin reasoned that the process of natural selection eventually could result in the appearance of new species.

Section 2 Evidence of Evolution

derived trait (p. 424)
ancestral trait (p. 424)
homologous structure (p. 424)
vestigial structure (p. 425)
analogous structure (p. 426)
embryo (p. 426)
biogeography (p. 428)
fitness (p. 428)
camouflage (p. 428)
mimicry (p. 429)

MAIN Idea Multiple lines of evidence support the theory of evolution.

- Fossils provide strong direct evidence to support evolution.
- Homologous and vestigial structures indicate shared ancestry.
- Examples of embryological and biochemical traits provide insight into the evolution of species.
- Biogeography can explain why certain species live in certain locations.
- Natural selection gives rise to features that increase reproductive success.

Section 3 Shaping Evolutionary Theory

Hardy-Weinberg principle (p. 431)
genetic drift (p. 433)
founder effect (p. 433)
bottleneck (p. 433)
stabilizing selection (p. 434)
directional selection (p. 435)
disruptive selection (p. 436)
sexual selection (p. 436)
prezygotic isolating mechanism (p. 437)
postzygotic isolating mechanism (p. 437)
allopatric speciation (p. 438)
sympatric speciation (p. 438)
adaptive radiation (p. 439)
gradualism (p. 440)
punctuated equilibrium (p. 440)

MAIN Idea The theory of evolution continues to be refined as scientists learn new information.

- The Hardy-Weinberg principle describes the conditions within which evolution does not occur.
- Speciation often begins in small, isolated populations.
- Selection can operate by favoring average or extreme traits.
- Punctuated equilibrium and gradualism are two models that explain the tempo of evolution.

Review Vocabulary eGames

Chapter 15 Assessment

Section 1

Vocabulary Review

Replace the underlined portions of the sentences below with words from the Study Guide to make each sentence correct.

1. Natural selection is a mechanism for species change over time.
2. Selective breeding was used to produce purebred Chihuahuas and cocker spaniels.
3. Differential survival by members of a population with favorable adaptations is a mechanism for a theory developed by Charles Darwin.

Understand Main Ideas

4. Which best describes the prevailing view about the age of Earth and evolution before Darwin's voyage on the HMS *Beagle?*
   A. Earth and life are recent and have remained unchanged.
   B. Species evolved rapidly during the first six thousand to a few hundred thousand years.
   C. Earth is billions of years old, but species have not evolved.
   D. Species have evolved on Earth for billions of years.

Use the photo below to answer question 5.

5. Which statement about the tortoise above would be part of an explanation for tortoise evolution based on natural selection?
   A. All tortoises look like the above tortoise.
   B. Tortoises with domed shells have more young than tortoises with flat shells.
   C. All the tortoises born on the island survive.
   D. The tortoise shell looks nothing like the shell of either parent.

Constructed Response

6. MAIN Idea Summarize Darwin's theory of evolution by using an example.
7. **Short Answer** How is artificial selection similar to natural selection?

Think Critically

8. **Sequence** Sequence events leading to evolution by natural selection.
9. **Recognize Cause and Effect** What is the likely evolutionary effect on a species of an increase in global temperatures over time?

Section 2

Vocabulary Review

The sentences below include terms that have been used incorrectly. Make the sentences true by replacing the italicized word with a vocabulary term from the Study Guide page.

10. Anatomical parts that have a reduced function in an organism are *analogous structures.*
11. *Biogeography* is a measure of the relative contribution an individual trait makes to the next generation.
12. *Camouflage* occurs when two or more species evolve adaptations to resemble each other.

Understand Main Ideas

Use the photos below to answer question 13.

13. These organisms have similar features that are considered what kind of structures?
   A. vestigial
   B. homologous
   C. analogous
   D. comparative

Assessment Online Test Practice

Use the photo below to answer question 14.

14. The photo of the bird above shows what kind of morphological adaptation?
- **A.** vestigial organ
- **B.** camouflage
- **C.** mimicry
- **D.** analogous structure

15. Which is not an example of a morphological adaptation?
- **A.** Cytochrome *c* is similar in monkeys and humans.
- **B.** Butterflies evolve similar color patterns.
- **C.** A harmless species of snake resembles a harmful species.
- **D.** Young birds have adaptations for blending into the environment.

16. Industrial melanism could be considered a special case of which of the following?
- **A.** embryological adaptation
- **B.** mimicry
- **C.** physiological adaptation
- **D.** structural adaptation

17. Which sets of structures are homologous?
- **A.** a butterfly's wing and a bat's wing
- **B.** a moth's eyes and a cow's eyes
- **C.** a beetle's leg and a horse's leg
- **D.** a whale's pectoral fin and a bird's wing

Constructed Response

18. Short Answer Describe how cytochrome *c* provides evidence of evolution.

19. Short Answer What can be concluded from the fact that many insects are resistant to certain pesticides?

20. MAIN Idea Why are fossils considered to provide the strongest evidence supporting evolution?

Think Critically

21. **THEME FOCUS Scientific Inquiry** How could you design an experiment to show that a species of small fish has the ability to evolve a camouflage color pattern?

22. **CAREERS IN BIOLOGY** An evolutionary biologist is studying several species of closely related lizards found on Cuba and surrounding islands. Each species occupies a somewhat different niche, but in some ways they all look similar to the green anole lizard found in Florida. Suggest the pattern of lizard evolution.

Section 3

Vocabulary Review

Choose the vocabulary term from the Study Guide page that best matches each of the following descriptions.

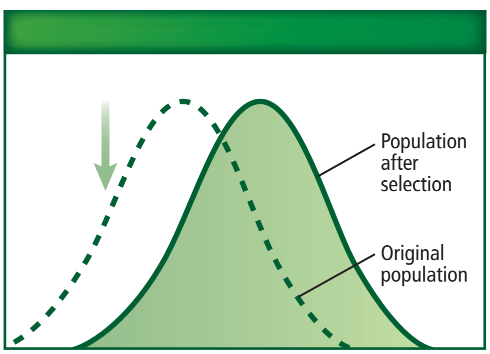
23. one species evolves over millions of years to become two different but closely related species

24. a species evolves into a new species without a physical barrier

25. the random changes in gene frequency found in small populations

Understand Main Ideas

Use the figure below to answer question 26.



26. The graph above best represents which kind of selection?
- **A.** directional
- **B.** disruptive
- **C.** sexual
- **D.** stabilizing

Assessment Online Test Practice

Use the photo below to answer question 27.

27. The plant in the above illustration looks like a cactus but is classified in a completely separate group of plants. This would be an example of which mechanism?

A. adaptive radiation
B disruptive selection
C. convergent evolution
D. punctuated equilibrium

Constructed Response

28. Open Ended Discuss why the Hardy-Weinberg principle is often violated in real populations.

29. Open Ended Sea stars eat clams by pulling apart the two halves of a clam's shell. Discuss how this could result in directional selection of clam muscle size.

30. Short Answer Compare and contrast genetic drift and natural selection as mechanisms of evolution.

Think Critically

31. Make and Use Graphs Draw a graph that would illustrate a population that has a wide variation of color from light to dark brown. Then draw on the same graph what that population would look like after several years of stabilizing selection. Label your graph.

32. MAIN Idea What would you conclude about the evolutionary process that produces two unrelated species that share similar niches on different continents?

Summative Assessment

33. BIG Idea Imagine that there has been a major climate shift. Most of Earth is covered in ice, and the equatorial regions are temperate. Describe how plant and animal distribution might change over time through natural selection. Also, describe new available niches that could develop and the types of organisms that may fill them.

34. WRITING in Biology Imagine that you are Charles Darwin and write a letter to your father detailing your observations aboard the Beagle.

35. WRITING in Biology Write a paragraph that explains why a genetic bottleneck can be an important evolutionary factor for a species.

36. Choose three lines of evidence that support evolution. Give an example of each.

DBQ Document-Based Questions

Darwin,Charles. 1859. *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life.*

Naturalists continually refer to external conditions, such as climate, food, etc., as the only possible cause of variation. In one very limited sense, as we shall hereafter see, this may be true; but it is preposterous to attribute to mere external conditions, the structure, for instance, of the woodpecker, with its feet, tail, beak, and tongue, so admirably adapted to catch insects under the bark of trees.

37. In Darwin's time, most naturalists considered only external conditions as causes of variation. What nonexternal mechanism did Darwin propose as a cause of variation?

38. How would modern scientists explain the nonexternal mechanisms that Darwin proposed?

39. Consider Darwin's example of the woodpecker. Explain the role that natural selection has producing a bird species with a woodpeckerlike beak.

Assessment Online Test Practice

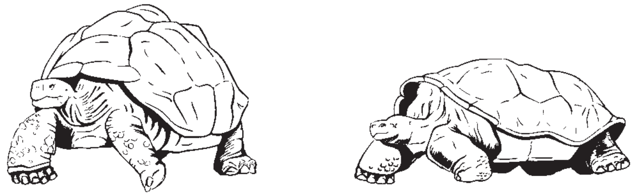
Standardized Test Practice

Cumulative

Multiple Choice

1. Which experimental setup did Francesco Redi use to test the idea of spontaneous generation?
A. a flask filled with all the chemicals present on early Earth
B. mice sealed in jars with lit candles and jars with unlit candles
C. rotten meat in covered jars and uncovered jars
D. special flasks that were filled with broth

Use the illustration below of tortoises on two different islands to answer questions 2 and 3.



Large Island **Small Island**

2. The above illustrates which principle of natural selection?
A. inheritance
B. variation
C. differential reproduction
D. overproduction of offspring

3. Tortoises that have shells with higher openings can eat taller plants. Others can only reach vegetation close to the ground. Judging from the differences in the tortoises' shells, what kind of vegetation would you expect to find on the large and small islands?
A. Both islands have a dense ground cover of low-growing plants.
B. Both islands have similar plants, but vegetation is more spread out on the large island.
C. On the large island, the land is mostly dry, and only tall trees grow.
D. The small island is less grassy, and plants grow with their leaves farther above ground.

4. A dinosaur footprint in rocks would be which kind of fossil?
A. cast fossil
B. petrified fossil
C. replacement fossil
D. trace fossil

5. Which concept is essential for the process of DNA fingerprinting?
A. location of genes for related traits on different chromosomes
B. organization of human DNA into 46 chromosomes
C. provision by DNA of the codes for proteins in the body
D. uniqueness of each person's pattern of noncoding DNA

6. Chargaff's rules led to the understanding of which aspect of DNA structure?
A. base pairing
B. helix formation
C. alternation of deoxyribose and phosphate
D. placement of 3' and 5' carbons

Use the Punnett square below to answer question 7.

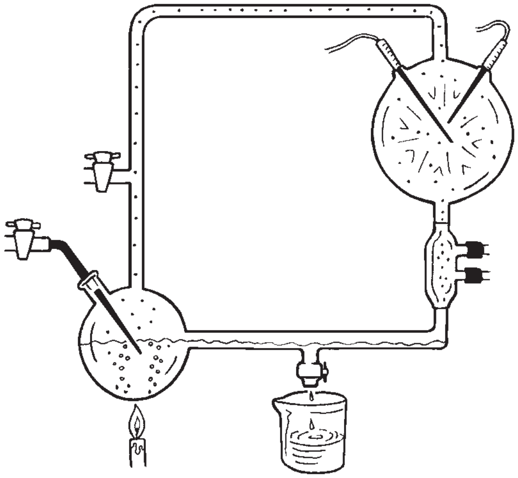
	B	?
b		
b		

7. A test cross, shown in the Punnett square above, is used to determine the genotype of an animal that is expressing a dominant gene (B) for a particular characteristic. If the animal is homozygous for the dominant trait, which percentage of its offspring will have the dominant gene?
A. 25%
B. 50%
C. 75%
D. 100%

8. What prevents the two strands of DNA from immediately coming back together after they unzip?
A. addition of binding proteins
B. connection of Okazaki fragments
C. parting of leading and lagging strands
D. use of multiple areas of replication

Short Answer

Use the diagram of Miller and Urey's experiment below to answer questions 9 and 10.



9. What are the possible consequences of a different mix of gases in the apparatus?

10. Some scientists think that lightning might not have been present on Earth in the past. What other energy sources might have caused these reactions?

11. Describe briefly how scientists could use a particular kind of bacteria to synthesize a specific protein.

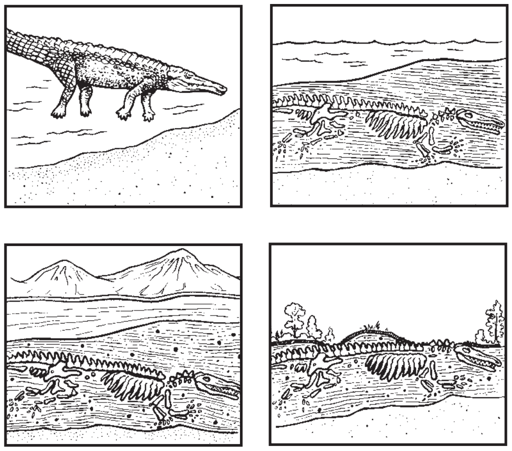
12. Predict two positive outcomes and two negative outcomes of using transgenic plants for agricultural purposes.

13. Explain the connection between excess reproduction and the concept of natural selection as formulated by Darwin.

14. How would a primitive cell benefit from a symbiotic relationship with a mitochondrion?

Extended Response

Use the diagram below to answer questions 15 and 16.



15. Describe the process illustrated in the figure.

16. Explain why a fossil is more likely to form in a wet environment than in a dry environment.

Essay Question

Scientists think that archaea living today are similar to ancient archaea. Many archaea today are found in places such as hot springs, deep-ocean hydrothermal vents, polar ice, and other extreme environments. The organisms living in these environments might be similar to organisms that existed in the distant past.

Using the information in the paragraph above, answer the following question in essay format.

17. Scientists also study organisms in extreme environments to help identify where life might exist on other planets. Why would understanding the origins of life on Earth help with discovering life on other planets?

NEED EXTRA HELP?																	
If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Review Section . . .	14.2	15.1, 15.3	15.1	14.1	12.1	13.1	10.2	12.2	14.2	14.2	13.2	13.2	15.1	14.2	14.1	14.1	14.2

CHAPTER 16

Primate Evolution

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- Inquiry
- WebQuest
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Launch Lab

What are the characteristics of primates?

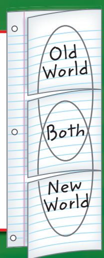
If you've been to the zoo or seen pictures of African wildlife, you have probably observed monkeys, chimpanzees, and gorillas. Maybe you've even seen pictures of lemurs. What makes these animals primates? What makes you a primate? In this lab, you will investigate the features that you share with these other primates.

For a lab worksheet, use your StudentWorks™ Plus Online.

Inquiry Launch Lab

FOLDABLES®

Make a three-tab book with the labels shown. Use it to organize your notes on monkeys.



THEME FOCUS Change

The changes that separated hominins from hominoids took place over 20–25 million years.

BIG Idea Evolutionary change in a group of small, tree-living mammals eventually led to a diversity of species that includes modern humans.

Section 1

Primates

Reading Preview

Essential Questions

- What are the characteristics of primates?
- What are the similarities and differences between major primate groups?
- How can the evolution of primates be traced?

Review Vocabulary

extinction: the disappearance of a species when the last of its members dies

New Vocabulary

opposable first digit
binocular vision
diurnal
nocturnal
arboreal
anthropoid
prehensile tail
hominin

g Multilingual eGlossary

■ **Figure 1** This squirrel monkey is using its opposable digits to hold its dinner—a lantern fly.
Infer ***other ways that a primate might use an opposable digit.***

MAIN Idea Primates share several behavioral and biological characteristics, which indicates that they evolved from a common ancestor.

Real-World Reading Link You can often tell that your aunts, uncles, or cousins are related to you. Perhaps they have the same color hair or similar features, or they are as tall as you are. Just as you can tell that you are related to your biological family, characteristics of primates show that they are also a related family.

Characteristics of Primates

Humans, apes, monkeys, and lemurs belong to a group of mammals called primates. Though primates are highly diverse, they share some general features. Some primates have a high level of manual dexterity, which is the ability to manipulate or grasp objects with their hands. They usually also have keen eyesight and long, highly movable arms. Compared to other animals, they have large brains. The primates with the largest brains, which includes humans, have the capacity to reason.

Manual dexterity Primates are distinguished by their flexible hands and feet. All primates typically have five digits on each hand and foot; as you know, humans have fingers and toes. Most have flat nails and sensitive areas on the ends of their digits. The first digits on most primates' hands are opposable, and the first digit on many primates' feet are opposable. An **opposable first digit,** either a thumb or a great toe, is set apart from the other digits. This digit can be brought across the palm or foot so that it touches or nearly touches the other digits. This action allows the primate to grasp an object in a powerful grip. Some primates also have lengthened first digits that provide added dexterity. **Figure 1** shows a monkey using its opposable thumbs to grasp its food.

Senses Though there are exceptions, primates rely more on vision and less on their sense of smell than other mammals do. Their eyes, protected by bony eye sockets, are on the front of their face. This creates overlapping fields of vision, often called **binocular vision.** Forward-looking eyes allow for a greater field of depth perception and enable primates to judge relative distance and movement of an object.

Most primates are **diurnal** (di YUR nul), which means they are active during the day. Because these primates are active in daylight, most also have color vision. Primates that are **nocturnal** (nahk TUR nul) are active at night. They see only in black and white. An increased sense of vision is generally accompanied by a decreased sense of smell. Nocturnal primates' snouts are smaller and their faces tend to be flattened, which increases the degree of binocular vision. Their teeth are reduced in size and usually are unspecialized, meaning that they are suitable for many different types of diets.

Locomotion Another characteristic of primates is their flexible bodies. Primates have limber shoulders and hips and primarily rely on hind limbs for locomotion. Most primates live in trees and have developed an extraordinary ability to move easily from branch to branch. When on the ground, all primates except humans walk on all four limbs. Many primates can walk upright for short distances, and many have a more upright posture compared to four-legged animals.

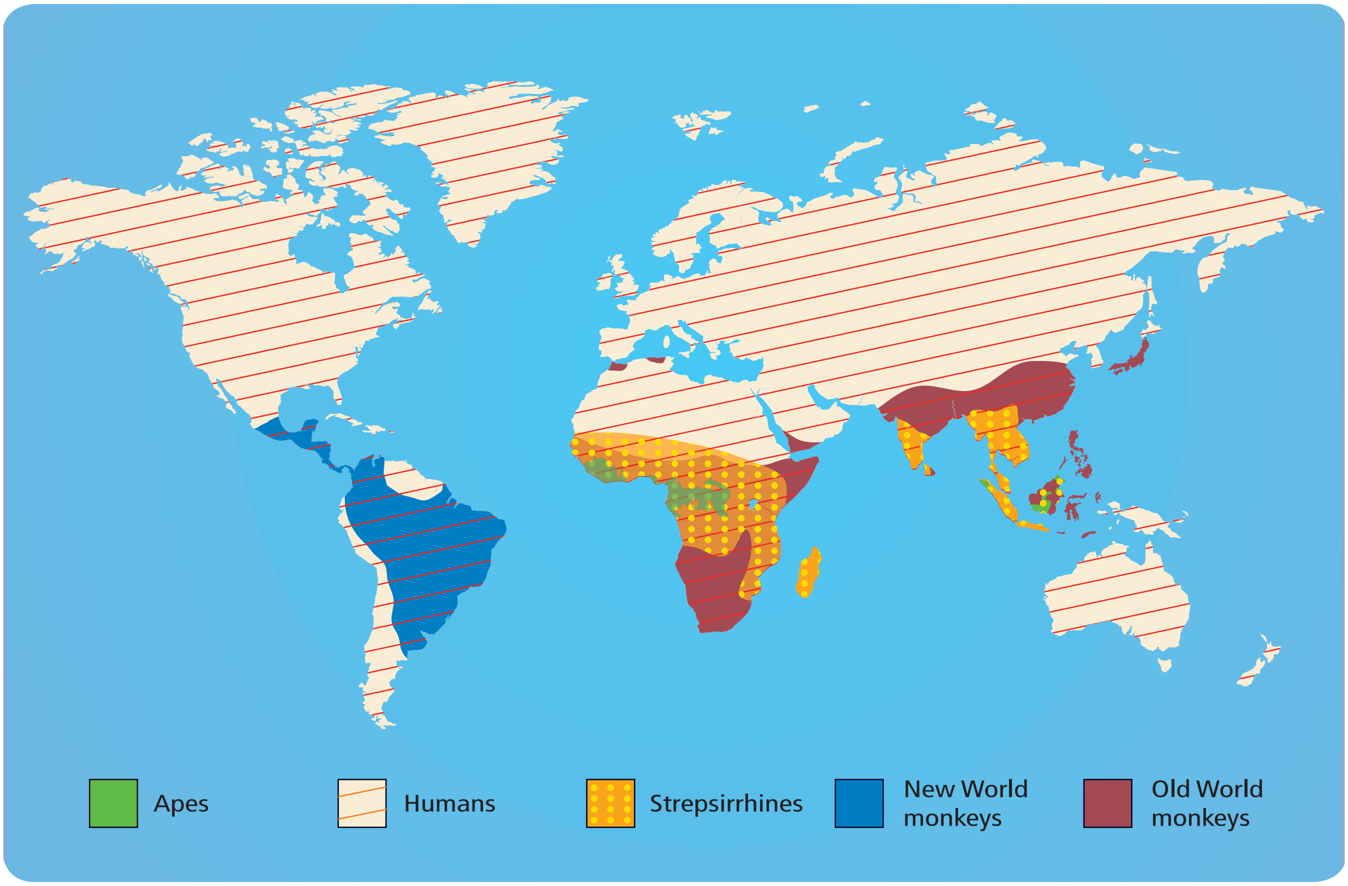
Complex brains and behaviors Primates tend to have large brains in relation to their body size. Their brains have fewer areas devoted to smell and more areas devoted to vision. They also tend to have larger areas devoted to memory and the coordination of arm and leg movement. Along with larger brains, many primates have problem-solving abilities and well-developed social behaviors, such as grooming and communicating. Most diurnal primates spend a great deal of time socializing by spending time grooming each other. In addition, many primates have complex ways of communicating to each other, which include a wide range of facial expressions.

Reproductive rate Most primates have fewer offspring than other animals. Usually, primates give birth to one offspring at a time. Compared to other mammals, pregnancy is long, and newborns are dependent on their mothers for an extended period of time. For many primates, this time period allows for the increased learning of complex social interactions. A low reproductive rate, the loss of tropical habitats, and human predation has threatened some primate populations. Many are endangered. **Figure 2** illustrates the tropical areas of the world, such as Africa and Southeast Asia, where primates live.

Inquiry **Launch Lab**

Review **Based on what you have read about primate characteristics, how would you now answer the analysis questions?**

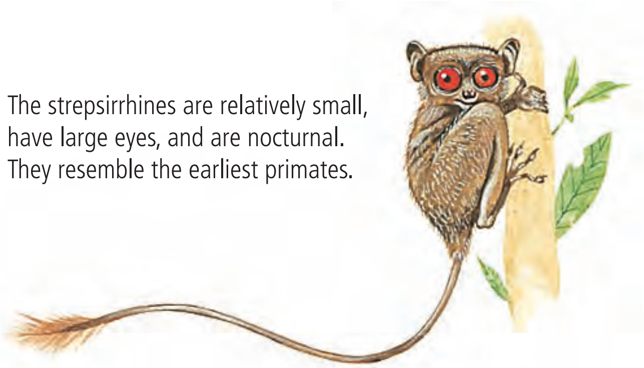
Figure 2 Nonhuman primates live in a broad area spanning most of the world's tropical regions. Use this map as you read about the different primates.



Visualizing Primates

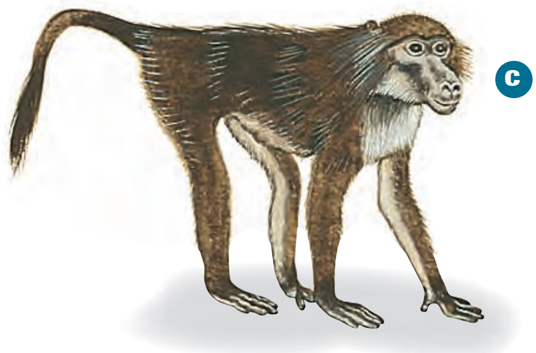
Figure 3

Primates are members of a highly diverse order of mammals. Most primates share common features such as binocular vision and opposable digits.

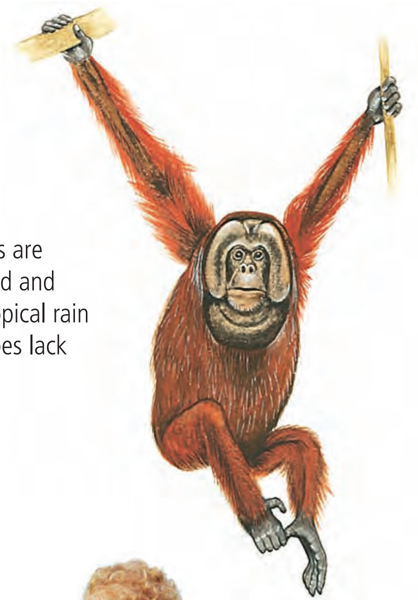


A The strepsirrhines are relatively small, have large eyes, and are nocturnal. They resemble the earliest primates.

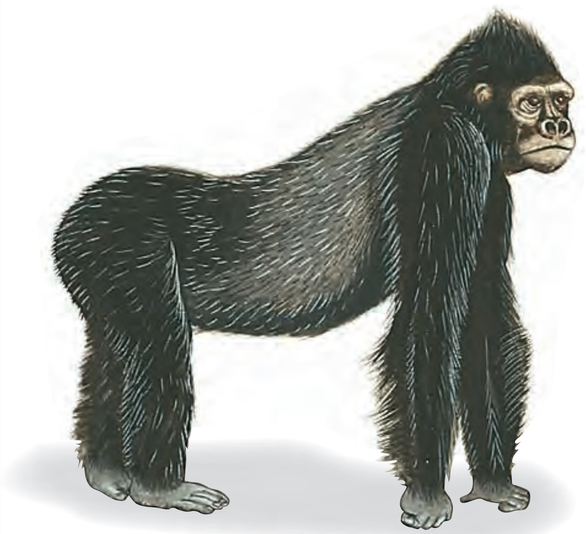
B New World monkeys are characterized by relatively long tails. Many have prehensile tails.



C Old World monkeys resemble New World monkeys but lack prehensile tails. Some have reduced tails.



D Asian apes are long-armed and inhabit tropical rain forests. Apes lack tails.



E African apes live in family groups or small bands and display complex social behavior.

F Humans, *Homo sapiens*, are the only living species in the hominin group. Hominins are unique because they possess the ability to walk for long distances on two legs.

Concepts in Motion **Animation**

Primate Groups

Primates are a large, diverse group of more than 200 living species. Examine **Figure 3** as you read about this diverse group. Most primates are **arboreal** (ar BOHR ee uhl), or tree-dwelling. Arboreal primates live in the world's tropical and subtropical forests. Primates that live on the ground are considered terrestrial primates.

Primates are classified into two subgroups based on characteristics of their noses, eyes, and teeth. The most basic subgroup is the strepsirrhines (STREP sihr ines) (also called "wet-nosed primates"), such as the lemur. The second subgroup consists of the haplorhines (HAP lohr ines), also called "dry-nosed primates." The haplorhines include the **anthropoids** (AN thruh poydz), a group of large-brained, diurnal monkeys and hominoids.

Reading Check **Differentiate** between strepsirrhines and haplorhines.

Strepsirrhines

Strepsirrhines can be identified by their large eyes and ears. However, they are the only primates that rely predominantly on smell for hunting and social interaction. Some members of this primate group can be found in tropical Africa and Asia. Most are found in Madagascar and nearby islands. As Madagascar drifted away from the African mainland, these animals evolved which left them reproductively isolated. This isolation resulted in their diversification. **Table 1** lists characteristics of some strepsirrhine groups.

VOCABULARY

WORD ORIGIN

Lemur
comes from Latin, meaning *spirit of the night*

Table 1 **Characteristics of Strepsirrhines** Concepts in Motion Interactive Table

Group	Lemurs	Aye-Ayes	Lorises	Galagos
Example				
Active Period	Large—diurnal Small—nocturnal	Nocturnal	Nocturnal	Mostly nocturnal
Range	Madagascar	Madagascar	Africa and Southeast Asia	Africa
Characteristics	• Vertical leaper • Uses long bushy tail for balance • Herbivores and omnivores	• Taps bark, listens, fishes out grubs with long third finger	• Small and slow climber, solitary • Lack tails • Some have toxic secretions	• Small and fast leaper • No opposable digit • Long tail

Figure 4 Lemurs vary in their size and color. Some lemurs, like this sifaka, spend time on the ground.

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Incorporate information from this section into your Foldable.

Figure 5 This spider monkey uses its prehensile tail as a fifth limb.

Most small lemurs are nocturnal and solitary. Only a few large species, such as the sifaka shown in **Figure 4,** are diurnal and social. The indri is unique because it does not have a tail, unlike most lemurs that use their bushy tails for balance as they jump from branch to branch. Lorises are similar to lemurs but are found primarily in India and Southeast Asia. Galagos (ga LAY gohs), also called bushbabies, are found only in Africa.

Haplorhines

The second group of primates is a much larger group. The haplorhines include tarsiers, monkeys, and apes. The apes, in turn, include gibbons, orangutans, gorillas, chimpanzees, and humans.

The tarsier is found only in Borneo and the Philippines. It is a small, nocturnal creature with large eyes. It has the ability to rotate its head 180 degrees like an owl. It lives in trees, where it climbs and leaps among the branches. The tarsier shares characteristics with both lemurs and monkeys. Scientists once classified it with the lemurs, but new evidence suggests that it is more closely related to anthropoids, which makes it part of the haplorhine group.

Anthropoids are generally larger than strepsirrhines, and they have large brains relative to their body size. They are more likely to be diurnal, with eyes adapted to daylight and sometimes to color. Anthropoids also have more complex social interactions. They tend to live longer than lemurs and other strepsirrhines. The anthropoids are split into the New World monkeys and the Old World monkeys. "New World" refers to the Americas; "Old World" refers to Africa, Asia, and Europe. New World monkeys are the only monkeys that live in the Americas.

New World monkeys The New World monkeys are a group of about 60 species of arboreal monkeys that inhabit the tropical forests of Mexico, Central America, and South America. New World monkeys include the marmosets and tamarins. These are among the smallest and most unique primates. Neither species has fingernails or opposable digits.

The New World monkeys also include the squirrel monkeys, spider monkeys, and capuchin monkeys. Some of these monkeys have opposable digits, and most are diurnal and live together in social bands. Most are also distinguished by their prehensile (pree HEN sul) tails. A **prehensile tail** functions like a fifth limb. It can grasp tree branches or other objects and support a monkey's weight, as shown in **Figure 5.**

Old World monkeys Old World monkeys live in a wide variety of habitats throughout Asia and Africa, from snow-covered mountains in Japan to arid grasslands in Africa. Some Old World monkeys live in Gibraltar, which is located at the southern tip of Spain. There are about 80 species in this group, including macaques and baboons in one subgroup, and colobus and proboscis monkeys in another. Old World monkeys are similar to New World monkeys in many ways. They are diurnal and live in social groups. However, their noses tend to be narrower and their bodies are usually larger. They also spend more time on the ground. None have prehensile tails, and some have no tails. Most Old World monkeys have opposable digits.

Apes Only a handful of ape species exist today. Apes generally have larger brains in proportion to their body size than monkeys. They also have longer arms than legs, barrel-shaped chests, no tails, and flexible wrists. They are often highly social and have complex vocalizations. They are classified into two subcategories: the lesser apes, which include the gibbons and siamangs, and the great apes, which include orangutans, gorillas, chimpanzees, and humans.

Lesser apes The Asian gibbons and their close relatives, the larger siamangs, are the arboreal gymnasts of the ape family. Though they have the ability to walk on either two or four legs like all great apes, they generally move from branch to branch using a hand-over-hand swinging motion called brachiation. This motion, as shown in **Figure 6,** enables an adult gibbon to move almost 3 m in one swing.

Great apes Orangutans are the largest arboreal primates and the only great ape species that lives exclusively in Asia. Orangutans are large enough that the males are often more comfortable on the ground, though they are not efficient walkers. Female orangutans give birth once every eight years and nurse their young for up to six years. A male orangutan, with prominent cheek pads, and a female orangutan with her offspring are shown in **Figure 7.**

The gorillas are the largest of the primates. Like all great apes, they are predominantly terrestrial animals. They walk on all four limbs, supporting themselves by their front knuckles. Also, like other great apes, they use sticks as simple tools in the wild, and some living in captivity have been taught to recognize written characters and numbers.

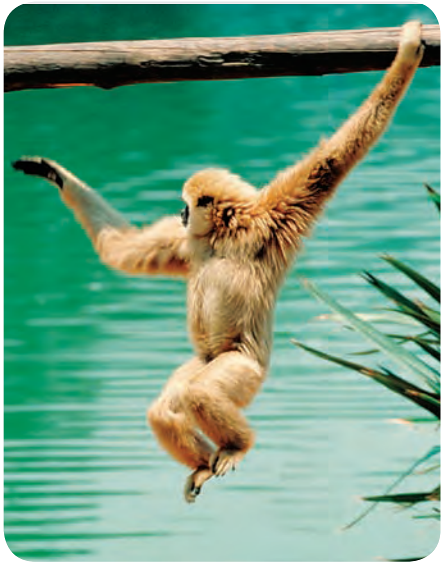


Figure 6 Lesser apes, such as this gibbon, move through trees primarily by brachiation—a hand-over-hand swinging motion.

Figure 7 Male orangutans are much larger and more solitary than females. The females spend most of their time raising their offspring.

■ **Figure 8** The bonobo is slightly smaller than the chimpanzee. Like the chimpanzee, it is structurally and behaviorally similar to humans.

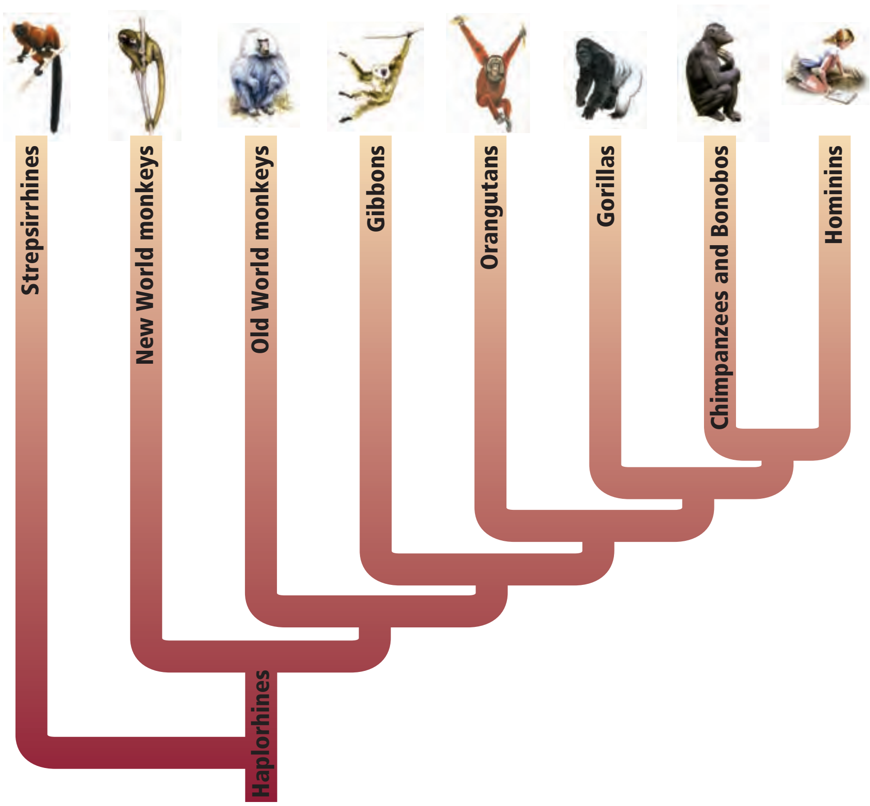
Chimpanzees and their close relatives, the bonobos, are also knucklewalkers. They have well-developed communication systems, such as body positions and gestures, and social behavior, and they live in a wide variety of habitats. They are more like humans in their physical structure and behavior than any other primates are. The bonobo, shown in **Figure 8,** is slightly smaller than the chimpanzee. It was once called the "pygmy chimpanzee," but it now is considered a separate species.

Humans are included in the great ape family. They are then classified in a separate subcategory of hominids called hominins. **Hominins** are humanlike primates that appear to be more closely related to present-day humans than they are to present-day chimpanzees and bonobos. Though many species of hominins have existed on Earth, only one species—the group to which you belong—survives today. The diagram in **Figure 9** illustrates evolutionary relationships among primates.

Primate Evolution

Most primates today are arboreal. Prehensile tails, long limbs, binocular vision, brachiation, and opposable digits are traits that help them take full advantage of their forest environments.

Arboreal adaptation Some scientists suggest that primates evolved from ground-dwelling animals that searched for food in the top branches of forest shrubbery. They then evolved into additional food-gathering niches in trees. For example, the flexible hand with its opposable digits evolved not to grasp tree branches but to catch insects. Other scientists suggest that the rise of flowering plants provided new niche opportunities, and that arboreal adaptations allowed primates to take advantage of the fruits and flowers of trees.



■ **Figure 9** This branching diagram illustrates the diverging pattern of primate evolution.

Interpret ***Which primate was the earliest to diverge?***

Primate ancestors Genetic data suggest that the first primates probably lived about 85 mya, when dinosaurs still roamed Earth. However, the earliest primate fossils do not appear in the fossil record until the beginning of the Eocene epoch, about 60 mya. One of the earliest fossil primates, called *Altiatlasius* (al tee aht lah SEE us), was a small, nocturnal animal that ate insects and fruits using its hands and feet for grasping. It might have resembled the tiny tree shrew in **Figure 10,** but it had some features similar to those of lemurs today. Learn more about the early evolution of primates in **Data Analysis Lab 1.**

Diverging primates Lemurlike primates were widespread by about 50 mya, and many species existed on all continents except Australia and Antarctica. Sometime around 50 mya, and possibly earlier, the anthropoids diverged from the tarsiers; this might have occurred in Asia, where the tarsiers are found today. The earliest anthropoids leaped less and walked more than the strepsirrhines and tarsiers, but they were still tiny and their brains were still small. By the end of the Eocene, 30–35 mya, the anthropoids had diverged and spread widely.

Displacement Many early strepsirrhines appear to have become extinct by the end of the Eocene. This might have been caused by a change in climate. Many major geological events took place at the end of the Eocene and temperatures became cooler. Or, it could have been caused by the divergence of the anthropoids. The anthropoids of this time generally were larger and had bigger brains than the strepsirrhines did. Thus, the anthropoids might have outcompeted some of the strepsirrhines for resources. This idea is supported by the observation that today, the nocturnal strepsirrhines do not interact with the diurnal anthropoids when the habitats of these two groups overlap.

Figure 10 The earliest primate ancestor might have looked like this tree shrew.

DATA ANALYSIS LAB 1

Based on Real Data*

Interpret Scientific Illustrations

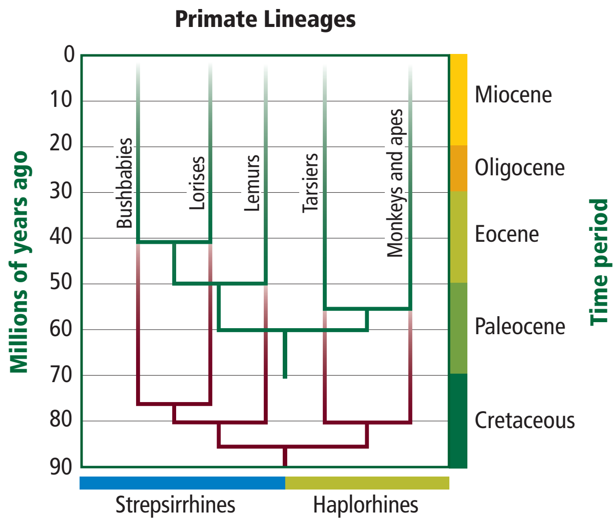
When did early primate lineages diverge?

The fossil record for primate evolution is sparse. In the simplified primate evolutionary tree at right, the green diagram shows the present divergence according to known fossils. The red diagram shows the time line with presumed fossils filling the gaps. Use the diagrams to answer the following questions.

Think Critically

1. **Summarize** why lemurs, lorises, and bushbabies are considered descendants of the earliest primates.
2. **Extrapolate** how far back the divergence of the lemurs might have occurred.
3. **Infer** whether tarsiers are more closely related to apes or to lemurs.

Data and Observations



*Data obtained from: Martin, Robert D. 2003. Paleontology: combing the primate record. *Nature* 422: 388–391.

Monkeys The end of the Eocene also saw the appearance of the monkeys. Early monkeys had larger brains than their anthropoid ancestors did, and their eyes were more forward-looking. Their snouts were less pointed and they relied less on smell. Scientists hypothesize that the New World monkeys diverged from the line that gave rise to the Old World monkeys sometime between 35 and 25 mya in Africa. While the Old World monkeys continued to evolve in Africa, the New World monkeys developed distinct characteristics in South America. By this time, Africa and South America had separated into two continents. How, then, did the New World monkeys arrive in South America?

Journey to South America Many scientists hypothesize that the New World monkeys evolved from an isolated group of ancestral anthropoids that somehow drifted to South America from Africa, perhaps on rafts of vegetation and soil, much like how the ancestors of lemurs might have drifted to Madagascar from the African mainland. Some scientists suggest that the New World monkeys might have diverged from the anthropoid lineage and made their journey millions of years earlier, when sea levels were lower and the continents were closer.

VOCABULARY

ACADEMIC VOCABULARY

Diverge
to become different in character or form
Their ideas diverged so much that they could not come to an agreement.

Aegyptopithecus In Africa and Asia, anthropoids continued to evolve. Many anthropoid fossils have been found at a site in present-day Egypt called the Fayum Basin. Now a desert, the Fayum was predominantly tropical when dozens of anthropoid species lived there 36–31 mya. The largest among them was *Aegyptopithecus* (ee gypt oh PIH thuh kus), often called the dawn ape. Some scientists hypothesize that this arboreal animal, which was about the size of a domestic cat, was ancestral to the apes. It might have been part of the anthropoid line that split from the Old World monkeys and might have given rise to orangutans, gorillas, chimpanzees, and humans.

Section 1 Assessment

Section Summary

- All primates share certain anatomical and behavioral characteristics.
- Primates include lemurs, New World monkeys, Old World monkeys, apes, and humans.
- Strepsirrhines are the most primitive living lineages of primates to evolve. They diverged from haplorhines before 55 mya.
- Anthropoids diverged from tarsiers by 50 mya.
- New World monkeys are the only nonhuman primates in the Americas.

Understand Main Ideas

1. MAIN Idea **List** four characteristics that are representative of most primates that lead paleoanthropologists to conclude that primates share a common ancestry.
2. **Describe** how the characteristics of primates make them well-adapted for an arboreal lifestyle.
3. **Diagram** the evolutionary relationships of primates.
4. **Compare and contrast** major primate groups.

Think Critically

5. **Hypothesize** how the breakup of Pangaea might have contributed to the evolutionary history of primates.

MATH in Biology

6. Assume that life on Earth began 3.5 billion years ago. To the nearest percent, how much of this time have anthropoids been living?

Assessment Online Quiz

Section 2

Reading Preview

Essential Questions

- What are the features of hominoids and hominins?
- How can hominoid evolution be traced from *Proconsul* to *Homo*?
- What are the similarities between the various australopithecine species?

Review Vocabulary

savanna: a flat grassland of tropical or subtropical regions

New Vocabulary

hominoid
bipedal
australopithecine

Multilingual eGlossary

Hominoids to Hominins

MAIN Idea **Hominins, a subgroup of the hominoids, likely evolved in response to climate changes of the Miocene epoch.**

Real-World Reading Link Have you ever tried to put together a puzzle that is missing some of its pieces? Human evolution is like that puzzle. Scientists who try to understand how humans evolved are slowed by the holes in the fossil record. Recent advances in genetics and molecular biology have helped, but the puzzle that is human evolution remains only partially assembled.

Hominoids

Hominoids (HAH mih noydz) include all nonmonkey anthropoids—the living and extinct gibbons, orangutans, chimpanzees, gorillas, and humans. The fossil transition from early anthropoid to ape is not clear; very few fossils from the late Oligocene epoch exist. The earliest hominoid fossils appear in the fossil record only about 25 mya, at the beginning of the Miocene epoch. These hominoids retained some ancestral primate features. For example, most had bodies adapted for brachiation. There is evidence that they had relatively large brains and had shoulders and hips that moved freely, and some might even have had the ability to stand on two legs.

Connection to Chemistry Scientists use fossils to help them determine when ancestral hominoids diverged into the hominoids that exist today. However, because the fossil record for hominoids is so sparse, scientists also turn to biochemical data to help them with this task. By comparing the DNA of living hominoid species, researchers conclude that gibbons likely diverged first from an ancestral anthropoid, followed by orangutans, gorillas, chimpanzees and bonobos, and finally, humans. **Figure 11** shows the potential divergence of these species. Chimpanzees and bonobos are the closest living relatives to humans. All three share at least 96 percent of their DNA sequences.

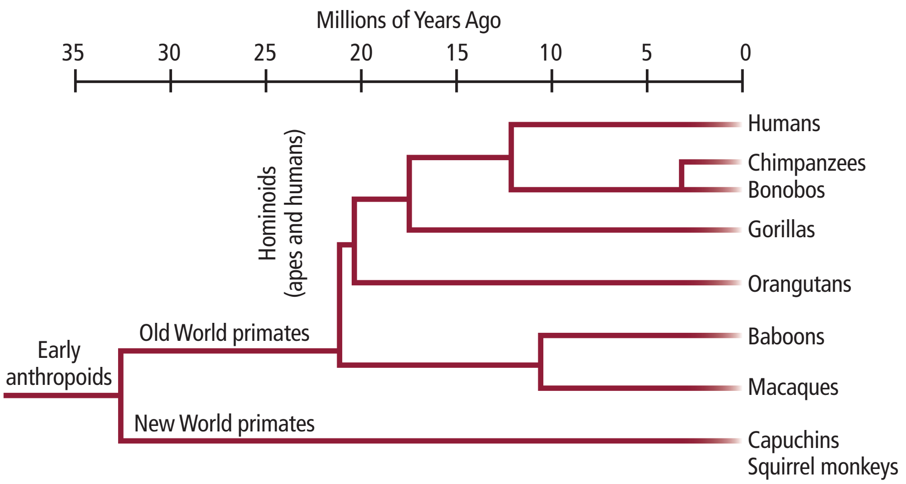


Figure 11 Orangutans, gorillas, bonobos, and chimpanzees all diverged from an ancestral anthropoid.

■ **Figure 12** *Proconsul* was an early, small-brained hominoid that might have been a human ancestor.

Hominoid characteristics Hominoids are the largest of the primates, and they have the largest brain size in relation to their body size. They tend to have broad pelvises, long fingers, no tail, and flexible arm and shoulder joints. They also have semi-upright or upright posture, and, except for hominins, their arms are longer than their legs. Their teeth are less specialized than those of other animals, and their molars have a distinctive pattern that scientists use to distinguish hominoid fossils from other primate fossils.

Hominoid biogeography During the Miocene epoch (24–5 mya), the world's climate became warmer and drier. As a result, tropical rain forests in Africa began to shrink. Many new animals, including new hominoids, evolved as they adapted to the changing environments. Between about 23 and 14 mya, perhaps as many as 100 hominoid species existed. Early hominoids were more diverse than the modern apes, and they migrated from Africa to Europe and Asia.

Proconsul The best-known hominoid fossils, and some of the oldest, are those from the genus *Proconsul*. **Figure 12** shows a fossil skull of one *Proconsul* species discovered by Mary Leakey in Kenya in 1948. This *Proconsul* species generally had the smallest brains of the hominoids. Most had freely moving arms and legs, and while they lived predominantly in trees, some might have had the ability to walk upright. Some scientists think that this *Proconsul* species is a human ancestor, but others suggest that one of the European hominoids—whose fossils are in some ways more humanlike than *Proconsul*—might have returned to Africa at the end of the Miocene and given rise to the human line.

Hominins

The lineage that most likely led to humans split off from the other African apes sometime between 8 and 5 mya. The hominins include humans and all their extinct relatives. These extinct relatives are more closely related to humans than to chimpanzees. The time line in **Figure 13** highlights some important hominin discoveries.

■ **Figure 13**

Hominin Evolution

Discoveries have shaped our understanding of how *Homo sapiens* evolved from hominoids.

Concepts in Motion

The Interactive Timeline

1859 Charles Darwin's theory of evolution sparks a heated debate over whether humans and apes share a common ancestor.

1893 A fossil of "Java Man" is the first *Homo erectus* fossil discovered.

1960–1962 Researchers find fossils of *Homo habilis*, the first large-brained hominin.

1856 A partial skeleton of *Homo neanderthalensis* was discovered in a cave in Germany's Neander Valley.

1926 Raymond Dart finds the first *Australopithecus* fossil. The "Taung Child" sparks debate about bipedalism.

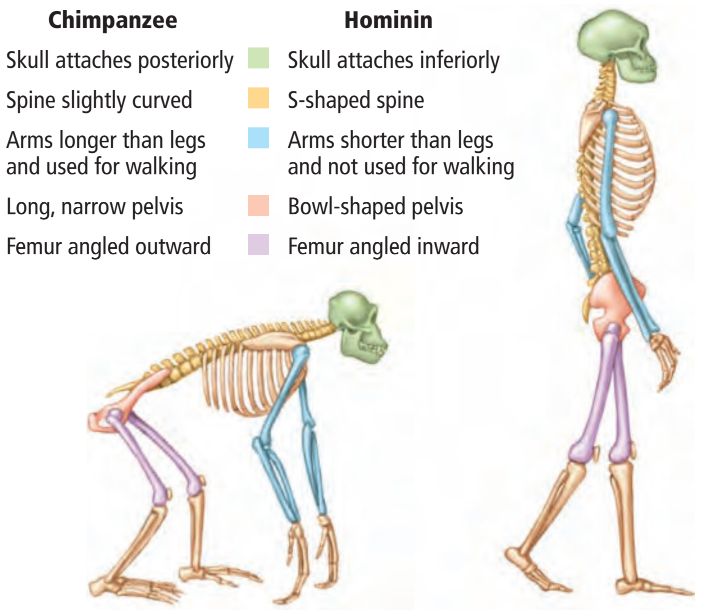


Figure 14 A comparison between chimpanzee and hominin skeletons illustrates evolutionary changes leading to bipedalism.
Observe and Infer ***What differences in the lengths of the arms and the legs do you detect?***

Hominin characteristics Hominins have bigger brains than other hominoids, with more complexity in parts of the brain where high-level thought occurs. The hominin face is thinner and flatter than those of other hominoids. Hominin teeth are also smaller. With lengthened thumbs and more flexible wrists, hominins have high manual dexterity. Hominins are also **bipedal,** which means that they can walk upright on two legs.

Examine **Figure 14,** which illustrates anatomical differences in a quadruped and a biped. When becoming bipedal, hominins developed a fully upright stance, shortened arms, restructured pelvic bones and foot bones, and a change in the position of the head on the spinal cord. In quadrupedal animals, or those that walk on all four limbs, the foramen magnum—the hole in the skull where the spine extends from the brain—is located at the back of the skull. In hominins, it is positioned at the base of the skull.

1974 The fossil remains of "Lucy" are discovered, providing convincing evidence that *Australopithecus* was bipedal.

1987 The theory of "Mitochondrial Eve" is proposed.

2000 A worldwide study of Y-chromosomes reveals that *Homo sapiens* emerged from Africa, supporting the Out-of-Africa hypothesis.

1970 — 1985 — 2000

1999 The discovery of a Neanderthal–Cro-Magnon hybrid child fossil supports the multiregional theory of human evolution.

2009 Scientists complete the sequence of mitochondrial DNA in the Neanderthal genome.

Disadvantages of bipedalism Bipedalism is not necessarily more efficient than quadrupedalism. Bipedal individuals are easier for predators to see, they might not run as fast, and bipedalism puts greater strain on the hips and back. Also, standing upright defies gravity and therefore requires more energy. Why, then, did hominins become bipedal when their ancestors were so well adapted to life in the trees?

Advantages of bipedalism There is no single answer to the question of why bipedalism developed. Bipedalism could have been selected for because it uses less energy than walking on all fours over long distances. Also, standing upright could have made it easier to see food sources. Walking upright for long distances might also have reduced the total area of the body exposed to sunlight and increased the area exposed to cooling winds.

One hypothesis explaining bipedalism is based on the idea that the African landscape was changing during the period when hominins evolved. Many scientists suggest that bipedalism was an adaptation to the new environment. The most successful hominins may have been those that evolved at the boundaries of the environments. Bipedalism would have allowed them to carry objects while walking through the forest, and to see above tall grasses to find food and avoid predators.

Another hypothesis, based on fossils of *Ardipithecus ramidus*, suggests that bipedalism evolved due to social structure. Fossils indicate that a social structure existed in which males cooperated with females to raise offspring. Males may have traveled through the forest to find food for their offspring. Bipedalism would have allowed *Ar. ramidus* to keep hands free while traveling with food or other objects.

Reading Check **Summarize** the advantages and disadvantages of bipedalism.

MiniLab 1

Observe the Functions of an Opposable Thumb

Inquiry MiniLab

How do opposable thumbs aid in everyday tasks? Explore the advantages of performing everyday activities with and without the aid of opposable thumbs.

Procedure

1. Read and complete the lab safety form.
2. Create a data table to record your observations.
3. Have a partner tape your thumbs to the sides of your hands with **masking tape.**
4. Using your taped hands, perform the following tasks: pick up a **pen or pencil** and write your name on a **piece of paper,** tie your **shoelaces,** and open a **closed door.** Have your partner use a **stopwatch** to time each task.
5. Have your partner remove the tape from your hands, then repeat the activities in Step 4 with the use of your thumbs. Have your partner time each task.

Analysis:

1. **Compare and contrast** the time and effort required to complete each task with and without the aid of your thumbs.
2. **Infer** the advantages that ancestral primates with opposable thumbs would have had over competitors without opposable thumbs.

Hominin fossils Bipedalism evolved before many other hominin traits, and it is often used to identify hominin fossils. The earliest fossils of species that show some degree of bipedalism are 6–7 million years old. Evidence of true bipedalism has been suggested by the fossilized remains of *Ar. ramidus* and the australopithecines (aw stray loh PIH thuh seens).

Australopithecines lived in the east-central and southern parts of Africa between 4.2 and 1 mya. They were small—the males were only about 1.5 m tall—and they had apelike brains and jaws. However, their teeth and limb joints were humanlike.

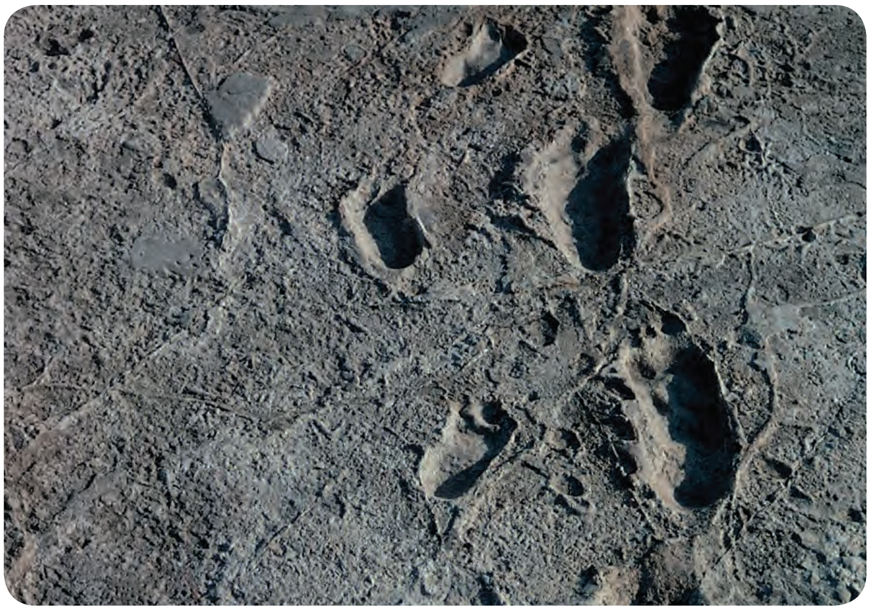
The Taung child Anthropologist Raymond Dart (1893–1988) identified the first australopithecine fossil, the "Taung child," in Africa in 1926. He called the species *Australopithecus africanus,* meaning "southern ape from Africa." *A. africanus* likely lived between 3.3 and 2.3 mya. The placement of the foramen magnum in the skull of the Taung child, shown in **Figure 15,** convinced Dart that *A. africanus* was bipedal. Not everyone agreed, because *A. africanus* had a small brain. Some scientists thought that larger brains evolved before bipedalism. The question continued to be debated for many years, even after the discovery of other African australopithecine fossils such as *A. bosei* and *A. robustus,* which indicated bipedalism and small brains.

Figure 15 The Taung child skull convinced Raymond Dart that *A. africanus* walked upright.

Lucy In 1974 in Kenya, anthropologist Donald Johanson discovered an australopithecine skeleton that helped resolve the debate. Lucy is one of the most complete australopithecine fossils ever found. She was a member of the species *A. afarensis,* which lived between 4 and 2.9 mya.

Lucy was about the size of a chimpanzee. She had the typical australopithecine skull and small brain, and her arms were still somewhat long in proportion to her legs. She also had finger bones that were more curved than those of modern humans, which indicates that she was capable of arboreal activity. However, her hip and knee joints were humanlike. It was clear that she walked upright. A few years later, Mary Leakey uncovered further evidence that australopithecines were bipedal when she discovered fossilized australopithecine footprints. Lucy's skeleton and the footprints of her relatives are illustrated in **Figure 16.**

Figure 16 Fossilized footprints indicate that Lucy was bipedal. Though incomplete, this skeleton of Lucy indicates that *A. afarensis* had a small brain but also had the ability to walk upright.
Infer ***what bones scientists would examine to determine if Lucy walked upright.***



Vocabulary

Word origin

Australopithecine
from the Latin word *australis,* meaning *southern,* and the Greek word *pithekos,* meaning *ape*.

Mosaic pattern Like other hominin fossils, Lucy and her relatives show a patchwork of human and apelike traits. In this way, they follow a mosaic pattern of evolution. Mosaic evolution occurs when different body parts or behaviors evolve at different rates. For example, hominins developed the ability to walk upright nearly two million years before they developed modern flat faces and larger brains.

Hominin evolution Within the last 30 years, scientists have discovered many more early hominin fossils. Some defy characterization and have led to new genus designations. Scientists have estimated that *Kenyanthropus platyops* (ken yan THROH pus • PLAT ee ops), for example, lived between 3.5 and 3.2 mya. Some scientists think that *K. platyops,* which means "flat-faced man," represents a completely new hominin genus.

Paranthropus There is also confusion about where *A. bosei* and *A. robustus* fit in the classification of hominins. Traditionally, these two species have been classified as robust forms of australopithecines, distinguished from the smaller, more slender forms by their size and muscular jaws. Today, many scientists prefer to put these primates in a separate genus called *Paranthropus.* Paranthropoids, which thrived between 2 and 1.2 mya, were an offshoot of the human line that lived alongside human ancestors but were not directly related.

Overlapping hominins However they are classified, these robust hominins appear to have lived alongside some of the slender australopithecines. They might have overlapped, for example, with *A. garhi,* an African australopithecine that was discovered in 1999. The illustration of the evolution of hominins is more like a bush than a tree. Many species lived successfully for years, often overlapping with earlier species and then—for unknown reasons—became extinct. By 1 mya, all australopithecines had disappeared from the fossil record. The only hominin fossils found after that time belong to the genus *Homo.*

Section 2 Assessment

Section Summary

- Hominoids are all of the apes, including gibbons, orangutans, gorillas, chimpanzees, and humans and their extinct relatives.
- Several species of hominins appear in the fossil record.
- Hominins include humans, australopithecines, and other extinct species more closely related to humans than to chimpanzees.
- Bipedalism was one of the earliest hominin traits to evolve.

Understand Main Ideas

1. MAIN Idea **Summarize** how the climate of the Miocene epoch impacted the evolution of hominins.
2. **Describe** characteristics unique to hominoids.
3. **Describe** characteristics unique to hominins.
4. **Outline** hominoid evolution from *Proconsul* to *Homo.*
5. **Compare** australopithecine species.

Think Critically

6. **Discuss** Do you think hominins would have evolved if the climate had not changed during the Miocene epoch? Why?
7. **Classify** If you found a primate skeleton with arms shorter than legs, in what general category would you place it?

Assessment Online Quiz

Section 3

Reading Preview

Essential Questions

- How can the species in the genus *Homo* be described?
- What is the Out-of-Africa hypothesis?
- What are the similarities and differences between Neanderthals and modern humans?

Review Vocabulary

mitochondrion: an organelle found in eukaryotic cells containing genetic material and responsible for cellular energy

New Vocabulary

Homo
Neanderthal
Cro-Magnon

g Multilingual eGlossary

Human Ancestry

MAIN Idea **Tracing the evolution of the genus *Homo* is important for understanding the ancestry of humans, the only living species of *Homo*.**

Real-World Reading Link Have you ever heard anyone use the term "cave man" in an insulting way? Unfortunately, this term is used sometimes to indicate brutish behavior. However, the people who lived in caves 40,000 years ago were very much like modern humans. Their art was beautiful, and their tools were sophisticated.

The Genus *Homo*

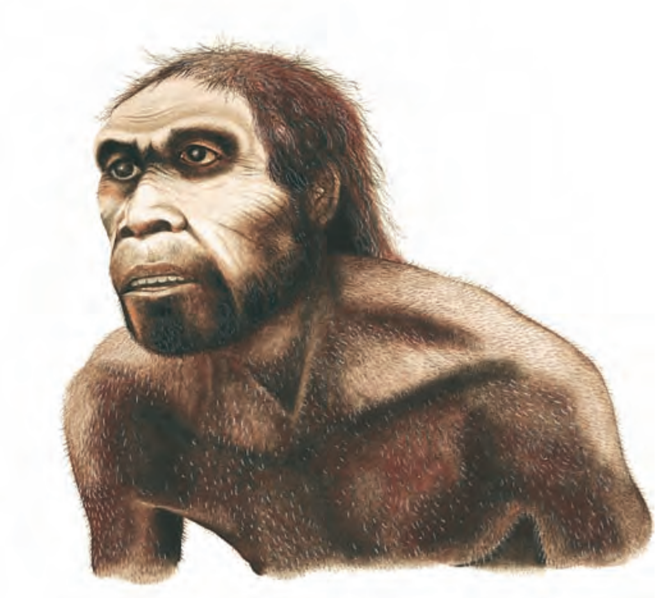
The African environment became considerably cooler between 3 and 2.5 mya. Forests became smaller in size, and the range of grasslands was extended. The genus ***Homo,*** which includes living and extinct humans, first appeared during these years. Although the fossil record is lacking fossils, many scientists infer that they evolved from an ancestor of the australopithecines.

Homo species had bigger brains, lighter skeletons, flatter faces, and smaller teeth than their australopithecine ancestors. They are also the first species known to control fire and to modify stones for tool use. As they evolved, they developed language and culture.

Homo habilis used stone tools The earliest known species that is generally accepted as a member of the genus *Homo* is *Homo habilis,* called "handy man" because of its association with primitive stone tools. This species lived in Africa between about 2.4 and 1.4 mya. **Figure 17** shows a scientific illustrator's idea of what *H. habilis* might have looked like.

H. habilis possessed a brain averaging 650 cm^3, about 20 percent larger than that of the australopithecines. It also had other *Homo* species traits, including a smaller brow, reduced jaw, flatter face, and more humanlike teeth. Like australopithecines, it was small, long-armed, and seems to have retained the ability to climb trees. Other *Homo* species might have coexisted with *H. habilis*, among them a species called *Homo rudolfensis*. Because few fossils of *H. rudolfensis* have been found, its exact relationship to the rest of the *Homo* line is uncertain.

Figure 17 Scientific illustrators use fossils and their knowledge of anatomy to create drawings of what *H. habilis* might have looked like.



■ **Figure 18** Models of nonliving species can be created from fossil remains. *H. ergaster* appeared in the fossil record about 1.8–1.3 mya.

***Homo ergaster* migrated** Within about 500,000 years of the appearance of *H. habilis,* another *Homo* species, *Homo ergaster,* emerged with an even larger brain. *H. ergaster,* illustrated in **Figure 18,** appeared only briefly in the fossil record, from about 1.8 to 1.3 mya. *H. ergaster* was taller and lighter than *H. habilis,* and had longer legs and shorter arms. Its brain averaged 1000 cm^3, and it had a rounded skull, reduced teeth, and what many scientists think was the first human nose (with the nostrils facing downward).

Tools Carefully made hand axes and other tools associated with *H. ergaster* fossils suggest to some scientists that *H. ergaster* was a hunter, but others think that *H. ergaster* was primarily a scavenger and used the tools to scrape the meat off scavenged bones.

MiniLab 2

Explore Hominin Migration

? Inquiry MiniLab

Where did early hominins live? Scientists carefully record the locations where fossils are found. The latitude and longitude coordinates represent the known geographic points of each *Homo* species' range.

Procedure

1. Read and complete the lab safety form.
2. Plot the following fossil sites on the map that your teacher gives you. Use a different color for each species. When you are finished, lightly shade in the approximate boundaries.

   H. habilis (2.4–1.4 million years ago): 37°E: 4°S, 36°E: 3°N, 36°E: 7°N, 43°E: 8°N

   H. erectus (2 million–400,000 years ago): 112°E: 38°N, 13°E: 47°N, 7°W: 34°N, 112°E: 8°S

   H. neanderthalensis (300,000–200,000 years ago): 8°E: 53°N, 66°E: 39°N, 5°W: 37°N, 36°E: 33°N

   H. sapiens (195,000 years ago–present): 70°E: 62°N, 24°E: 30°S, 138°E: 34°S, 112°E: 38°N, 99°W: 19°N, 102°W: 32°N

Analysis

1. **Hypothesize** when was the earliest that hominins could have migrated out of Africa. Where did they go? Use the map you made for reference.
2. **Determine** what sets of fossils overlapped in geographic ranges. What does this suggest?

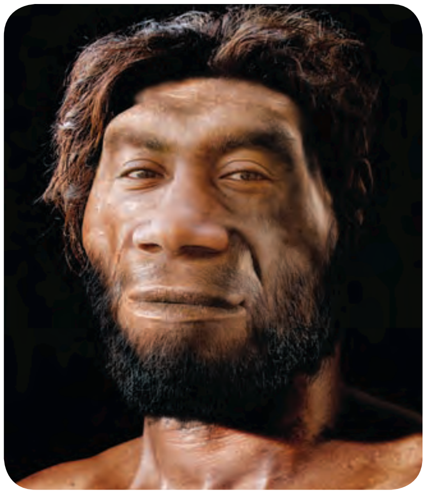


Figure 19 *H. erectus* might have lived in caves, made tools, and used fire.
Explain ***some of the advantages*** **H. erectus** ***would have over*** **H. ergaster.**

Migration Both scavenging and hunting are associated with a migratory lifestyle, and *H. ergaster* appears to have been the first African *Homo* species to migrate in large numbers to Asia and possibly Europe, perhaps following the trail of migrating animals. The later Eurasian forms of *H. ergaster* are called *Homo erectus*. Because *H. ergaster* shares features with modern humans, scientists hypothesize that *H. ergaster* is an ancestor of modern humans.

Homo erectus **used fire** *H. erectus,* illustrated in **Figure 19,** lived between 1.8 million and 400,000 years ago and appears to have evolved from *H. ergaster* as it migrated out of Africa. While some scientists consider *H. ergaster* and *H. erectus* a single species, *H. erectus* appears to have evolved traits that the early African *H. ergaster* species did not have. Members of this species seem to have been more versatile than their predecessors, and they adapted successfully to a variety of environments. *H. erectus* includes "Java Man," discovered in Indonesia in the 1890s, and "Peking Man," discovered in China in the 1920s.

In general, *H. erectus* was larger than *H. habilis* and had a bigger brain. It also had teeth that were more humanlike. Brain capacity ranged from about 900 cm^3 in early specimens to about 1100 cm^3 in later ones. It was as tall as *H. sapiens,* but it had a longer skull, lower forehead, and thicker facial bones than either *H. ergaster* or *H. sapiens.* It also had a more prominent browridge. Evidence indicates that *H. erectus* made sophisticated tools, used fire, and sometimes lived in caves.

Homo floresiensis**—"The Hobbit"** In 2003 a curious set of fossils were discovered on the Indonesian island of Flores. These fossils, which are about 18,000 years old, are heavily debated in the scientific community. Some scientists think they might represent a species called *Homo floresiensis* (flor eh see EN sus). Others think that the fossils belong to early human dwarfs and do not warrant classification as a separate species. *H. floresiensis,* nicknamed "The Hobbit," was only about 1 m tall when fully grown. While it had brain and body proportions like all the australopithecines, primitive stone tools were found with its fossils. In 2007 a study showed that *H. floresiensis* had apelike wrist bones—further support for its status as a separate species. You can compare *H. floresiensis* and *H. sapiens* skulls in **Figure 20.**

Reading Check What are the evolutionary relationships among *H. habilis, H. ergaster,* and *H. erectus?*

Figure 20 Scientists are debating whether *H. floresiensis* is a new species. The *H. floresiensis* skull on the left is smaller than the human skull on the right.
Infer ***what this skull comparison might predict about the evolutionary relationship between*** **H. floresiensis** ***and*** **H. sapiens.**

***Homo heidelbergensis*—traits** The transition from *H. ergaster* to modern humans appears to have occurred gradually. Numerous transitional fossils have been found that display a mixture of *H. ergaster* and *H. sapiens* traits. These fossils are often categorized as *Homo heidelbergensis,* but some scientists put them in the category *Homo sapiens*. These humans generally had larger brains and thinner bones than *H. ergaster* did, but they still had browridges and receding chins.

Reading Check **Relate** *H. heidelbergensis* to *H. sapiens.*

***Homo neanderthalensis* built shelter** A distinct human species called *Homo neanderthalensis,* or the **Neanderthals,** evolved exclusively in Europe and Asia about 200,000 years ago, likely from *H. erectus* or a *Homo* intermediary. Neanderthals were shorter but had more muscle mass than most modern humans do. Their brains were sometimes even larger than the brains of modern humans, though the brains might have been organized in different ways. Neanderthals had thick skulls, bony browridges, and large noses. They also had a heavily muscled, robust stature, as illustrated in **Figure 21.** Evidence of heavy musculature appears in the extremely large muscle attachments and the bowing of the long bones.

Neanderthals lived near the end of the Pleistocene ice age, a time of bitter cold. Their skeletons reflect lives of hardship; bone fractures and arthritis seem to have been common. There is evidence that they used fire and constructed complex shelters. They hunted and skinned animals, and it is possible that they had basic language. There is also some evidence that they cared for their sick and buried their dead.

Are Neanderthals our ancestors? In some areas of their range, particularly in the Middle East and southern Europe, Neanderthals and modern humans overlapped for as long as 10,000 years. Some scientists suggest that the two species interbred. However, some studies suggest that Neanderthals were a distinct species that likely did not contribute to the modern human gene pool. As new information is discovered, scientists continue to debate the interactions between Neanderthals and modern humans. Neanderthals became extinct about 30,000 years ago.

Figure 21 *H. neanderthalensis* had much thicker bones than modern humans and a pronounced browridge. Neanderthals were hunters who used fire and tools.

Emergence of Modern Humans

The species that displaced the Neanderthals, *Homo sapiens*, is characterized by a more slender appearance than all other *Homo* species. They have thinner skeletons, rounder skulls, and smaller faces with prominent chins. Their brain capacity averages 1350 cm^3. *H. sapiens* first appeared in the fossil record, in what is now Ethiopia, about 195,000 years ago. These early *H. sapiens* made chipped hand axes and other sophisticated stone tools. They appear to have had the ability to use a range of resources and environments, and at some point they began migrating out of Africa. **Table 2** compares modern humans with other *Homo* species.

Table 2 **Characteristics of the *Homo* species** Concepts in Motion Interactive Table

Species	Skull	Time in fossil record	Characteristics
Homo habilis		2.4–1.4 million years ago	• Average brain had a capacity of 650 cm^3 • Used tools
Homo ergaster		1.8–1.2 million years ago	• Average brain had a capacity of 1000 cm^3 • Had thinner skull bones • Had humanlike nose
Homo erectus		1.8 million–400,000 years ago	• Average brain had a capacity of 1000 cm^3 • Had thinner skull bones • Used fire
Homo neanderthalensis		300,000–200,000 years ago	• Average brain had a capacity of 1500 cm^3 • Buried their dead • Possibly had a language
Homo sapiens		195,000 years ago to present	• Average brain has a capacity of 1350 cm^3 • Does not have browridge • Has a small chin • Has language and culture

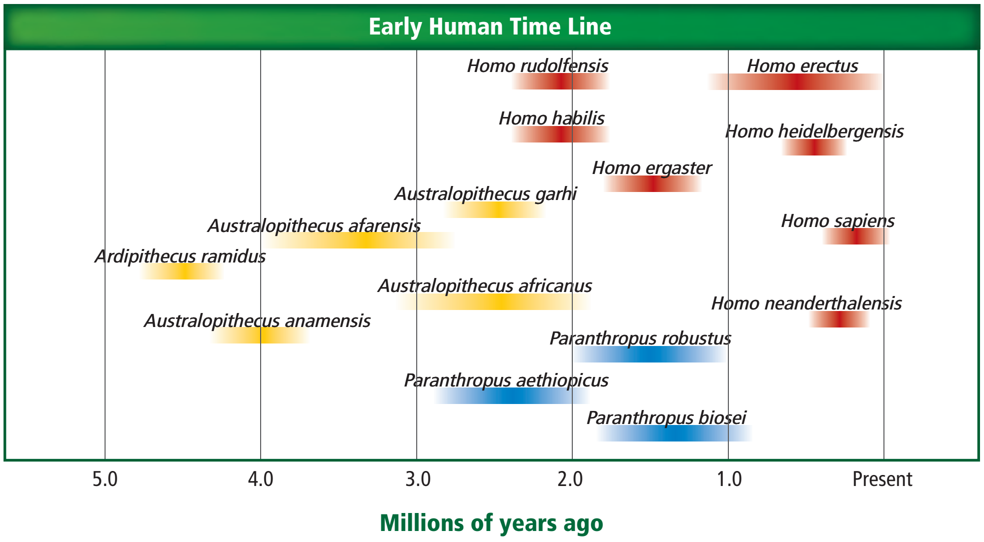


Figure 22 The period of existence of several early hominins overlapped until about 30,000 years ago.

Out-of-Africa hypothesis The world's population 200,000 years ago looked significantly different from how it does today. It was inhabited by a morphologically diverse genus of hominins, including primitive humans, Neanderthals, and modern humans, as illustrated in **Figure 22.** By 30,000 years ago, however, only modern humans remained. Some scientists propose that these modern humans evolved from several dispersed populations of early *Homo* species at the same time in different areas of the world. According to this multiregional evolution model, modern races of humans arose in isolated populations by convergent evolution.

Most scientists explain the global dominance of modern humans with the African Replacement model or, more commonly, the Out-of-Africa hypothesis. According to this hypothesis, which was first proposed by Christopher Stringer and Peter Andrews of the British Museum of Natural History in 1988, modern humans evolved only once, in Africa, and then migrated to all parts of the world, eventually displacing other hominins.

"Mitochondrial Eve" The Out-of-Africa hypothesis was supported by mitochondrial DNA analysis of contemporary humans in the early 1990s. Mitochondrial DNA changes very little over time, and humans living today have nearly identical mitochondrial DNA. Researchers Allan Wilson and Rebecca Cann of the University of California, Berkeley, reasoned that the population with the most variation should be the population that has had the longest time to accumulate diversity. This was exactly what they found in the mitochondrial DNA of Africans. Because mitochondrial DNA is inherited only from the mother, this analysis suggested that *H. sapiens* emerged in Africa about 200,000 years ago from a hypothetical "Mitochondrial Eve."

Later, work by other scientists studying DNA sequences in the male Y chromosome yielded similar results. While some scientists think that a single movement of only a few hundred modern humans ultimately gave rise to the world's current population, others think the process occurred in phases, with some interbreeding among the species that humans displaced.

Reading Check **Describe** evidence in support of the Out-of-Africa hypothesis.

Study Tip

Discussion Group Discuss with your classmates what you've learned about human evolution. What characteristics of early hominins have surprised you or your classmates?

■ **Figure 23** Cro-Magnons were known for their sophisticated cave paintings, tools, and weapons. The painting on the left was found in Lascaux Cave in France.

The beginning of culture The first evidence of complex human culture appeared in Europe only about 40,000 years ago, shortly before the Neanderthals disappeared. Unlike the Neanderthals, early modern humans expressed themselves symbolically and artistically in decorative artifacts and cave drawings, as illustrated in **Figure 23.** They developed sophisticated tools and weapons, including spears and bows and arrows. They were the first to fish, the first to tailor clothing, and the first to domesticate animals. These and many other cultural expressions marked the appearance of fully modern humans, the subspecies *Homo sapiens.* Some people call them **Cro-Magnons.** They represent the beginning of historic hunter-gatherer societies.

Connection to History Humans continued their migration throughout Europe and Asia. They probably reached Australia by boat and traveled to North America via a land bridge from Asia. From North America, they spread to South America. They adapted to new challenges along the way, leaving behind a trail of artifacts that we study today.

Section 3 Assessment

Section Summary

- The genus *Homo* is thought to have evolved from genus *Australopithecus.*
- Of the many species that have existed in the hominin group, only one species survives today.
- The first member of the genus *Homo* was *H. habilis.*
- The Out-of-Africa hypothesis suggests that humans evolved in Africa and migrated to Europe and Asia.
- *H. neanderthalensis* became extinct about 30,000 years ago, and *H. sapiens* moved into those areas inhabited by *H. neanderthalensis* at about the same time.

Understand Main Ideas

1. **MAIN Idea** **Hypothesize** why only one genus and species remains in the hominin group.
2. **Describe** how *H. habilis* might have lived.
3. **Apply** what you have learned about the Out-of-Africa hypothesis to what you know about the arrival of *H. sapiens* in North America.
4. **Compare and contrast** *H. neanderthalensis* and *H. sapiens*.

Think Critically

5. **Classify** how you would classify a fossil that was found in France and dated at about 150,000 years old if the skull had a thick browridge, but in most other ways appeared human.

WRITING in Biology

6. **Hypothesize** the importance of language to the early modern humans and how it might have contributed to their success.

BioDiscoveries

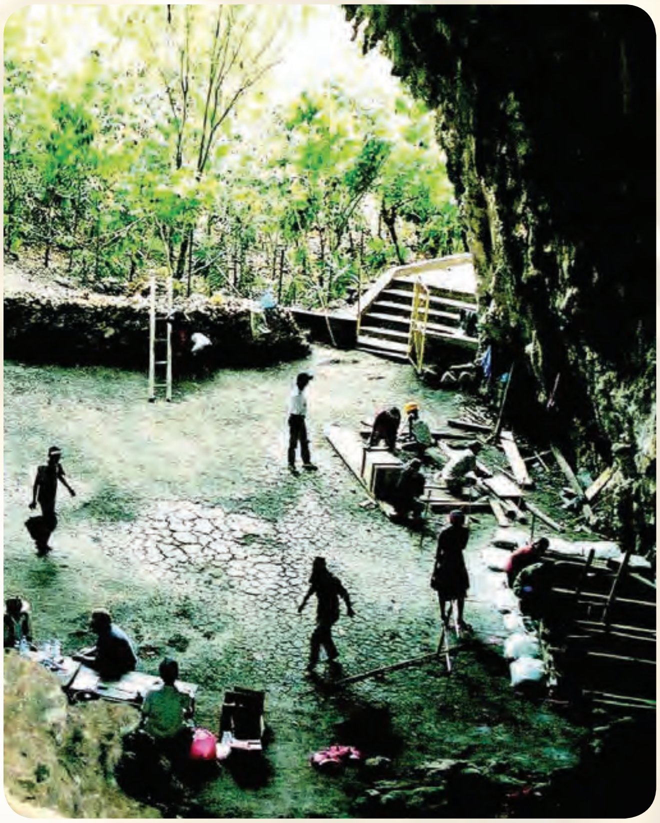
A New Species… or Something Else?

In 2003, scientists found a partial skeleton and fragments of six or more other skeletons in a cave on the island of Flores, Indonesia. The "hobbits," as the scientists dubbed them, were humanlike beings a little over three feet tall, with heads the size of grapefruits and chimpanzee-sized brains. Tests revealed that the partial skeleton and fragments ranged between 13,000 and 95,000 years old.

These little creatures are the cause of a big disagreement within the scientific community. Since their discovery, some scientists have claimed the "hobbits" are *Homo sapiens*, or modern humans, with a medical condition that caused their diminutive stature. Others insist that they are a new species, *Homo floresiensis.* Scientists on each side are using scientific methods to uncover the truth. Their different interpretations of the data are part of the collaborative scientific process.

Diseased modern humans? Scientists who doubt the "new species hypothesis" proposed several hypotheses to explain the tiny creatures' sizes and other characteristics. Some suggested that the "hobbits" were pygmies who suffered from microcephaly, a rare, sometimes genetic neurological disorder that results in a smaller-than-normal head. Other scientists have hypothesized that the miniature humans had hypothyroidism.

A new species? Most scientists who support the hypothesis that the "hobbits" are the new species *Homo floresiensis* think that they evolved from members of *Homo erectus*, a precursor to modern humans. Some, however, think that the "hobbits" evolved from an even earlier species of human called *Homo habilis*. Once on the island of Flores, scientists think that the organisms evolved to be dwarflike.



Scientists search for fossils at a cave site called Liang Bau on the island of Flores.

Structural differences Both groups of scientists are using the structural data provided by the bone fragments. These include the skull, wrist, foot, and shoulders. As more bone fragments are discovered and studied, more pieces are added to the puzzle.

WRITING in Biology

Peer Review Research the controversial fossils found on Flores. Write an article as though you are one of the researchers. Include your hypothesis, evidence, and conclusions. Submit your article to your classmates for peer review.

WebQuest

BIOLAB

WHAT CAN YOU LEARN ABOUT BIPEDALISM FROM COMPARING BONES?

Background: **Humans and chimpanzees have the same number of bones in the same places, but humans walk upright and chimpanzees do not. Can you identify the skeletal features that enable humans to walk upright on two legs? Assume that you are a paleontologist and have been given chimpanzee and human bones to identify and assemble. Then, you receive a third set. How is the mystery skeleton related to the human and chimpanzee skeletons?**

Question: *What unique skeletal features did humans evolve to become bipedal?*

Materials

envelopes containing paper bones and clues (2)
paper, pencil, and ruler

Safety Precautions

Procedure

1. Read and complete the lab safety form.
2. Make a data table to help you compare the following characteristics of each of the three fossil sets you will examine: skull, rib cage, pelvis, arms, legs, and feet.
3. Make sure your teacher approves your table.
4. Open envelope #1.
5. Using the clues in your envelope, identify the bones, determine to which species they belong, and write down at least one distinguishing characteristic of each on your data table.
6. Open envelope #2.
7. Using the new set of clues, classify each new bone as chimpanzee, human, similar to both, similar to chimpanzee, or similar to human. Record the data in your table.

Analyze and Conclude

1. **List** features that a scientist might use to determine if a fossil organism was bipedal.
2. **Think Critically** Based on your knowledge, do you think the mystery fossil is bipedal? Why?
3. **Conclude** What organism do you think your mystery bones represent?
4. **Compare** your table with those of other students in the class. Did you arrive at the same conclusions? If not, discuss the differences.
5. **Experiment** Chimpanzees cannot completely straighten—or lock—their knees as humans can and must use more muscles when standing upright. Try standing for 10 s with your knees locked and for 10 s with your knees bent. Describe how your legs feel at the end.
6. **Reason,** from your mystery fossil bones, what it means to say that humans evolved in a mixed, or mosaic, pattern.

WRITING in Biology

Research and discuss why bipedalism is often thought of as an evolutionary compromise. List skeletal injuries that humans suffer as a result of walking upright.

Chapter 16 Study Guide

THEME FOCUS Change The changes that separated hominins from hominoids, such as larger brains and bipedalism, took place over 20–25 million years ago.

BIG Idea **Evolutionary change in a group of small, tree-living mammals eventually led to a diversity of species that includes modern humans.**

Section 1 Primates

opposable first digit (p. 452)
binocular vision (p. 452)
diurnal (p. 452)
nocturnal (p. 452)
arboreal (p. 455)
anthropoid (p. 455)
prehensile tail (p. 456)
hominin (p. 458)

MAIN Idea **Primates share several behavioral and biological characteristics, which indicates that they evolved from a common ancestor.**

- All primates share certain anatomical and behavioral characteristics.
- Primates include lemurs, New World monkeys, Old World monkeys, apes, and humans.
- Strepsirrhines are the most primitive living lineages of primates to evolve. They diverged from haplorhines before 55 mya.
- Anthropoids diverged from tarsiers by 50 mya.
- New World monkeys are the only nonhuman primates in the Americas.

Section 2 Hominoids to Hominins

hominoid (p. 461)
bipedal (p. 463)
australopithecine (p. 465)

MAIN Idea **Hominins, a subgroup of the hominoids, likely evolved in response to climate changes of the Miocene epoch.**

- Hominoids are all of the apes, including gibbons, orangutans, gorillas, chimpanzees, and humans and their extinct relatives.
- Several species of hominins appear in the fossil record.
- Hominins include humans, australopithecines, and other extinct species more closely related to humans than to chimpanzees.
- Bipedalism was one of the earliest hominin traits to evolve.

Section 3 Human Ancestry

Homo (p. 467)
Neanderthal (p. 470)
Cro-Magnon (p. 473)

MAIN Idea **Tracing the evolution of the genus *Homo* is important for understanding the ancestry of humans, the only living species of *Homo*.**

- The genus *Homo* is thought to have evolved from the genus *Australopithecus.*
- Of the many species that have existed in the hominin group, only one species survives today.
- The first member of the genus *Homo* was *H. habilis.*
- The Out-of-Africa hypothesis suggests that humans evolved in Africa and migrated to Europe and Asia.
- *H. neanderthalensis* went extinct about 30,000 years ago and *H. sapiens* moved into those areas inhabited by *H. neanderthalensis* about the same time.

Review Vocabulary eGames

Chapter 16 Assessment

Section 1

Vocabulary Review

Replace each underlined word or phrase with the correct vocabulary term from the Study Guide page.

1. A fifth limb might be used by a primate to grip a limb while engaged in reaching for and eating food.

2. Primates that are active at night are "wet-nosed" primates.

3. Depth perception evolved as the faces of primates became flattened.

Understand Main Ideas

Use the figure below to answer question 4.

4. Which is the term for the movement demonstrated by this gibbon?
A. brachiation
B. knuckle-walking
C. quadruped movement
D. upright locomotion

5. Which group was the first to evolve?
A. African apes
B. hominins
C. New World monkeys
D. Old World monkeys

6. Which adaptation results in a better gripping ability?
A. complex brain
B. flexible forelimbs
C. opposable digits
D. prehensile tail

7. The first primates most resembled which animal?
A. gibbon
B. gorilla
C. tamarin
D. lemur

Constructed Response

8. Open Ended Describe the usefulness of binocular and color vision.

9. Short Answer Which groups of primates make up the anthropoids?

Think Critically

10. Hypothesize Why do you think primate fossils have not been found on Antarctica?

11. MAIN Idea Suppose that while on a trip to Brazil, you found a fossil of a primate that closely resembles a squirrel monkey. Into which group of anthropoids would the specimen be placed?

Section 2

Vocabulary Review

Define the following vocabulary terms in complete sentences.

12. australopithecine

13. bipedal

14. hominoid

Understand Main Ideas

15. Which hominin species made the fossilized footprints shown in **Figure 16?**
A. *A. afarensis*
B. *A. africanus*
C. *Paranthropus*
D. *Proconsul*

16. Which hominoid might be ancestral to apes and humans?
A. *A. afarensis*
B. *A. africanus*
C. *Paranthropus*
D. *Proconsul*

Assessment Online Test Practice

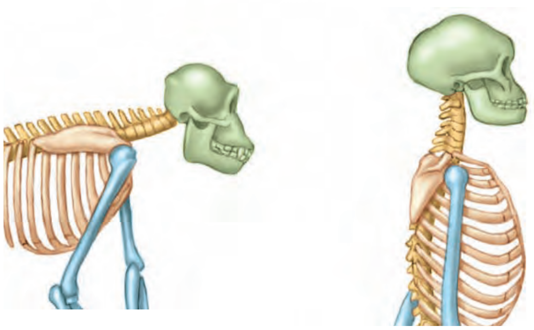
17. Which is the correct sequence of fossils as evidenced by the fossil record?
    A. *A. africanus, A. afarensis, Paranthropus, Proconsul*
    B. *Proconsul, A. afarensis, A. africanus, Paranthropus*
    C. *Proconsul, Paranthropus, A. afarensis, A. africanus*
    D. *Paranthropus, Proconsul, A. africanus, A. afarensis*

18. *A. afarensis* was bipedal but exhibited apelike traits. What type of evolutionary pattern might account for this?
    A. convergence
    B. mosaic
    C. divergence
    D. coevolution

Constructed Response

19. **Open Ended** Discuss the debate regarding the classification of *Paranthropus*.

Use the figure below to answer question 20.



20. **Short Answer** Describe the relevance of the foramen magnum's location to bipedalism.

Think Critically

21. MAIN Idea Explain how climate change might have contributed to the evolution of bipedalism.

22. **THEME FOCUS Change** Why is biochemical evidence important in helping scientists learn about the divergence of primate groups?

Section 3

Vocabulary Review

Each of the following sentences is false. Make each sentence true by replacing the underlined word with a vocabulary term from the Study Guide page.

23. The genus *Australopithecus* is thought to be ancestral to the genus *Proconsul*.

24. Cro-Magnons were adapted to cold climates. They eventually were replaced by modern humans.

25. *H. neanderthalensis* is the scientific name for modern humans.

Understand Main Ideas

Use the figure below to answer question 26.

26. The large brain and thickened browridges illustrated by the skull above are characteristic of which species?
    A. Cro-Magnons
    B. modern *H. sapiens*
    C. Neanderthals
    D. *Proconsul*

27. The first undisputed member of the hominin group was which of the following?
    A. *A. africanus*
    B. *H. antecessor*
    C. *H. ergaster*
    D. *H. habilis*

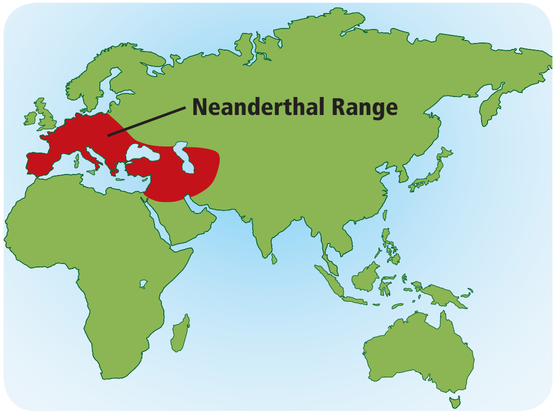
28. Which hominin was likely the first to migrate long distances?
    A. *H. ergaster*
    B. *H. antecessor*
    C. *H. neanderthalensis*
    D. *H. sapiens*

29. Which hominin likely first used fire, lived in caves, and made tools?
    A. *H. ergaster*
    B. *H. erectus*
    C. *H. neanderthalensis*
    D. *H. sapiens*

30. *H. heidelbergensis* is generally considered part of which group?
    A. Neanderthals
    B. *H. sapiens*
    C. Cro-Magnons
    D. australopithecines

Assessment Online Test Practice

Use the figure below to answer questions 31 and 32.



31. The map above represents the geographic range of which species?
- **A.** *Homo erectus*
- **B.** *Homo sapiens*
- **C.** *Homo neanderthalensis*
- **D.** *Homo heidelbergensis*

32. During what time did the species represented on the map live?
- **A.** 300,000–200,000 years ago
- **B.** 100,000–12,000 years ago
- **C.** 2.4–1.4 million years ago
- **D.** 1.8–1.2 million years ago

Constructed Response

33. MAIN Idea Describe the importance of *H. habilis* in human evolution.

34. Short Answer Describe the importance of fire to the migration of early *Homo* species.

35. Open Ended From what you have learned about the evolution of primates, do you think *Homo sapiens,* our species, will continue to evolve? Why?

Think Critically

36. Apply Concepts Explain why mitochondrial DNA instead of nuclear DNA is used to study the evolution of modern humans.

37. Predict If modern humans had not arrived in Europe, do you think Neanderthals would have persisted?

38. Hypothesize How might *H. floresiensis* have coexisted with modern humans?

Summative Assessment

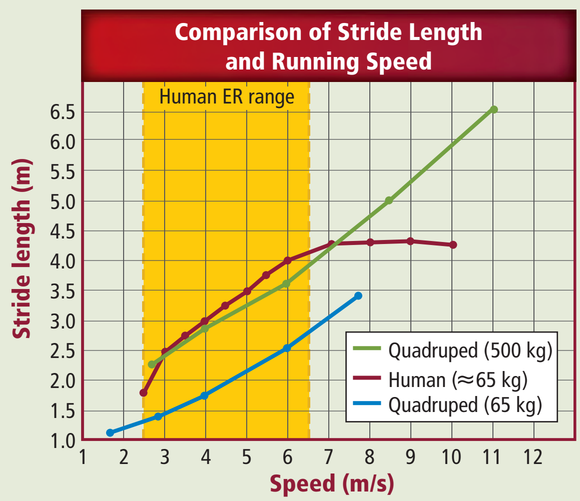
39. BIG Idea Identify three characteristics that modern humans share with other primates, and three that separate them from other primates. Infer why the three that separate humans from other primates are important.

40. WRITING in Biology Write a paragraph to describe what you imagine a day in the life of *A. afarensis* to have been like.

Document-Based Questions

Scientists generally consider walking, but not running, to be a key trait in the evolution of humans. Like apes, humans are poor sprinters when compared to quadruped animals such as horses and dogs. Unlike apes, but like some quadrupeds, humans are capable of endurance running (ER), running long distances over extended time periods. The graph below compares speed during ER to length of an organism's stride (two steps for a human).

Data obtained from: Bramble, D. and Lieberman, D. 2004. Endurance running and the evolution of *Homo*. *Nature* 432: 345–352.



41. During ER, is the stride length of a human more like that of a 65-kg quadruped or a 500-kg quadruped?

42. Is a human more efficient at endurance running than a similar-sized quadruped, such as a cheetah or a leopard? Explain.

Assessment Online Test Practice

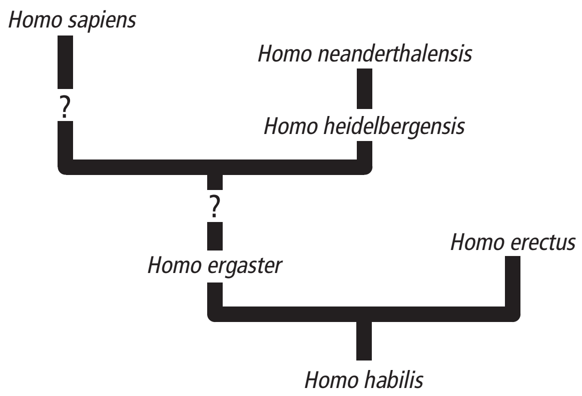
Standardized Test Practice

Cumulative

Multiple Choice

1. A scientific understanding of which natural process helped Darwin formulate the concept of natural selection?
   A. artificial selection
   B. continental drift
   C. group selection
   D. plant genetics

Use the diagram below to answer question 2.

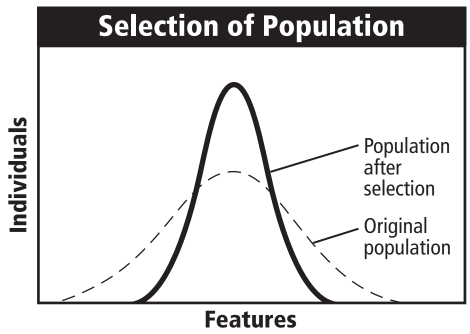


2. According to the diagram of the evolution of genus *Homo*, which is an ancestor of *Homo sapiens*?
   A. *Homo erectus*
   B. *Homo ergaster*
   C. *Homo neanderthalensis*
   D. *Homo rudolfensis*

3. Which is a physiological adaptation?
   A. A beaver's teeth grow throughout its life.
   B. A chameleon's skin changes color to blend in with its surroundings.
   C. A human sleeps during the day in order to work at night.
   D. An insect does not respond to a chemical used as an insecticide.

4. Which process can include the use of selective breeding?
   A. curing a tree of a disease
   B. finding the gene that makes a type of tree susceptible to disease
   C. mapping the genome of a fungus that causes disease in trees
   D. producing trees that resist certain diseases

Use the illustration below to answer question 5.



5. Which description fits the graph above?
   A. Average-sized features are selected for in population X.
   B. Larger features are selected for in population X.
   C. Smaller features are selected for in population X.
   D. Average-sized features are selected against in population X.

6. Which sequence correctly traces the order of hominin evolution?
   A. *Australopithecus afarensis* → *Australopithecus africanus* → *Proconsul* → *Homo*
   B. *Australopithecus africanus* → *Australopithecus afarensis* → *Proconsul* → *Homo*
   C. *Homo* → *Australopithecus africanus* → *Australopithecus afarensis* → *Proconsul*
   D. *Proconsul* → *Australopithecus afarensis* → *Australopithecus africanus* → *Homo*

7. Which of the following is NOT a reason why scientists support the endosymbiont theory?
   A. Mitochondria and chloroplasts are found living outside eukaryotic cells.
   B. Mitochondria and chloroplasts reproduce by fission.
   C. The size and structure of mitochondria and chloroplasts is similar to prokaryotic cells.
   D. The genetic material in mitochondria and chloroplasts is circular.

Short Answer

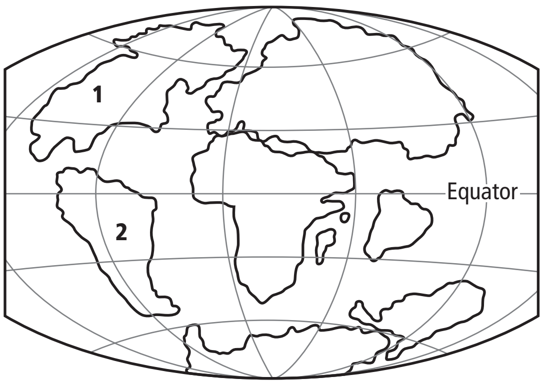
8. The gene that controls the fur color of guinea pigs codes for either dominant black fur (B) or recessive white fur (b). Suppose you want to find the genotype of a black guinea pig. Explain how you would do a test cross. Then use one or both Punnett squares below to show possible test-cross results.

9. A species of bird has a chemical in its tissue that is poisonous to many potential predators. Suppose you find another bird with a coloring pattern similar to the feathers of the first bird. What is this adaptation? Explain its importance.

10. Contrast the multiregional hypothesis and the Out-of-Africa hypothesis for human evolution.

11. Malathion is a pesticide used to control mosquitoes. Suppose a population of mosquitoes develops an ability to survive malathion spraying. How does this phenomenon fit with the ideas of variation and heritability in natural selection?

Use the figure below to answer question 12.



12. Discuss how land species and environments might change if the two numbered continents in the figure collided.

Extended Response

13. Suppose you are explaining human evolution to someone who is unfamiliar with the topic. Hypothesize why *Homo sapiens* is the only surviving member of the human family.

14. Some aggressive bacterial infections are treated with combinations of antibiotics. How would such a treatment affect drug resistance?

Essay Question

"If evolution almost always occurs by rapid speciation in small, peripheral isolates, then what should the fossil record look like? We are not likely to detect the event of speciation itself. It happens too fast, in too small a group, isolated too far from the ancestral range. Only after its successful origin will we first meet the new species as a fossil—when it reinvades the ancestral range and becomes a large central population in its own right. During its recorded history in the fossil record, we should expect no major change."

Gould, Stephen Jay. "Ladders, Bushes, and Human Evolution," *Natural History* 85 (April 1976): 30–31.

Using the information in the paragraph above, answer the following question in essay format.

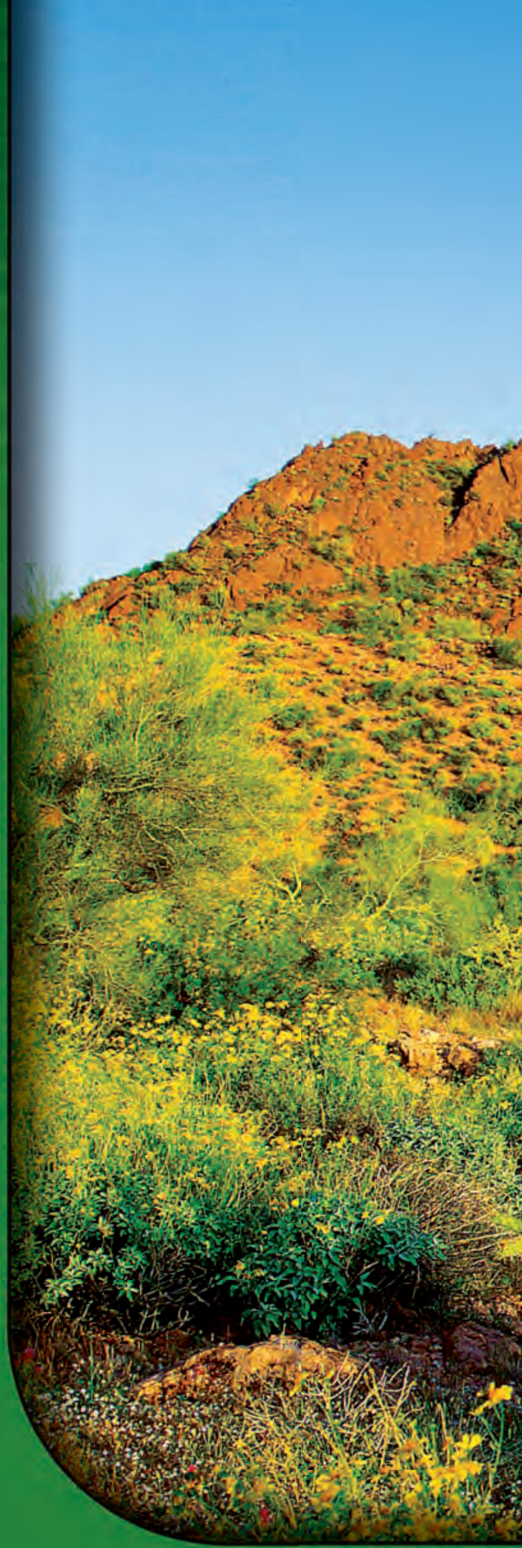
15. Gould's research in evolution was devoted, in part, to explaining his theory of punctuated equilibrium. In an essay, explain why the fossil record is incomplete.

NEED EXTRA HELP?

If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Review Section . . .	15.1	16.3	15.2	13.1	15.3	16.2	14.2	13.1	15.3	16.3	15.1	14.1	16.3	15.2	15.3

CHAPTER 17

Organizing Life's Diversity



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- Inquiry
- WebQuest
- Assessment
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Launch Lab

How can desert organisms be grouped?

You might think of a desert as a place without much biodiversity, but a wide variety of species have adaptations for desert life. Some adaptations are useful for grouping these organisms. In this lab, you will develop a system for grouping desert organisms.

For a lab worksheet, use your StudentWorks™ Plus Online.

Inquiry **Launch Lab**

FOLDABLES®

Make a layered look book Foldable. Label it as shown. Use it to organize your notes about the six kingdoms.

THEME FOCUS Diversity

Scientists have always searched for ways to classify the biodiversity observed on Earth.

BIG Idea Evolution underlies the classification of life's diversity.

Section 1 • The History of Classification

Section 2 • Modern Classification

Section 3 • Domains and Kingdoms

Section 1

Reading Preview

Essential Questions

- What are the similarities and differences between Aristotle's and Linnaeus's methods of classification?
- Using binomial nomenclature, how are scientific names written?
- What are the categories used in biological classification?

Review Vocabulary

morphology: the structure and form of an organism or one of its parts

New Vocabulary

classification
taxonomy
binomial nomenclature
taxon
genus
family
order
class
phylum
division
kingdom
domain

g Multilingual eGlossary

The History of Classification

MAIN Idea Biologists use a system of classification to organize information about the diversity of living things.

Real-World Reading Link Think about how frustrating it would be if you went into a music store and all the CDs were in one big pile. You might need to go through all of them to find the one you want. Just as stores group CDs according to type of music and artist, biologists group living things by their characteristics and evolutionary relationships.

Early Systems of Classification

Has anyone ever told you to get organized? You are probably expected to keep your room in order. Your teachers might have asked you to organize your notes or homework. Keeping items or information in order makes them easier to find and understand. Biologists find it easier to communicate and retain information about organisms when the organisms are organized into groups. One of the principal tools for this is biological classification. **Classification** is the grouping of objects or organisms based on a set of criteria.

Aristotle's system More than two thousand years ago, the Greek philosopher Aristotle (384–322 B.C.) developed the first widely accepted system of biological classification. Aristotle classified organisms as either animals or plants. Animals were classified according to the presence or absence of "red blood." Aristotle's "bloodless" and "red-blooded" animals nearly match the modern distinction of invertebrates and vertebrates. Animals were further grouped according to their habitats and morphology. Plants were classified by average size and structure as trees, shrubs, or herbs. **Table 1** shows how Aristotle might have divided some of his groups.

Table 1 Aristotle's Classification System

Concepts in Motion — Interactive Table

Plants		
Herbs	**Shrubs**	**Trees**
Violets Rosemary Onions	Blackberry bush Honeysuckle Flannelbush	Apple Oak Maple
Animals with red blood		
Land	**Water**	**Air**
Wolf Cat Bear	Dolphin Eel Sea bass	Owl Bat Crow

Aristotle's system was useful for organizing, but it had many limitations. Aristotle's system was based on his view that species are distinct, separate, and unchanging. The idea that species are unchanging was common until Darwin presented his theory of evolution. Because of his understanding of species, Aristotle's classification did not account for evolutionary relationships. Additionally, many organisms do not fit easily into Aristotle's system, such as birds that do not fly or frogs that live both on land and in water. Nevertheless, many centuries passed before Aristotle's system was replaced by a new system that was better suited to the increased knowledge of the natural world.

Linnaeus's system In the eighteenth century, Swedish naturalist Carolus Linnaeus (1707–1778) broadened Aristotle's classification method and formalized it into a scientific system. Like Aristotle, he based his system on observational studies of the morphology and the behavior of organisms. For example, he organized birds into three major groups depending on their behavior and habitat. The birds in **Figure 1** illustrate these categories. The eagle is classified as a bird of prey, the heron as a wading bird, and the cedar waxwing is grouped with the perching birds.

Linnaeus's system of classification was the first formal system of taxonomic organization. **Taxonomy** (tak SAH nuh mee) is a discipline of biology primarily concerned with identifying, naming, and classifying species based on natural relationships. Taxonomy is part of the larger branch of biology called systematics. Systematics is the study of biological diversity with an emphasis on evolutionary history.

Binomial nomenclature Linnaeus's method of naming organisms, called binomial nomenclature, set his system apart from Aristotle's system and remains valid today. **Binomial nomenclature** (bi NOH mee ul • NOH mun klay chur) gives each species a scientific name that has two parts. The first part is the genus (JEE nus) name, and the second part is the specific epithet (EP uh thet), or specific name, that identifies the species. Latin is the basis for binomial nomenclature because Latin is an unchanging language, and, historically, it has been the language of science and education.

Figure 1 Linnaeus would have classified these birds based on their morphological and behavioral differences.
Infer ***in which group Linnaeus might have placed a robin.***

American bald eagle
Bird of prey

Great blue heron
Wading bird

Cedar waxwing
Perching bird

■ **Figure 2** *Cardinalis cardinalis* is a bird with many common names and is seen throughout much of the United States. It is the state bird of Illinois, Indiana, Kentucky, North Carolina, and Ohio.
Identify ***some other animals that have multiple common names.***

VOCABULARY
WORD ORIGIN
Binomial nomenclature
comes from the Latin words *bi,* meaning *two; nomen,* meaning *name;* and *calatus,* meaning *list.*

Biologists use scientific names for species because common names vary in useage. Many times the bird shown in **Figure 2** is called a red-bird, sometimes it is called a cardinal, and other times it is called a Northern cardinal. In 1758, Linnaeus gave this bird its scientific name, *Cardinalis cardinalis.* The use of scientific names avoids the confusion that can be created with common names. Binomial nomenclature also is useful because common names can be misleading. If you were doing a scientific study on fish, you would not include starfish in your studies. Starfish are not fish. In the same way, great horned owls do not have horns and sea cucumbers are not plants.

When writing a scientific name, scientists follow these rules.

- The first letter of the genus name is always capitalized, but the rest of the genus name and all letters of the specific epithet are lowercase.
- If a scientific name is written in a printed book or magazine, it should be italicized.
- When a scientific name is written by hand, both parts of the name should be underlined.
- After the scientific name has been written once completely, the genus name often will be abbreviated to the first letter in later appear-ances. For example, the scientific name of *Cardinalis cardinalis* can be written *C. cardinalis.*

Reading Check **Explain** why Latin is the basis for many scientific names.

Modern classification systems The study of evolution in the 1800s added a new dimension to Linnaeus's classification system. Many scientists at that time, including Charles Darwin, Jean-Baptiste Lamarck, and Ernst Haeckel, began to classify organisms not only on the basis of morphological and behavioral characteristics. They also included inferred evolutionary relationships in their classification systems. Today, while modern classification systems remain rooted in the Linnaeus tradition, they have been modified to reflect new knowledge about evolutionary ancestry.

Taxonomic Categories

Think about how things are grouped in your favorite video store. How are the DVDs arranged on the shelves? They might be arranged according to genre—action, drama, or comedy—and then by title and year. Although taxonomists group organisms instead of DVDs, they also subdivide groups based on more specific criteria. The taxonomic categories used by scientists are part of a nested-hierarchical system—each category is contained within another, and they are arranged from broadest to most specific.

Species and genus A named group of organisms is called a **taxon** (plural, taxa). Taxa range from having broad diagnostic characteristics to having specific characteristics. The broader the characteristics, the more species the taxon contains. One way to think of taxa is to imagine nesting boxes—one fitting inside the other. You have already learned about two taxa used by Linnaeus—genus and species. Today, a **genus** (plural, genera) is defined as a group of species that are closely related and share a common ancestor.

Note the similarities and differences among the three species of bears in **Figure 3.** The scientific names of the American black bear *(Ursus americanus)* and Asiatic black bear *(Ursus thibetanus)* indicate that they belong to the same genus, *Ursus.* All species in the genus *Ursus* have massive skulls and similar tooth structures. Sloth bears *(Melursus ursinus),* despite their similarity to members of the genus *Ursus,* usually are classified in a different genus, *Melursus,* because they are smaller, have a different skull shape and size, and have two fewer incisor teeth than bears of the genus *Ursus*.

Family All bears, both living and extinct species, belong to the same family, Ursidae. A **family** is the next higher taxon, consisting of similar, related genera. In addition to the three species shown in **Figure 3,** the Ursidae family contains six other species: brown bears, polar bears, giant pandas, Sun bears, and Andean bears. All members of the bear family share certain characteristics. For example, they all walk flatfooted and have forearms that can rotate to grasp prey closely.

CAREERS IN BIOLOGY

Wildlife Biologist A scientist who studies organisms in the wild is called a wildlife biologist. Wildlife biologists might study populations of bears or work to educate the public about nature.

Figure 3 All species in the genus *Ursus* have large body size and massive skulls. Sloth bears are classified in the genus *Melursus*.

Ursus americanus
American black bear

Ursus thibetanus
Asiatic black bear

Melursus ursinus
Sloth bear

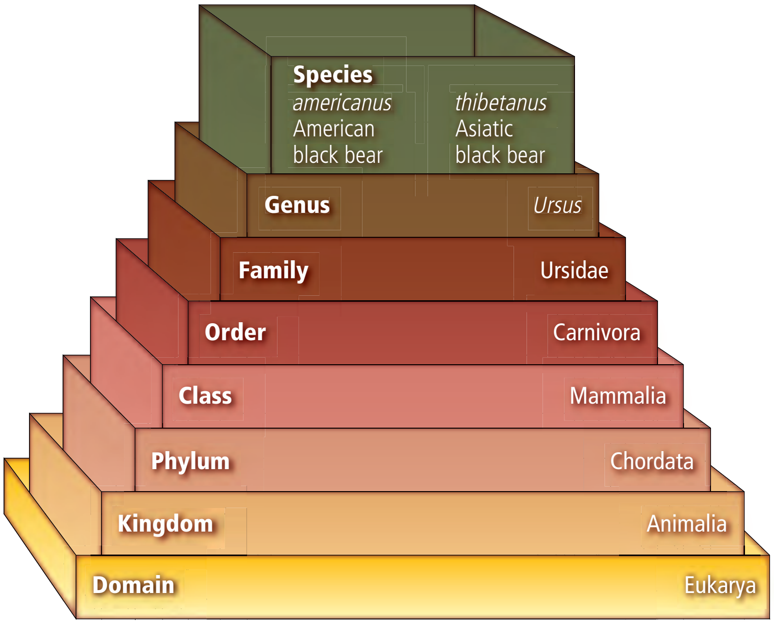


Figure 4 Taxonomic categories are contained within one another like nesting boxes. Notice that the American black bear and Asiatic black bear are different species; however, their classification is the same for all other categories.

Figure 4 shows how the taxa are organized into a hierarchical system. The figure also shows the complete classification from domain to species for the American black bear and the Asiatic black bear. Notice that the only difference in the classification of the two different bears is in the species category.

Higher taxa An **order** contains related families. A **class** contains related orders. The bears in **Figure 3** belong to the order Carnivora and class Mammalia. A **phylum** (FI lum) (plural, phyla) or **division** contains related classes. The term *division* is used instead of *phylum* for the classification of bacteria and plants. Sometimes scientists break the commonly used taxa into subcategories, such as subspecies, subfamilies, infraorders, and subphyla.

The taxon composed of related phyla or divisions is a **kingdom**. Bears are classified in phylum Chordata, Kingdom Animalia, and Domain Eukarya. The **domain** is the broadest of all the taxa and contains one or more kingdoms. The basic characteristics of the three domains and six kingdoms are described later in this chapter.

MiniLab 1

Inquiry MiniLab

Develop a Dichotomous Key

How can you classify items? Scientists group organisms based on their characteristics. These groups are the basis for classification tools called dichotomous keys. A dichotomous key consists of a series of choices that lead the user to the correct identification of an organism. In this lab, you will develop a dichotomous key as you group familiar objects.

Procedure

1. Read and complete the lab safety form.
2. Remove one **shoe** and make a shoe pile with other shoes from your group.
3. Write a question in your dichotomous key regarding whether the shoe has a characteristic of your choice. Divide the shoes into two groups based on that distinguishing characteristic.
4. Write another question for a different characteristic in your dichotomous key. Divide one of the subgroups into two smaller groups based on this distinguishing characteristic.
5. Continue dividing shoes into subgroups and adding questions to your key until there is only one shoe in each group. Make a branching diagram to identify each shoe with a distinctive name.
6. Use your diagram to classify your teacher's shoe.

Analysis

1. **Relate** taxa to the other groups you used to classify shoes. Which group relates to kingdom, phyla, and so on?
2. **Explain** how you were able to classify your teacher's shoe in Step 6.
3. **Critique** how your classification system could be modified to be more effective.

■ **Figure 5** This systematist is studying a cactus to determine if it is a new species.

Systematics Applications

Scientists who study classification provide detailed guides that help people identify organisms. Many times a field guide will contain a dichotomous (di KAHT uh mus) key, which is a key based on a series of choices between alternate characteristics. You can find out whether a plant or animal is poisonous by using a dichotomous key to identify it.

CAREERS IN BIOLOGY Systematists, like the one shown in **Figure 5** also work to identify new species and relationships among known species. They incorporate information from taxonomy, paleontology, molecular biology, and comparative anatomy in their studies. While the discovery of new species is exciting and important, learning a new connection between species also impacts science and society. For example, if a biologist knows that a certain plant such as the Madagascar periwinkle, *Catharanthus roseus,* produces a chemical that can be used to treat cancer, he or she knows that it is possible related plants also might produce the same or similar chemicals.

Section 1 Assessment

Section Summary

- Aristotle developed the first widely accepted biological classification system.
- Linnaeus used morphology and behavior to classify plants and animals.
- Binomial nomenclature uses the Latin genus and species to give an organism a scientific name.
- Organisms are classified according to a nested hierarchical system.

Understand Main Ideas

1. MAIN Idea **Explain** why a biological classification system is important.
2. **Summarize** the rules for using binomial nomenclature.
3. **Compare and contrast** how modern classification systems differ from those used by Aristotle and Linnaeus.
4. **Classify** a giant panda, *Ailuropoda melanoleuca,* completely from domain to species level by referring to **Figure 4.**

Think Critically

WRITING in Biology

5. Write a short story describing an application of biological classification.
6. **Consider** where you would expect to see more biodiversity: among members of a phyla or among members of a class. Why?
7. **Differentiate** between taxonomy and systematics.

Section 2

Reading Preview

Essential Questions

- What are the similarities and differences between species concepts?
- What are the methods used to reveal phylogeny?
- How is a cladogram constructed?

Review Vocabulary

evolution: the historical development of a group of organisms

New Vocabulary

phylogeny
character
molecular clock
cladistics
cladogram

g Multilingual eGlossary

Modern Classification

MAIN Idea **Classification systems have changed over time as information has increased.**

Real-World Reading Link Did you ever try a new way of organizing your school notes? Just as you sometimes make changes in the way you do something based on a new idea or new information, scientists adjust systems and theories in science when new information becomes available.

Determining Species

It is not always easy to define a species. Organisms that are different species by one definition might be the same species by a different definition. As knowledge increases, definitions change. The concept of a species today is much different than it was 100 years ago.

Typological species concept Aristotle and Linnaeus thought of each species as a distinctly different group of organisms based on physical similarities. This definition of species is called the typological species concept. It is based on the idea that species are unchanging, distinct, and natural types, as defined earlier by Aristotle. The type specimen was an individual of the species that best displayed the characteristics of that species. When another specimen was found that varied significantly from the type specimen, it was classified as a different species. For example, in **Figure 6** the color patterns on the butterflies' wings are all slightly different. At one time, they might have been classified as three different species because of these differences, but now they are classified as the same species.

Because we now know that species change over time, and because we know that members of some species exhibit tremendous variation, the typological species concept has been replaced. However, some of its traditions, such as reference to type specimens, remain.

Figure 6 Although these tropical butterflies vary in their color patterns, they are classified as different varieties of the same species, *Heliconius erato.*
Describe ***why early taxonomists might have classified them as separate species.***

Biological species concept Theodosius Dobzhansky and Ernst Mayr, two evolutionary biologists, redefined the term species in the 1930s and 1940s. They defined a species as a group of organisms that is able to interbreed and produce fertile offspring in a natural setting. This is called the biological species concept, and it is the definition for species used throughout this textbook. Though the butterflies in **Figure 6** have variable color patterns, they can interbreed to produce fertile offspring and therefore are classified as the same species.

There are limitations to the biological species concept. For example, wolves and dogs, as well as many plant species, are known to interbreed and produce fertile offspring even though they are classified as different species. The biological species concept also does not account for extinct species or species that reproduce asexually. However, because the biological species concept works in most everyday experiences of classification, it is used often.

Phylogenetic species concept In the 1940s, the evolutionary species concept was proposed as a companion to the biological species concept. The evolutionary species concept defines species in terms of populations and ancestry. According to this concept, two or more groups that evolve independently from an ancestral population are classified as different species. More recently, this concept has developed into the phylogenetic species concept. **Phylogeny** (fi LAH juh nee) is the evolutionary history of a species. The phylogenetic species concept defines a species as a cluster of organisms that is distinct from other clusters and shows evidence of a pattern of ancestry and descent. When a phylogenetic species branches, it becomes two different phylogenetic species. For example, recall that when organisms become isolated—geographically or otherwise—they often evolve different adaptations. Eventually, they might become different enough to be classified as a new species.

This definition of a species solves some of the problems of earlier concepts because it applies to extinct species and species that reproduce asexually. It also incorporates molecular data. **Table 2** summarizes the three main species concepts.

Study Tip

Note Discussions While you read, use self-adhesive notes to mark passages that you do not understand. In addition, mark passages you do understand and can explain to others with your own explanations, examples, and ideas. Then, discuss them with your classmates.

Inquiry **Launch Lab**

Review **Based on what you have read about classification systems, how would you now answer the analysis questions?**

Table 2 **Species Concepts** — Concepts in Motion — Interactive Table

Species Concept	Description	Limitation	Benefit
Typological species concept	Classification is determined by the comparison of physical characteristics with a type specimen.	Alleles produce a wide variety of features within a species.	Descriptions of type specimens provide detailed records of the physical characteristics of many organisms.
Biological species concept	Classification is determined by similar characteristics and the ability to interbreed and produce fertile offspring.	Some organisms, such as wolves and dogs that are different species, interbreed occasionally. It does not account for extinct species.	The working definition applies in most cases, so it is still used frequently.
Phylogenetic species concept	Classification is determined by evolutionary history.	Evolutionary histories are not known for all species.	Accounts for extinct species and considers molecular data.

VOCABULARY

SCIENCE USAGE V. COMMON USAGE

Character

Science usage: a feature that varies among species

Organisms are compared based on similar characters

Common usage: imaginary person in a work of fiction—a play, novel, or film

The queen was my favorite character in the book.

Characters

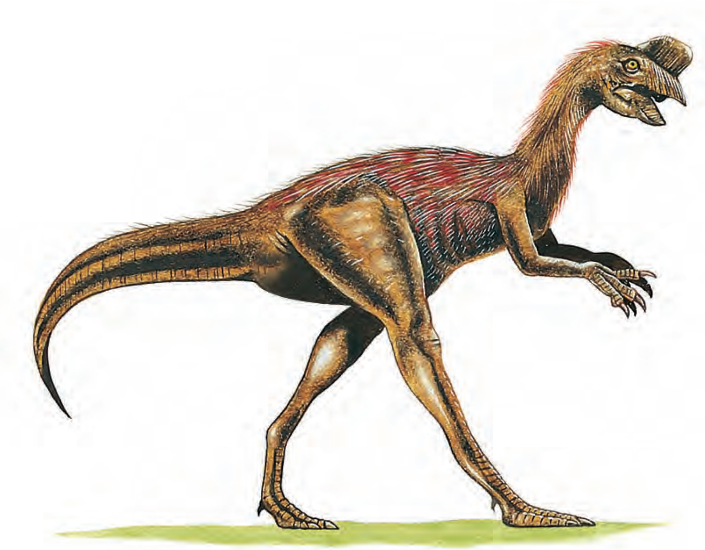
To classify a species, scientists often construct patterns of descent, or phylogenies, by using **characters**—inherited features that vary among species. Characters can be morphological or biochemical. Shared morphological characters suggest that species are related closely and evolved from a recent common ancestor. For example, because hawks and eagles share many morphological characters that they do not share with other bird species, such as keen eyesight, hooked beaks, and taloned feet, they should share a more recent common ancestor with each other than with other bird groups.

Morphological characters When comparing morphological characters, it is important to remember that analogous characters do not indicate a close evolutionary relationship. Remember that analogous structures are those that have the same function but different underlying construction. Homologous characters, however, might perform different functions but show an anatomical similarity inherited from a common ancestor.

Birds and dinosaurs Consider the oviraptor and the sparrow shown in **Figure 7.** At first you might think that dinosaurs and birds do not have much in common and do not share a close evolutionary relationship. A closer look at dinosaur fossils shows that they share many features with birds. Some fossil dinosaur bones, like those of the large, carnivorous theropod dinosaurs, show that their bones had large hollow spaces. Birds have bones with hollow spaces. In this respect, they are more like birds than most living reptiles, such as alligators, lizards, and turtles, which have dense bones. Also, theropods have hip, leg, wrist, and shoulder structures that are more similar to birds than to other reptiles. Recently, scientists have discovered some fossil dinosaur bones that suggest some theropods had feathers. The evidence provided by these morphological characters indicates that theropod dinosaurs are related more closely to modern birds than they are to other reptiles.

Reading Check **Explain** how morphological characters have influenced the classification of dinosaurs and birds.

Figure 7 This artist's conception of *Oviraptor philoceratops* might not appear to be related to the sparrow *Zonotrichia leucophrys,* but these animals share many characteristics that indicate a shared evolutionary history.
Deduce ***which similarities might prompt you to think that these species are more closely related than was commonly thought.***



Oviraptor philoceratops

Zonotrichia leucophrys

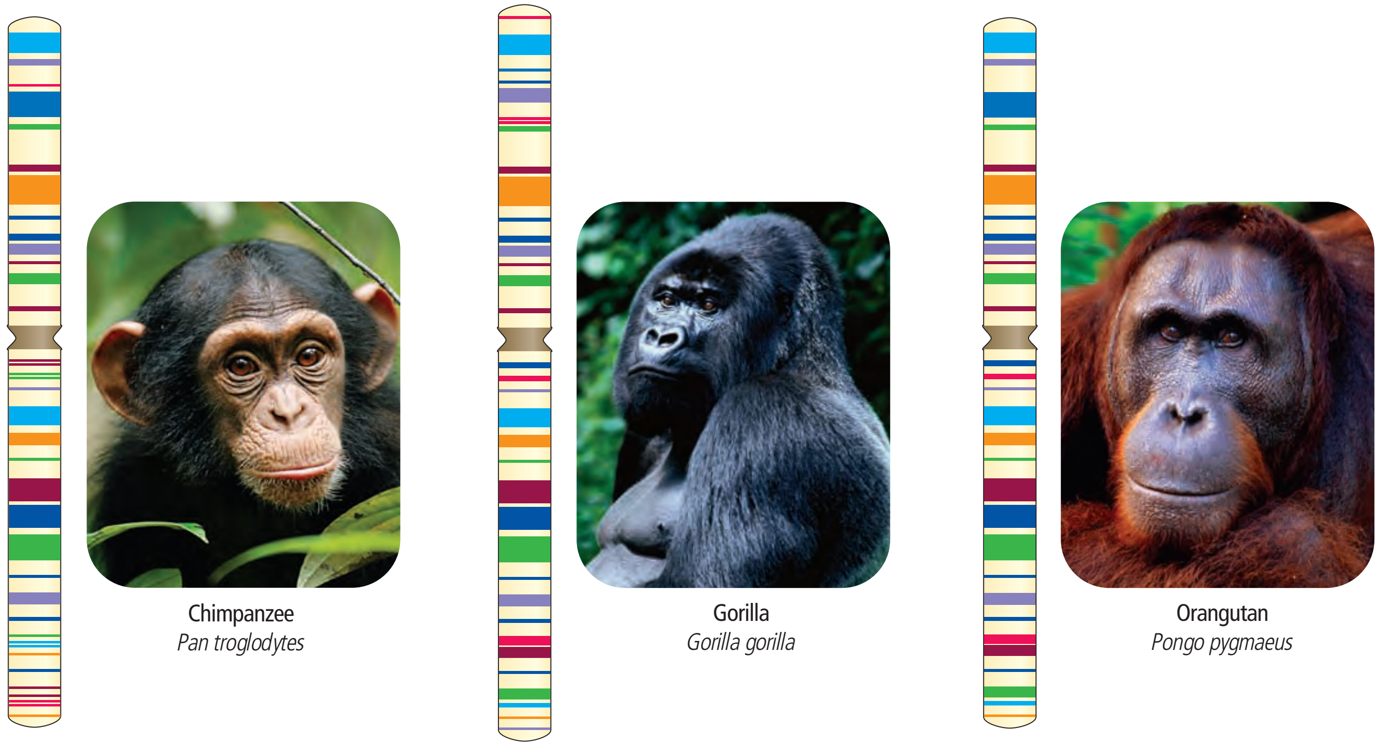


Figure 8 The representation of chromosome-banding patterns for these homologous chromosomes illustrates the evidence of a close evolutionary relationship among the chimpanzee, gorilla, and orangutan.

Biochemical characters Scientists use biochemical characters, such as amino acids and nucleotides, to help them determine evolutionary relationships among species. Chromosome structure and number is also a powerful clue for determining species similarities. For example, members of the mustard family (Cruciferae)—including broccoli, cauliflower, and kale—all look different in the garden, but these plants have almost identical chromosome structures. This is strong evidence that they share a recent common ancestor. Likewise, the similar appearance of chromosomes among chimpanzees, gorillas, and orangutans suggests a shared ancestry. **Figure 8** shows the similar appearance of a chromosome-banding pattern in these three primates.

DNA and RNA analyses are powerful tools for reconstructing phylogenies. Remember that DNA and RNA are made up of four nucleotides. The nucleotide sequences in DNA define the genes that direct RNA to make proteins. The greater the number of shared DNA sequences between species, the greater the number of shared genes—and the greater the evidence that the species share a recent common ancestor.

Scientists use a variety of techniques to compare DNA sequences when assessing evolutionary relationships. They can sequence and compare whole genomes of different organisms. They can compare genome maps made by using restriction enzymes. They also use a technique called DNA-DNA hybridization, during which single strands of DNA from different species are melted together. The success of the hybridization depends on the similarity of the sequences—complementary sequences will bind to each other, while dissimilar sequences will not bind. Comparing the DNA sequences of different species is an objective, quantitative way to measure evolutionary relationships.

VOCABULARY

ACADEMIC VOCABULARY

Corresponding
being similar or equivalent in character, quantity, origin, structure, or function
The corresponding sequences matched perfectly.

African elephant (savanna)

African elephant (forest)

Asiatic elephant

Figure 9 The two populations of African elephants have been classified as the same species; however, DNA analysis shows that they might be separate species. The Asiatic elephant belongs to a separate genus.

A species example The classification of elephants is one example of how molecular data has changed traditional taxonomic organization. **Figure 9** shows pictures of elephants that live in the world today. Taxonomists have classified the Asiatic elephant *(Elephas maximus)* as one species and the African elephant *(Loxodonta africana)* as another for over 100 years. However, they have classified the two types of African elephant as the same species, even though the two populations look different. The forest-dwelling elephants are much smaller and have longer tusks and smaller ears than the savanna-dwelling elephants. Even so, scientists thought that the elephants interbred freely at the margins of their ranges. Recent DNA studies, however, show that the African elephants diverged from a common ancestor about 2.5 million years ago. Scientists have proposed renaming the forest-dwelling elephant *Loxodonta cyclotis.* Use **Data Analysis Lab 1** to explore molecular evidence for renaming the forest-dwelling elephant.

DATA ANALYSIS LAB 1

Based on Real Data*

Draw a Conclusion

Are African elephants a separate species? Efforts to count and protect elephant populations in Africa were based on the assumption that all African elephants belong to the same species. Evidence from a project originally designed to trace ivory samples changed that assumption.

A group of scientists studied the DNA variation among 195 African elephants from 21 populations in 11 of the 37 nations in which African elephants range and from seven Asian elephants. They used biopsy darts to obtain plugs of skin from the African elephants. The researchers focused on a total of 1732 nucleotides from four nuclear genes that are not subject to natural selection. The following paragraph shows the results of the samples.

Data and Observations

"Phylogenetic distinctions between African forest elephant and savannah elephant population corresponded to 58% of the difference in the same genes between elephant genera Loxodonta (African) and Elephas (Asian)."

Think Critically

1. **Describe** the type of evidence used in the study.
2. **Explain** the evidence that there are two species of elephants in Africa.
3. **Propose** other kinds of data that could be used to support three different scientific names for elephants.
4. **Infer** Currently, *Loxodonta africana* is protected from being hunted. How might reclassification affect the conservation of forest elephants?

*Data obtained from: Roca, A.L., et al. 2001. Genetic evidence for two species of elephants in Africa. *Science* 293(5534): 1473-1477.

Molecular clocks You know that mutations occur randomly in DNA. As time passes, mutations accumulate, or build up, in the chromosomes. Some of these mutations do not affect the way cells function, and they are passed down from parent to offspring. Systematists can use these mutations to help them determine the degree of relationship among species. A **molecular clock** is a model that is used to compare DNA sequences from two different species to estimate how long the species have been evolving since they diverged from a common ancestor. **Figure 10** illustrates how a molecular clock works.

Scientists use molecular clocks to compare the DNA sequences or amino acid sequences of genes that are shared by different species. The differences between the genes indicate the presence of mutations. The more mutations that have accumulated, the more time that has passed since divergence. When the molecular clock technique was first introduced in the 1960s, scientists thought the rate of mutation within specific genes was constant. Hence, they used the clock as an analogy. However, scientists now know that the speed by which mutations occur is not always the same in a single gene or amino acid sequence.

The rate of mutation is affected by many factors, including the type of mutation, where it is in the genome, the type of protein that the mutation affects, and the population in which the mutation occurs. In a single organism, different genes might mutate, or "tick," at different speeds. This inconsistency makes molecular clocks difficult to read. Researchers try to compare genes that accumulate mutations at a relatively constant rate in a wide range of organisms. One such gene is the gene for cytochrome *c* oxidase, which is found in the mitochondrial DNA of most organisms.

Despite their limitations, molecular clocks can be valuable tools for determining a relative time of divergence of a species. They are especially useful when used in conjunction with other data, such as the fossil record.

Reading Check **Explain** what the molecular clock model uses to compare DNA.

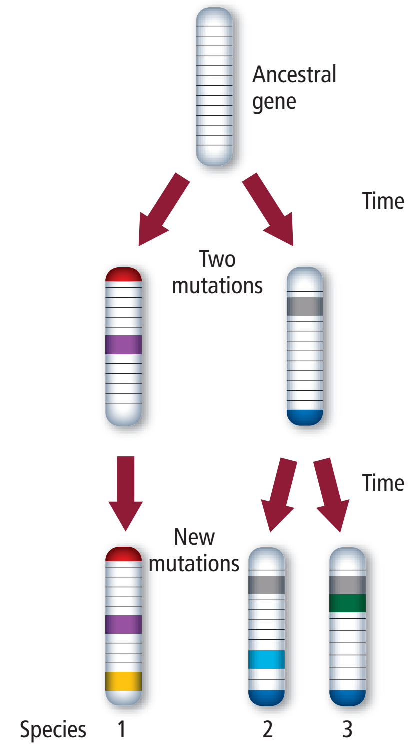


Figure 10 This molecular clock diagram shows how mutations might accumulate over time.
Infer ***why a clock is not a good analogy for this process.***

Phylogenetic Reconstruction

The most common systems of classification today are based on a method of analysis called cladistics. **Cladistics** (kla DIHS tiks) is a method that classifies organisms according to the order that they diverged from a common ancestor.

VOCABULARY
WORD ORIGIN
Cladistics
comes from the Greek word *klados*, meaning *sprout* or *branch*

Character types Scientists consider two main types of characters when doing cladistic analyses. An ancestral character is found within the entire line of descent of a group of organisms. Derived characters are present in members of one group of the line but not in the common ancestor. For example, when considering the relationship between birds and mammals, a backbone is an ancestral character because both birds and mammals have a backbone and so did their shared ancestor. However, birds have feathers and mammals have hair. Therefore, having hair is a derived character for mammals because only mammals have an ancestor with hair. Likewise, having feathers is a derived character for birds.

CAREERS IN BIOLOGY

Evolutionary Geneticist An evolutionary geneticist uses genetic analysis to establish evolutionary relationships. Often, they work at colleges and universities where they teach and perform research.

Cladograms Sytematists use shared derived characters to make a cladogram. A **cladogram** (KLAD uh gram) is a branching diagram that represents the proposed phylogeny or evolutionary history of a species or group. A cladogram is a model similar to a pedigree. Just as a pedigree's branches show direct ancestry, a cladogram's branches indicate phylogeny. The groups used in cladograms are called clades. A clade is one branch of the cladogram.

Constructing a cladogram **Figure 11** is a simplified cladogram for some major plant groups. This cladogram was constructed in the following way. First, two species were identified, conifers and ferns, to compare with the lily species. Then, another species was identified that is ancestral to conifers and ferns. This species is called the outgroup. The outgroup is the species or group of species on a cladogram that has more ancestral characters with respect to the other organisms being compared. In the diagram below, the outgroup is moss. Mosses are more distantly related to ferns, conifers, and lilies.

The cladogram is constructed by sequencing the order in which derived characters evolved with respect to the outgroup. The closeness of clades in the cladogram indicate the number of characters shared. The group that is closest to the lily shares the most derived characters with lilies and thus shares a more recent common ancestor with lilies than with the groups farther away. The nodes where the branches originate represent a common ancestor. This common ancestor generally is not a known organism, species, or fossil. Scientists hypothesize its characters based on the traits of its descendants.

The primary assumption The primary assumption that systematists make when constructing cladograms is that the greater the number of derived characters shared by groups, the more recently the groups share a common ancestor. Thus, as shown in **Figure 11,** lilies and conifers have three derived characters in common and are presumed to share a more recent common ancestor than lilies and ferns, which share only two characters.

A cladogram also is called a phylogenetic tree. Detailed phylogenetic trees show relationships among many species and groups of organisms. **Figure 12** illustrates a phylogenetic tree that shows the relationships among the domains and kingdoms of the most commonly used classification system today.

Concepts in Motion

Animation

Review

Personal Tutor

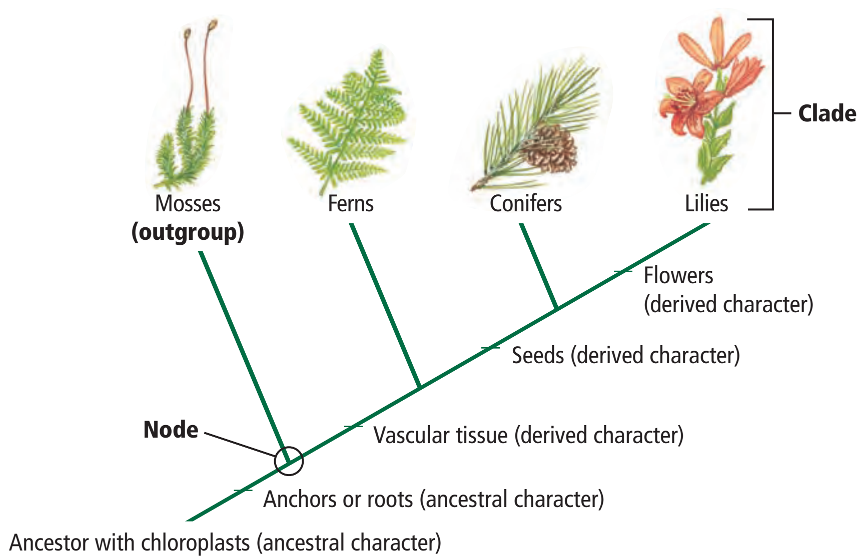


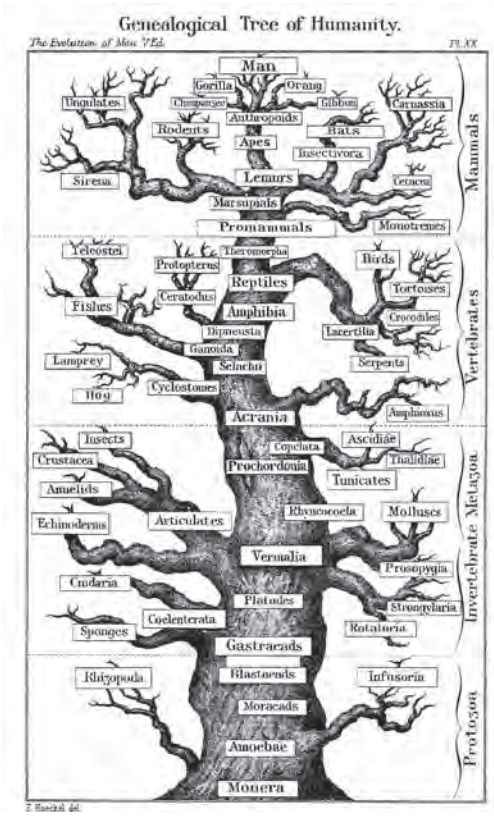
Figure 11 This cladogram uses the derived characters of plant taxa to model its phylogeny. Groups that are closer to the lily on the cladogram share a more recent common ancestor.

Identify ***which clades have chloroplasts but do not produce seeds.***

Visualizing the Tree of Life

Figure 12
This phylogenetic tree shows the main branches in the "tree of life." Notice the three domains and the four kingdoms of Domain Eukarya. All of the branches are connected at the trunk, which is labeled *Common Ancestor.*

Concepts in Motion **Animation**



■ **Figure 13** This illustration, made by Ernst Haeckel in the nineteenth century, was one of the first graphic depictions of evolutionary relationships.

Concepts in Motion

Animation

Connection to History **The tree of life** In his book *On the Origin of Species*, Charles Darwin used the analogy of a tree to suggest that all of the species developed from one or a few species. He imagined the tree's trunk to represent ancestral groups and each of the branches to have similar species. From each branch, smaller and smaller branches grew. Finally, at the tips of the twigs of these branches were the leaves, consisting of individual living species. This concept was developed further, and the term *tree of life* was coined by German biologist Ernst Haeckel (1834–1919). **Figure 13** shows Haeckel's Genealogical Tree of Humanity. Haeckel was the first to represent phylogenies in the form of a tree, and while his phylogenies are no longer completely accurate, they represent the first step in the reconstruction of phylogenies.

The tree of life diagram in **Figure 13** is a representation of the diversity of living organisms. A tree of life that incorporates all known organisms is almost unimaginably large. Scientists have discovered and described nearly 1.75 million species, and they estimate that millions more remain unclassified. Assembling a comprehensive tree of life requires a convergence of data from phylogenetic and molecular analysis. It also requires collaboration among many scientists representing many disciplines, from molecular biology to Earth science to computer science. Many scientists think that the construction of a comprehensive tree of life, though an enormous task, is an important goal. Knowing how all organisms are related would benefit industry, agriculture, medicine, and conservation.

Section 2 Assessment

Section Summary

- The definition of species has changed over time.
- Phylogeny is the inferred evolutionary history of a species, evidence for which comes from a variety of studies.
- A molecular clock uses comparisons of DNA sequences to estimate phylogeny and rate of evolutionary change.
- Cladistic analysis models evolutionary relationships based on sequencing derived characters.

Understand Main Ideas

1. **MAIN Idea** **Describe** how the changing species concept has affected classification systems.
2. **Summarize** the different concepts of a species.
3. **Describe** some methods used to determine phylogeny.
4. **Organize** the following derived characters on a cladogram in order of ascending complexity: multicellular, hair, backbone, unicellular, and four appendages.

Think Critically

MATH in Biology

5. **Describe** the mathematical challenges of counting the "ticks" of a molecular clock.
6. **Evaluate** the analogy of a tree for the organization of species based on phylogeny.
7. **Indicate** the hypothetical evolutionary relationship between two species if their DNA sequences share a 98 percent similarity.

Assessment **Online Quiz**

Section 3

Reading Preview

Essential Questions

- What are the major characteristics of the three domains?
- What are the differences among the six kingdoms?
- How are organisms classified at the kingdom level?

Review Vocabulary

eukaryote: an organism composed of one or more cells containing a nucleus and membrane-bound organelles

New Vocabulary

archaea
protist
fungus

g Multilingual eGlossary

? Inquiry Virtual Lab

Domains and Kingdoms

MAIN Idea The most widely used biological classification system has six kingdoms within three domains.

Real-World Reading Link What have you learned about the size of a kingdom as compared to a city, a village, or an individual home in your history classes? How does this knowledge help you understand the classification system?

Grouping Species

The broadest category in the classification system used by most biologists is the domain. There are three domains: Bacteria, Archaea, and Eukarya. Within these domains are six kingdoms: Bacteria, Archaea, Protists, Fungi, Plantae, and Animalia. Organisms are classified into domains according to cell type and structure, and into kingdoms according to cell type, structure, and nutrition.

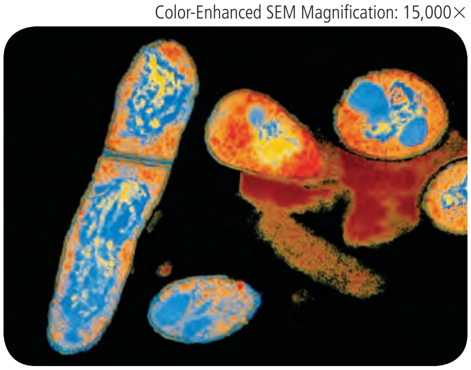
This three-domain, six-kingdom classification system has been in use for less than three decades. It was modified from a system that did not have domains but had five kingdoms after scientists discovered an entirely new kind of organism in the 1970s. These new organisms are unicellular prokaryotes that scientists named archaea (ar KEE uh). Subsequent biochemical studies found that archaea are significantly different from the only other prokaryotes then known—the bacteria—and, in 1990, they were renamed and a new classification scheme was proposed to accommodate them. Archaea are now members of their own domain.

Domain Bacteria

Connection to Chemistry Bacteria, members of Domain and Kingdom Bacteria, are prokaryotes whose cell walls contain peptidoglycan (pep tih doh GLY kan). Peptidoglycan is a polymer that contains two kinds of sugars that alternate in the chain. The amino acids of one sugar are linked to the amino acids in other chains, creating a netlike structure that is simple and porous, yet strong. Two examples of bacteria are shown in **Figure 14.**

Figure 14 Bacteria vary in their habitats and their methods of obtaining nourishment. The bacteria *Mycobacterium tuberculosis* that cause tuberculosis are heterotrophs. Cyanobacteria, such as *Anabaena,* are autotrophs.

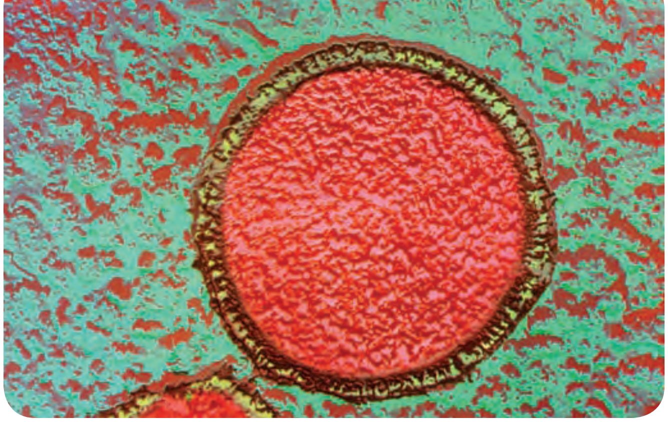
Color-Enhanced SEM Magnification: 15,000×



Mycobacterium tuberculosis

LM Magnification: 450×

Anabaena



TEM Magnification: 27,000×

■ **Figure 15** This electron microscope image of *Staphylothermus marinus* shows the cell wall (green) and cell contents (pink). *S. marinus* is an extremophile found in deep ocean thermal vents.

Bacteria are a diverse group that can survive in many different environments. Some are aerobic organisms that need oxygen to survive, while others are anaerobic organisms that die in the presence of oxygen. Some bacteria are autotrophic and produce their own food, but most are heterotrophic and get their nutrition from other organisms. Bacteria are more abundant than any other organism. There are probably more bacteria in your body than there are people in the world. You can view some different types of bacteria in **MiniLab 2.**

VOCABULARY

WORD ORIGIN

Archaea
comes from the Greek word *archaios,* meaning *ancient* or *primitive*.

Domain Archaea

Archaea (ar KEE uh), the species classified in Domain Archaea, are thought to be more ancient than bacteria and yet more closely related to eukaryote ancestors. Their cell walls do not contain peptidoglycan, and they have some of the same proteins that eukaryotes do. They are diverse in shape and nutrition requirements. Some are autotrophic, but most are heterotrophic. Archaea are called extremophiles because they can live in extreme environments. They have been found in boiling hot springs, salty lakes, thermal vents on the oceans' floors, and in the mud of marshes where there is no oxygen. The archaea *Staphylothermus marinus,* shown in **Figure 15,** is found in deep ocean thermal vents and can live in water temperatures up to 98°C.

MiniLab 2

Compare Bacteria

Inquiry MiniLab

How do the physical characteristics of various types of bacteria compare? Investigate the different features of bacteria by viewing prepared bacteria slides under the microscope.

Procedure

1. Read and complete the lab safety form.
2. Observe the prepared **slides of bacteria** with a **compound light microscope.**
3. Create a data table to compare the shapes and features of the bacteria you observe.
4. Compare and contrast the bacteria from the prepared slides. Record your observations and comparisons in your data table.

Analysis

1. **Compare and contrast** the shapes of the individual bacteria cells that you observed.
2. **Describe** whether any of your bacteria samples formed colonies. What does a colony look like?
3. **Design** a classification system for the bacteria that you observed based on the collected data.

Kelp

LM Magnification: 80×

Amoeba

Slime mold

Figure 16 These protists look different, but they all are eukaryotes, live in moist environments, and do not have organs.
Infer *which of these protists are plantlike, animal-like, or funguslike.*

Domain Eukarya

Cells with a membrane-bound nucleus and other membrane-bound organelles are called eukaryotic cells. All organisms with these cells are called eukaryotes and are classified in Domain Eukarya. Domain Eukarya contains Kingdom Protista, Kingdom Fungi, Kingdom Plantae, and Kingdom Animalia.

Kingdom Protista The wide variety of species shown in **Figure 16** belong to Kingdom Protista. Members of Kingdom Protista are called protists. **Protists** are eukaryotic organisms that can be unicellular, colonial, or multicellular. Unlike plants or animals, protists do not have organs. Though protists are not necessarily similar to each other, they do not fit in any other kingdoms. They are classified into three broad groups.

The plantlike protists are called algae. All algae, such as kelp, are autotrophs that perform photosynthesis. Animal-like protists are called protozoans. Protozoans, such as amoebas, are heterotrophs. Funguslike protists include slime molds and mildews, and they comprise the third group of protists. Euglenoids (yoo GLEE noyds) are a type of protist that has both plantlike and animal-like characteristics. They usually are grouped with the plantlike protists because they have chloroplasts and can perform photosynthesis.

Video BrainPOP

Kingdom Fungi A **fungus** is a unicellular or multicellular eukaryote that absorbs nutrients from organic materials in its environment. Members of Kingdom Fungi are heterotrophic, lack motility—the ability to move—and have cell walls. Their cell walls contain a substance called chitin (KI tun)—a rigid polymer that provides structural support. A fungus consists of a mass of threadlike filaments called hyphae (HI fee). Hyphae are threadlike filaments that are responsible for the fungus's growth, feeding, and reproduction. Fungi fossils exist that are over 400 million years old, and there are more than 70,000 known species.

FOLDABLES®
Incorporate information from this section into your Foldable.

■ **Figure 17** Fungi come in a variety of sizes, from microscopic yeasts to multicellular forms, such as the mushrooms shown here.

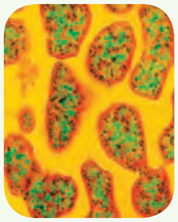
Fungi, such as the mushrooms in **Figure 17,** are heterotrophic organisms. Some fungi are parasites—organisms that grow and feed on other organisms. Other fungi are saprobes—organisms that get their nourishment from dead or decaying organic matter. Unlike heterotrophs that digest their food internally, fungi secrete digestive enzymes into their food source and then absorb digested materials directly into their cells. Fungi that live in a mutualistic relationship with algae are called lichens. Lichens get their food from the algae that live among their hyphae.

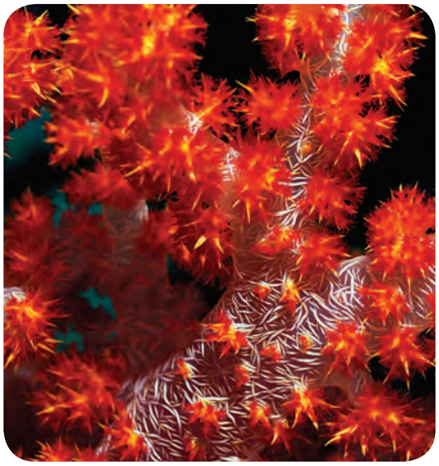
Kingdom Plantae There are more than 250,000 species of plants in Kingdom Plantae (PLAN tuh). These organisms form the base of all terrestrial habitats. All plants are multicellular and have cell walls composed of cellulose. Most plants contain chloroplasts, where photosynthesis is carried out, but a few plants are heterotrophic. For example, the parasitic dodder plant has no green parts and extracts its food from host plants through suckers.

All plants possess cells that are organized into tissues, and many plants also possess organs such as roots, stems, and leaves. Like the fungi, plants lack motility. However, some plants do have reproductive cells that have flagella, which propel them through water. The characteristics of plants and members of the other five kingdoms are summarized in **Table 3.**

Reading Check **Describe** three characteristics of plants.

Table 3 **Kingdom Characteristics** Concepts in Motion Interactive Table

Domain	Bacteria	Archaea	Eukarya			
Kingdom	Bacteria	Archaea	Protista	Fungi	Plantae	Animalia
Example	*Pseudomonas*  SEM Magnification: 5500×	*Methanopyrus*  TEM Magnification: 25,000×	*Paramecium*  LM Magnification: 150×	Mushroom 	Moss 	Earthworm 
Cell type	Prokaryote		Eukaryote			
Cell walls	Cell walls with peptidoglycan	Cell walls without peptidoglycan	Cell walls with cellulose in some	Cell walls with chitin	Cell walls with cellulose	No cell walls
Number of cells	Unicellular		Unicellular and multicellular	Most multicellular	Multicellular	
Nutrition	Autotroph or heterotroph			Heterotroph	Autotroph	Heterotroph


Coral


Fish


Rabbit

■ **Figure 18** Members of Kingdom Animalia can look very different from each other, even though they are in the same kingdom.

Kingdom Animalia Members of Kingdom Animalia are commonly called animals. More than one million animal species have been identified. All animals are heterotrophic, multicellular eukaryotes. Animal cells do not have cell walls. All animal cells are organized into tissues, and most tissues are organized into organs, such as skin, a stomach, and a brain. Animal organs often are organized into complex organ systems, like digestive, circulatory, or nervous systems. Animals range in size from a few millimeters to many meters. They live in the water, on land, and in the air. **Figure 18** shows some of the variety of organisms classified in Kingdom Animalia. Most animals are motile, although some, such as coral, lack motility as adults.

Viruses—an exception Have you ever experienced a cold or the flu? If so, you have had a close encounter with a virus. A virus is a nucleic acid surrounded by a protein coat. Viruses do not possess cells, nor are they cells, and are not considered to be living. Because they are nonliving, they usually are not placed in the biological classification system.

Section 3 Assessment

Section Summary

- Domains Bacteria and Archaea contain prokaryotes.
- Organisms are classified at the kingdom level based on cell type, structures, and nutrition.
- Domain Eukarya contains four kingdoms of eukaryotes.
- Because viruses are not living, they are not included in the biological classification system.

Understand Main Ideas

1. MAIN Idea **State** the three domains and the kingdoms in each.
2. **Compare and contrast** characteristics of the three domains.
3. **Explain** the difference between Kingdom Protista and Kingdom Fungi.
4. **Classify** to the kingdom level an organism that has organ systems, lacks cell walls, and ingests food.

Think Critically

5. **Summarize** the reasons why systematists separated Domain Bacteria from Domain Archaea.

WRITING in Biology

6. Write an essay for or against including viruses in the biological classification system.

Assessment Online Quiz

CUTTING-EDGE BIOLOGY

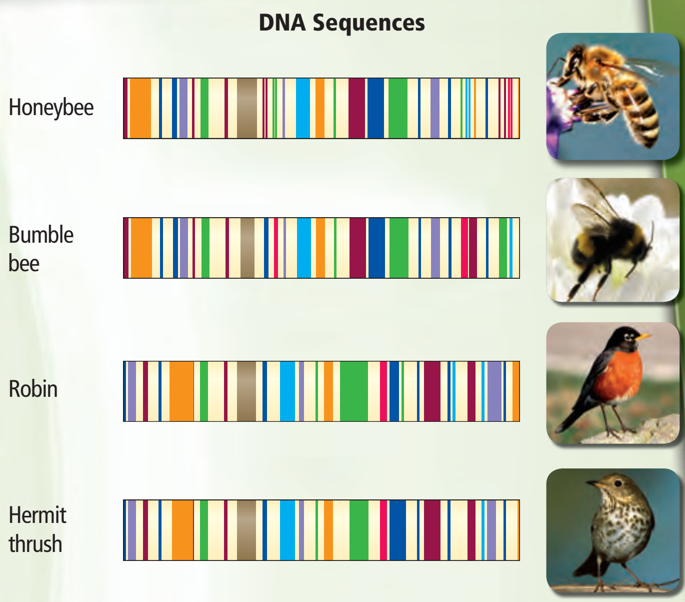
DNA BAR CODES

Most people would find it odd if their friend collected vials containing muscles from 940 different species of fish—but then again most people have not undertaken a project as ambitious as this one.

DNA UPC Paul Herbert, a geneticist at the University of Guelph in Ontario, Canada, is trying to gather cell samples from all of the world's organisms. With small pieces of tissue no larger than the head of a pin, Herbert and his international colleagues are working to assign DNA bar codes to every living species.

Herbert has shown that the segment of mitochondrial DNA, called cytochrome *c* oxidase I, or COI, can be used as a diagnostic tool to tell animal species apart. The COI gene is simple to isolate and allows for identification of an animal. A different gene would need to be used for plants. Just like UPC codes, the DNA segment sequence could be stored in a master database that would allow for easy access to the material. A hand scanner, when supplied with a small piece of tissue, such as a scale, a hair, or a feather, could identify the species almost instantly.

Potential benefits This technology has several potential benefits. A doctor might use it to pinpoint disease-causing organisms quickly to prevent epidemics or to determine what antivenom to give a snakebite victim. Health inspectors could scan foods for plant and animal contaminants. People who are curious about their surroundings could learn what lives around them. Farmers would be able to identify pests and use species-specific methods for their removal.



This representation of DNA barcodes shows that more closely related species would have more similar barcodes.

A new way to classify Using bioinformatics—a field of science in which biology, computer science, and information technology merge—to create a database of DNA barcodes allows taxonomists to classify more organisms quickly.

Currently, taxonomists have identified approximately 1.75 million species. Scientists estimate that anywhere between 10 and 100 million species exist. Historically, species have been classified using morphology, genetics, phylogeny, habitat, and behavior. While the bar codes would not replace classic taxonomic methods, they could supplement them by giving scientists another tool to use.

E-COMMUNICATION

Fact Finder Think of at least three questions you have about DNA bar coding. Research to find answers to your questions. Then, share your questions and answers with your class by e-mailing them to your teacher.

BIOLAB

HOW CAN ORGANISMS BE GROUPED ON A CLADOGRAM?

Background: **When a cladogram is made, derived characters are used to divide the organisms into groups called clades. In this exercise, you will use simulated data to learn how to make a simple cladogram and then make your own cladogram.**

Question: *How can you use organisms' characteristics to construct a cladogram?*

Materials

paper and pencil
examples of cladograms
photographs of various organisms
books describing characteristics of organisms

Procedure

1. Read and complete the lab safety form.
2. Examine the data table provided.
3. Compare the shared derived characteristics of the sample organisms. Assume that all the characteristics of your outgroup are ancestral. To make the data easier to compare, note that a "0" has been assigned to each ancestral character and a "1" to all derived characters.
4. Use the information to develop a cladogram that best shows the relationships of the organisms.
5. Make sure your teacher approves your cladogram before you proceed.
6. Choose four organisms from one of the domains you have studied that you believe are closely related.
7. Develop a table of derived characteristics of these organisms similar to the table you used in Step 2. Use your table to develop a cladogram that groups the organisms based on their shared derived characters.

Data Table for Cladistic Analysis

Organisms	Characters			
	1	2	3	4
A	b(1)	a(0)	a(0)	b(1)
B	b(1)	b(1)	b(1)	a(0)
C	b(1)	a(0)	b(1)	a(0)

Data obtained from: Lipscomb, D. 1998. Basics of cladistic analysis. George Washington University. http://www.gwu.edu/~clade/faculty/lipscomb/Cladistics.pdf

Analyze and Conclude

1. **Think Critically** How did you determine which were the ancestral and which were the derived characters of the organisms you examined?
2. **Explain** how you determined which characteristics to use to separate the clades.
3. **Explain** which organism is the outgroup on your cladogram. Why?
4. **Critique** Trade data tables with another lab group. Use their data to draw a cladogram. Compare the two cladograms and explain any differences.
5. **Error Analysis** What type of error would mistaking analogous structures as homologous introduce into a cladogram? Examine your second cladogram and determine if you have made this error.

APPLY YOUR SKILL

Construct Molecular data, such as the amino acid sequences of shared proteins, can be used to make cladograms. Research cytochrome *c*, a protein important in aerobic respiration, and decide how it could be used to construct a cladogram.

Chapter 17 Study Guide

THEME FOCUS Diversity Earth's diverse organisms are classified and organized into a hierarchy of domains and kingdoms using phylogeny and genetics.

BIG Idea Evolution underlies the classification of life's diversity.

Section 1 The History of Classification

classification (p. 484)
taxonomy (p. 485)
binomial nomenclature (p. 485)
taxon (p. 487)
genus (p. 487)
family (p. 487)
order (p. 488)
class (p. 488)
phylum (p. 488)
division (p. 488)
kingdom (p. 488)
domain (p. 488)

MAIN Idea Biologists use a system of classification to organize information about the diversity of living things.

- Aristotle developed the first widely accepted biological classification system.
- Linnaeus used morphology and behavior to classify plants and animals.
- Binomial nomenclature uses the Latin genus and species to give an organism a scientific name.
- Organisms are classified according to a nested hierarchical system.

Section 2 Modern Classification

phylogeny (p. 491)
character (p. 492)
molecular clock (p. 495)
cladistics (p. 495)
cladogram (p. 496)

MAIN Idea Classification systems have changed over time as information has increased.

- The definition of species has changed over time.
- Phylogeny is the inferred evolutionary history of a species, evidence for which comes from a variety of studies.
- A molecular clock uses comparisons of DNA sequences to estimate phylogeny and rate of evolutionary change.
- Cladistic analysis models evolutionary relationships based on sequencing derived characters.

Section 3 Domains and Kingdoms

archaea (p. 500)
protist (p. 501)
fungus (p. 501)

MAIN Idea The most widely used biological classification system has six kingdoms within three domains.

- Domains Bacteria and Archaea contain prokaryotes.
- Organisms are classified at the kingdom level based on cell type, structures, and nutrition.
- Domain Eukarya contains four kingdoms of eukaryotes.
- Because viruses are not living, they are not included in the biological classification system.

Review Vocabulary eGames

Chapter 17 Assessment

Section 1

Vocabulary Review

Match each definition with the correct term from the Study Guide page.

1. system of naming species using two words

2. taxon of closely related species that share a recent common ancestor

3. branch of biology that groups and names species based on studies of their different characteristics

Understand Main Ideas

4. On what did Linnaeus base his classification?
A. derived characters
B. binomial nomenclature
C. morphology and habitat
D. evolutionary relationship

Use the table to answer questions 5 and 6.

Classification of Selected Mammals

Kingdom	Animalia	Animalia	Animalia	Animalia
Phylum	Chordata	Chordata	Chordata	Chordata
Class	Mammalia	Mammalia	Mammalia	Mammalia
Order	Cetacea	Carnivora	Carnivora	Carnivora
Family	Mysticeti	Felidae	Canidae	Canidae
Genus	*Balenopora*	*Felis*	*Canis*	*Canis*
Species	*B. physalis*	*F. catus*	*C. latrans*	*C. lupus*
Common name	Blue whale	Domestic cat	Coyote	Wolf

5. Which animal is the most distant relative to the others?
A. wolf
B. coyote
C. domestic cat
D. blue whale

6. At which level does the domestic cat diverge from the coyote?
A. family **C.** order
B. class **D.** genus

Constructed Response

7. THEME FOCUS Diversity Explain the rules and uses of binomial nomenclature.

8. **Short Answer** Why is seahorse not a good scientific name?

Think Critically

9. MAIN Idea How does the system of classification relate to the diversity of species?

Section 2

Vocabulary Review

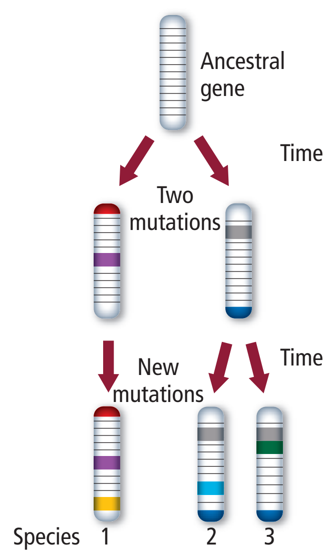
Differentiate between the following pairs.

10. phylogeny, character

11. cladogram, molecular clock

Understand Main Ideas

Use the figure below to answer questions 12 and 13.



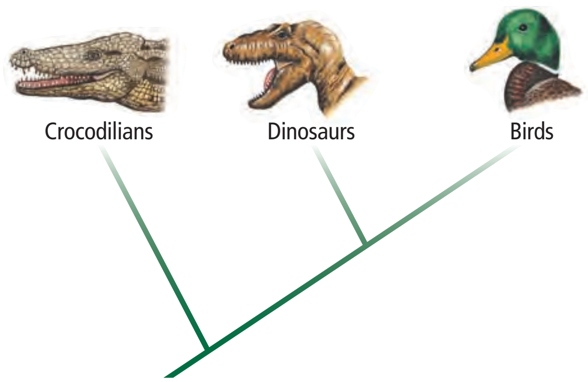
12. What does this figure represent?
A. pedigree **C.** molecular clock
B. cladogram **D.** phylogenetic tree

13. What do the colored bands in the figure represent?
A. mutations **C.** ancestral characters
B. derived characters **D.** genomes

Chapter 17 Assessment

14. Which species concept defines a species as a group of organisms that are able to reproduce successfully in the wild?
    - **A.** typological species concept
    - **B.** biological species concept
    - **C.** evolutionary species concept
    - **D.** phylogenetic species concept

Use the figure below to answer questions 15 and 16.



15. According to the figure, which organism diverged last?
    - **A.** alligators
    - **B.** birds
    - **C.** crocodiles
    - **D.** dinosaurs

16. Which is represented by the figure?
    - **A.** pedigree
    - **B.** cladogram
    - **C.** molecular clock
    - **D.** character

17. Which does not affect the rate of mutation in a molecular clock?
    - **A.** type of mutation
    - **B.** location of gene in genome
    - **C.** the protein affected
    - **D.** the time of divergence

Constructed Response

18. **Open Ended** Two scientists produce two different cladograms for the same groups of organisms. Explain how the differences are possible.

19. **Short Answer** Describe how to make a cladogram. Include the types of characters that are used and the judgments you must make about the characters.

20. **Short Answer** Summarize how biochemical characters can be used to determine phylogeny.

Think Critically

21. MAIN Idea Differentiate between the typological species concept and the phylogenetic species concept.

22. **Decide** How should molecular clocks be used if not all mutations occur at the same rate? Should they be considered reliable evidence of phylogeny? Explain your answer.

Use the figure below to answer question 23.

23. **Evaluate** evidence that suggests that the two organisms in the figure are closely related.

Section 3

Vocabulary Review

Replace the italicized words with the correct vocabulary terms from the Study Guide page.

24. Algae are a type of *archaea.*

25. *Bacteria* are called extremophiles because they grow in extreme environments.

26. Some types of *protists* are used to make food products like bread and cheese.

Understand Main Ideas

27. Which taxon contains one or more kingdoms?
    - **A.** genus
    - **B.** phylum
    - **C.** family
    - **D.** domain

28. In which kingdom would prokaryotes found living in acid runoff likely be classified?
    - **A.** Bacteria
    - **B.** Archaea
    - **C.** Fungi
    - **D.** Protista

Use the photograph below to answer question 29.

29. In which kingdom would this organism, which has chloroplasts, cell walls, but no organs, be classified?
A. Plantae
B. Animalia
C. Protista
D. Fungi

30. Which substance would most likely be in the cell walls of an organism with chloroplasts and tissues?
A. peptidoglycan
B. chitin
C. hyphae
D. cellulose

Constructed Response

31. MAIN Idea Indicate the relationship between domains and kingdoms.

32. **Short Answer** Predict in which domain a taxonomist would place a newly discovered photosynthetic organism that has cells without membrane-bound organelles and no peptidoglycan.

33. **Open Ended** Write an argument for or against including Bacteria and Archaea in the same domain. How would this affect the phylogenetic tree of life?

Think Critically

34. **Analyze** Using the model in **Figure 12,** decide which three of the kingdoms in Domain Eukarya evolved from the fourth.

35. **CAREERS IN BIOLOGY** A biologist studied two groups of frogs in the laboratory. The groups looked identical and produced fertile offspring when interbred. However, in nature, they do not interbreed because their reproductive calls are different and their territories do not overlap. Use your knowledge of species concepts and speciation to decide why they should or should not be placed in the same species.

Summative Assessment

36. BIG Idea Life on Earth was organized by Aristotle into three categories. Why has the classification system become so complex since Aristotle's time?

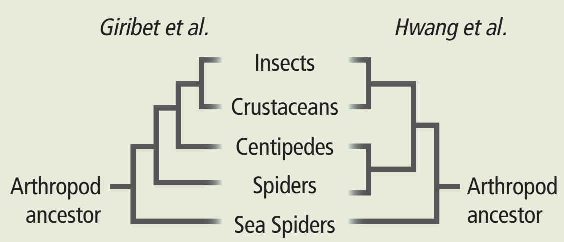
37. Draw a cladogram or phylogenetic tree that displays the order of evolution of the six kingdoms. Explain the reasoning for your interpretation.

38. WRITING in Biology Suppose you found a cricket near your home. After a biologist from a local university studies your find, you learn that the cricket is a new species. Write a paragraph to explain how the biologist might have determined that the cricket is a new species.

DBQ Document-Based Questions

Data obtained from: Blaxter, M. 2001. Sum of the arthropod parts. *Science* 413:121-122.

Scientists continue to debate about evolutionary relationships among organisms. Groups of arthropods were thought to be related in the way shown on the left, but new molecular evidence suggests that the grouping on the right is more accurate.



39. Compare and contrast the two cladograms. How did the molecular evidence change the relationship between centipedes and spiders?

40. To which group are crustaceans most closely related?

41. Which group in the cladogram appears to be the most ancestral?

Assessment Online Test Practice

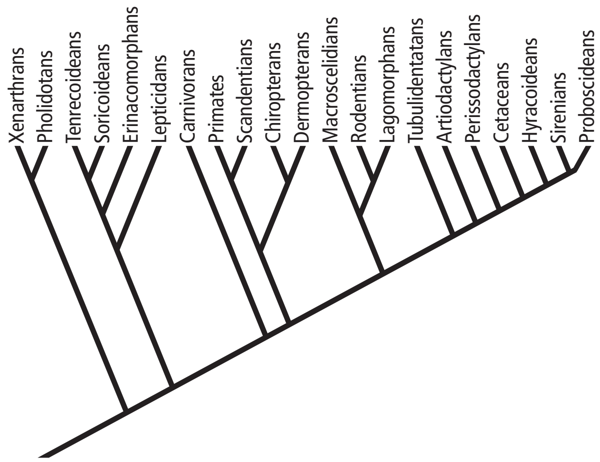
Standardized Test Practice

Cumulative

Multiple Choice

1. Which data shows that Neanderthals are not the ancestors of modern humans?
   A. differences in Neanderthal and human DNA
   B. evidence from Neanderthal burial grounds
   C. muscular build of Neanderthals, as compared to humans
   D. patterns of Neanderthal extinction

Use the illustration below to answer questions 2 and 3.



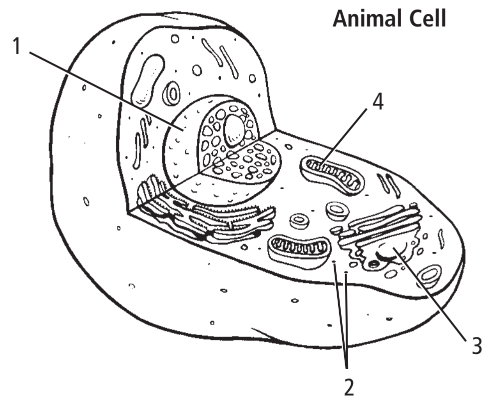
2. According to the cladogram of mammals, which two groups of animals have a more recent common ancestor?
   A. carnivorans and chiropterans
   B. cetaceans and hyracoideans
   C. dermopterans and carnivorans
   D. rodentians and lagomorphans

3. Which mammal is most closely related to bats (chiropterans)?
   A. carnivorans
   B. xenarthrans
   C. primates
   D. rodentians

4. Which radioactive isotope would be used to determine the specific age of a Paleozoic rock formation?
   A. Beryllium-10 (1.5 million years)
   B. Carbon-14 (5715 years)
   C. Thorium-232 (14 billion years)
   D. Uranium-235 (704 million years)

5. According to the Hardy-Weinberg principle, which situation would disrupt genetic equilibrium?
   A. A large population of deer inhabits a forest region.
   B. A particular population of flies mates randomly.
   C. A population of flowering plants always has the same group of natural predators.
   D. A small population of birds colonizes a new island.

Use the diagram below to answer question 6.



6. Which labeled structure contains the cell's genetic information?
   A. 1
   B. 2
   C. 3
   D. 4

7. Which structure is a vestigial structure?
   A. human appendix
   B. deer horns
   C. multiple cow stomachs
   D. snake tail

8. According to the endosymbiont theory, which part of the eukaryotic cell evolved from a prokaryotic cell?
   A. chloroplast
   B. golgi apparatus
   C. nucleus
   D. ribosome

Short Answer

9. List three primate adaptations found in humans, and explain how each one relates to a tree-dwelling habitat.

10. Assess how molecular clocks are useful in investigating phylogeny in ways that morphological characteristics are not.

11. In terms of their evolution, how are homologous structures and analogous structures different?

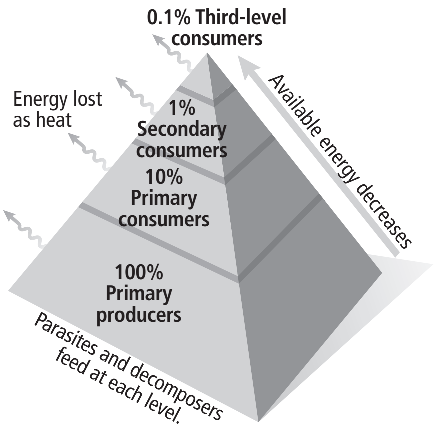
12. Assess the advantage of bipedalism.

13. Infer why Aristotle only used two kingdoms to classify living things.

14. Assess the significance of the discovery of the Lucy fossil.

15. Contrast one of the characteristics of living things with the characteristics of nonliving things such as rocks.

Use the figure below to answer question 16.



16. How much energy from one trophic level is available to organisms at the next higher trophic level?

Extended Response

17. How could a mutagen cause a change in the protein for which a DNA strand is coding? Trace the effect of a specific mutation through the process of protein synthesis.

18. Assess the value of the binomial system of naming organisms.

19. Name two animals that you would expect to have similar chromosomal characters. Design an experiment to test whether they are similar.

Essay Question

Scientists often use multiple types and sources of data in order to determine when different groups of organisms evolved. Taken together, the data can help construct an evolutionary history.

Using the information in the paragraph above, answer the following question in essay format.

20. What kind of evidence could help scientists determine whether bacteria or archaea evolved earlier on Earth? Write an essay that justifies what specific kinds of data would need to be collected to make this judgment.

NEED EXTRA HELP?																				
If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Review Section . . .	16.3	17.2	17.2	14.1	15.3	16.2	15.2	14.2	16.1	7.2	15.2	16.2	17.1	16.2	1.1	2.2	12.3	17.1	17.2	17.2, 17.3