Harris' antelope squirrel

Cardon cactus

Ocotillo plant

Desert orange tip

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

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

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

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	Interactive Table
Plants		
Herbs	Shrubs	Trees
Violets	Blackberry bush	Apple
Rosemary	Honeysuckle	Oak
Onions	Flannelbush	Maple
Animals with red blood		
Land	Water	Air
Wolf	Dolphin	Owl
Cat	Eel	Bat
Bear	Sea bass	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.
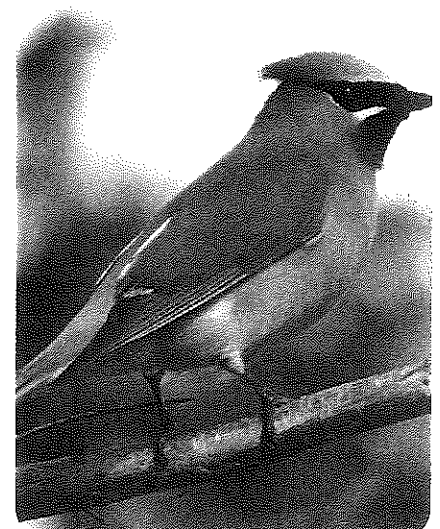**Infer** *in which group Linnaeus might have placed a robin.*

American bald eagle
Bird of prey

Great blue heron
Wading bird

Cedar waxwing
Perching bird

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 redbird, 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 the Grizzly bear (*Ursus arctos*) 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.*
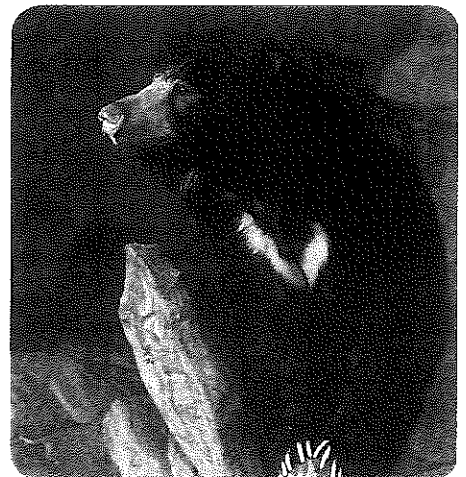
Family All bears, both living and extinct species, belong to the same family, Ursidae. A **family** is the next higher taxon, consisting of similar, related genera. In addition to the three species shown in **Figure 3,** the Ursidae family contains six other species: brown bears, polar bears, giant pandas, 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.

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 arctos
Grizzly bear
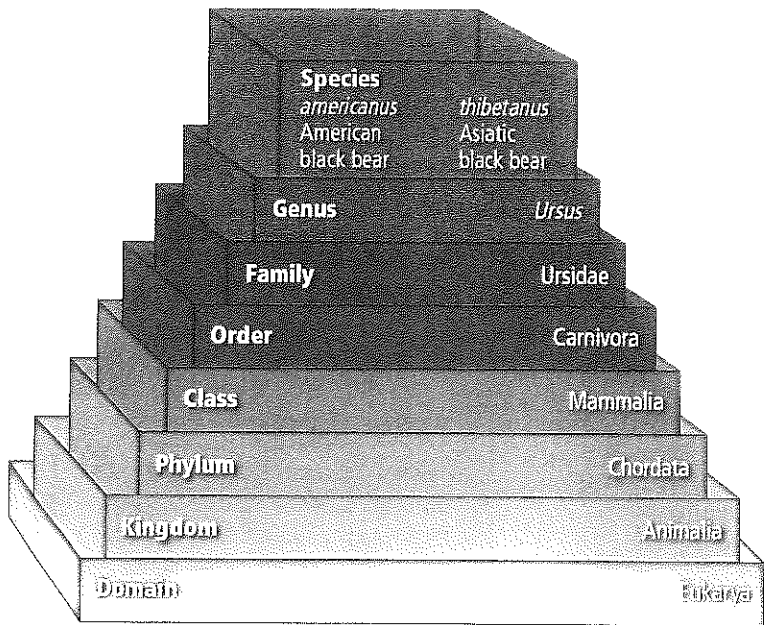
Melursus ursinus
Sloth bear

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

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.

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. **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.

Online Quiz

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

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.*
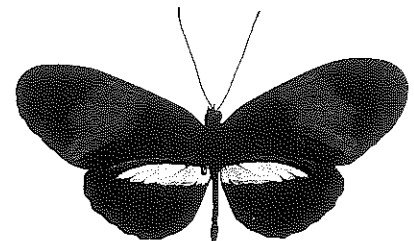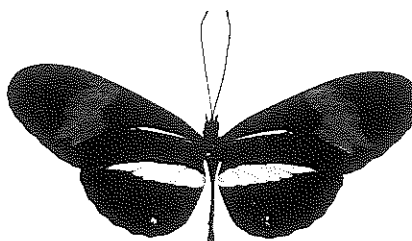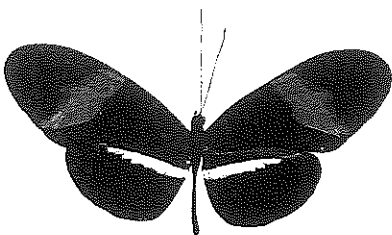
Barbara Strnadova/Photo Researchers

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.

Launch Lab

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

Table 2	Species Concepts			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.

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.

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.*
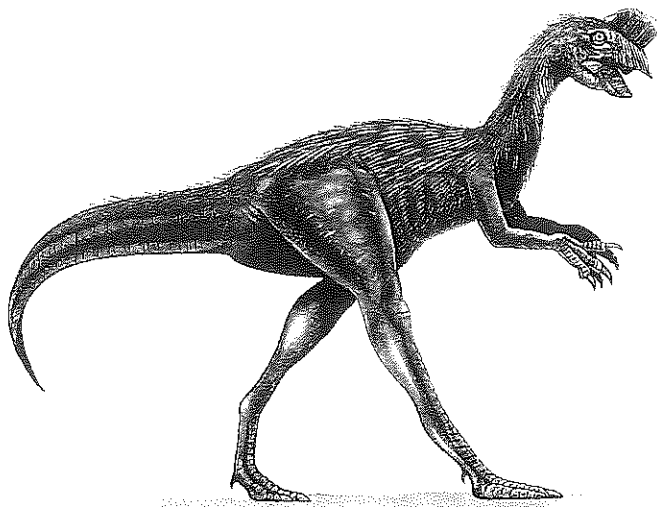
Characters

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.

Oviraptor philoceratops

Zonotrichia leucophrys

©G.I. Andrewartha/FLPA/Corbis

Chimpanzee
Pan troglodytes

Gorilla
Gorilla gorilla

Orangutan
Pongo pygmaeus

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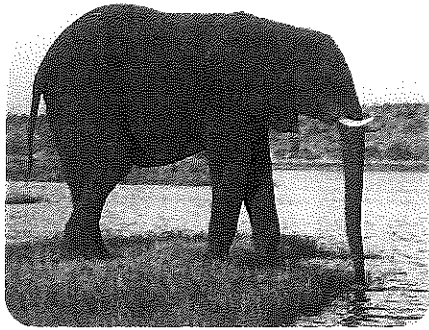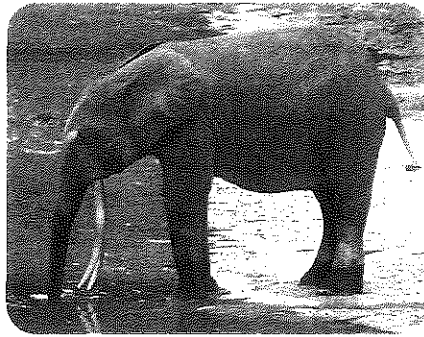
VOCABULARY
ACADEMIC VOCABULARY
Corresponding
being similar or equivalent in character, quantity, origin, structure, or function
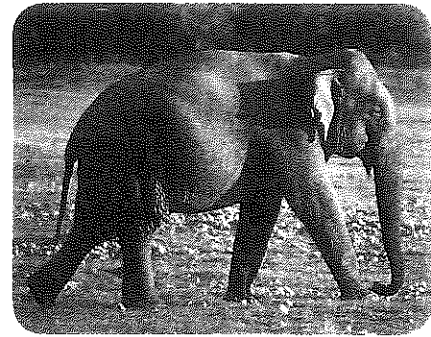*The corresponding sequences matched perfectly.*

(l)Michael Nichols/National Geographic Stock; (c)McGraw-Hill Education; (r)©Theo Allofs/zefa/Corbis

African elephant (savanna)   **African elephant (forest)**   **Asiatic elephant**

Figure 9 The two populations of African elephants had 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 obtained from: Roca, A.L., et al. 2001. Genetic evidence for two species of elephants in Africa. *Science* 293(5534): 1473-1477.

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?

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.

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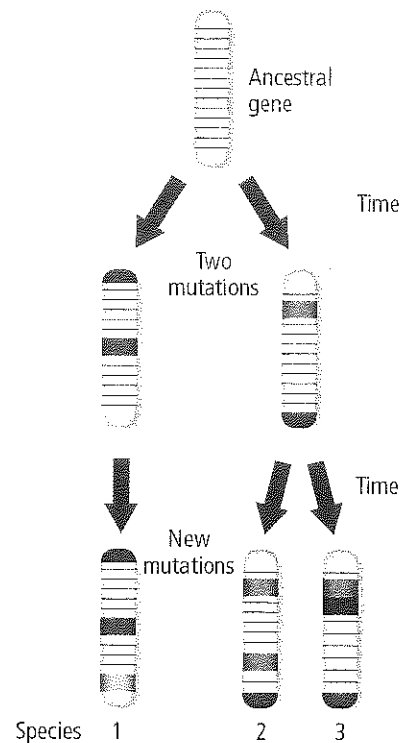
VOCABULARY
WORD ORIGIN
Cladistics
comes from the Greek word *klados*, meaning *sprout* or *branch*

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.
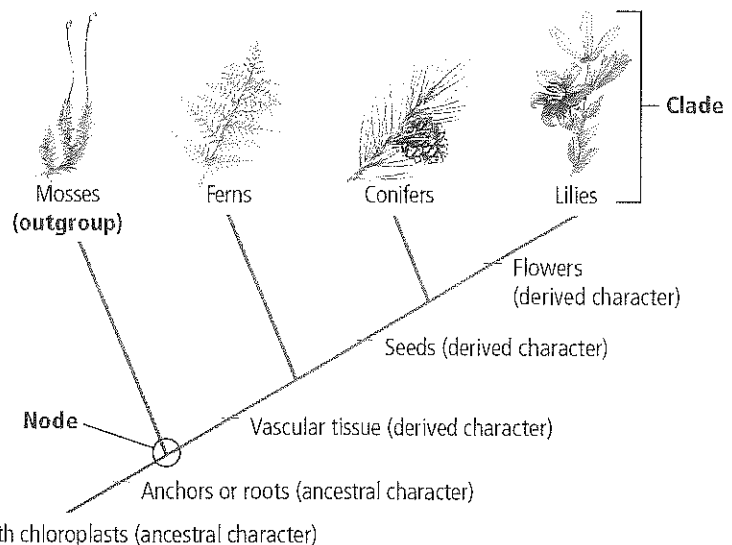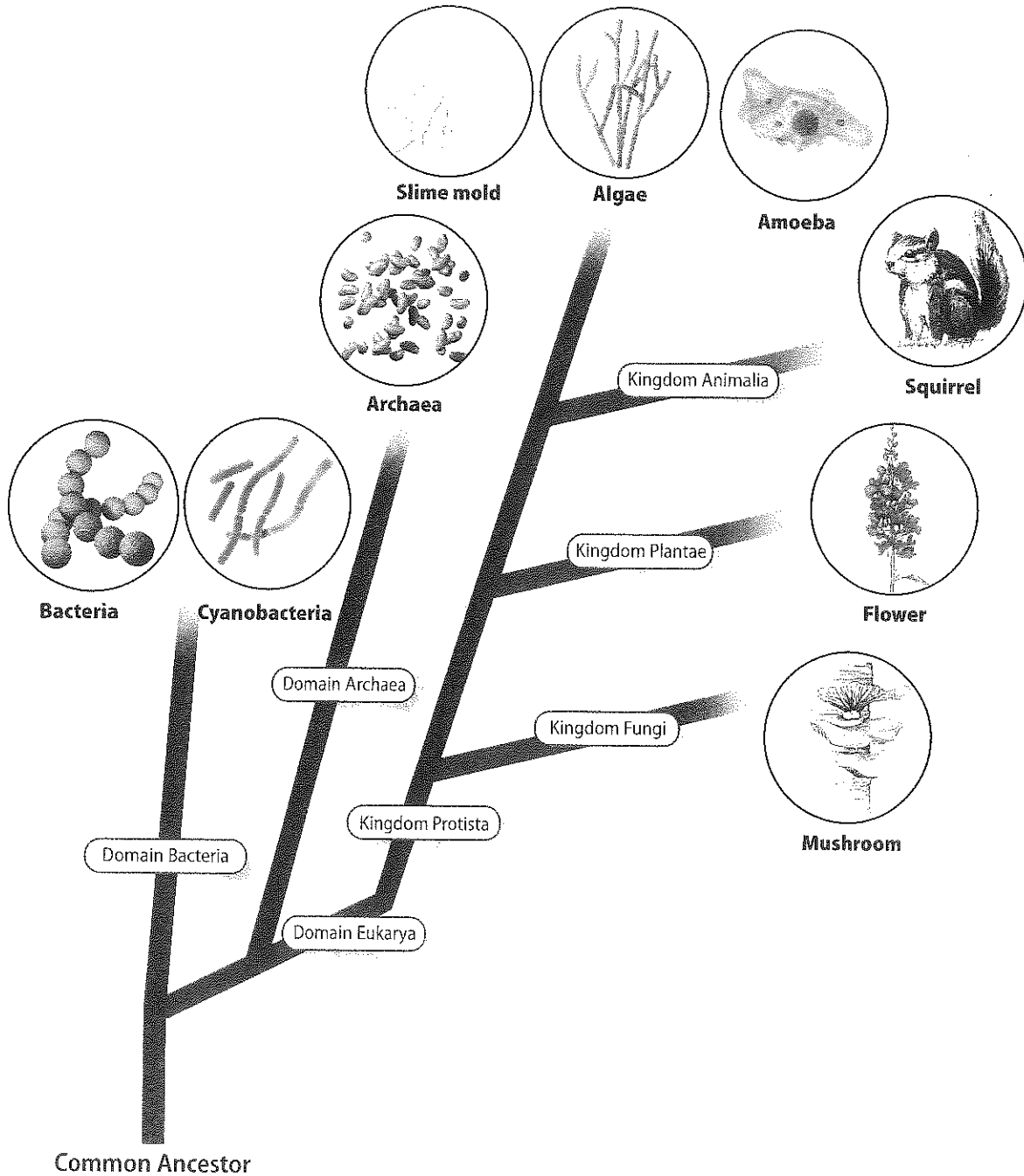
Animation

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.*

Mosses
(outgroup)　Ferns　Conifers　Lilies

Clade

Flowers
(derived character)

Seeds (derived character)

Node

Vascular tissue (derived character)

Anchors or roots (ancestral character)

Ancestor with chloroplasts (ancestral character)

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.*

Slime mold

Algae

Amoeba

Archaea

Squirrel

Bacteria

Cyanobacteria

Kingdom Animalia

Kingdom Plantae

Flower

Domain Archaea

Kingdom Fungi

Kingdom Protista

Mushroom

Domain Bacteria

Domain Eukarya

Common Ancestor

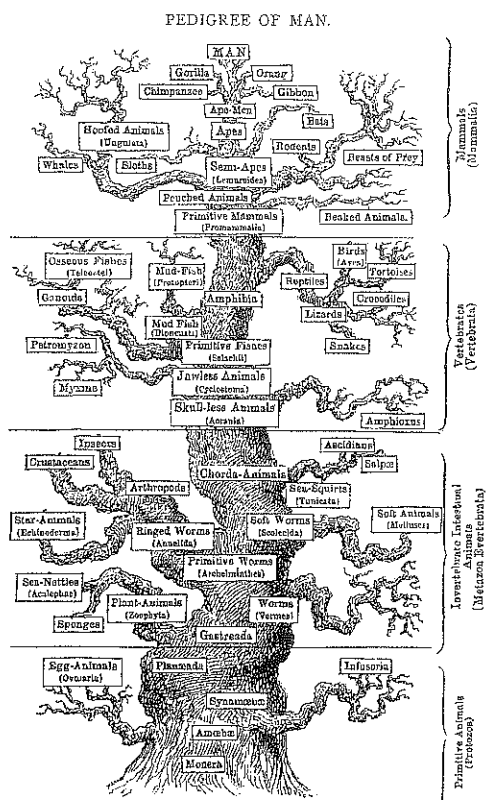▷ Animation

PEDIGREE OF MAN.

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

▶ Animation

Connection to 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.

☑ Online Quiz

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

Multilingual eGlossary

Virtual Lab

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

Anabaena

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 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.
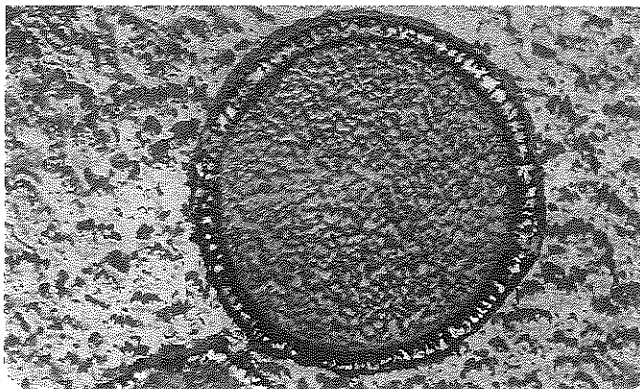
Bacteria are a diverse group that can survive in many different environments. Some are aerobic organisms that need oxygen to survive, while others are anaerobic organisms that die in the presence of oxygen. Some bacteria are autotrophic and produce their own food, but most are heterotrophic and get their 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.**

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.
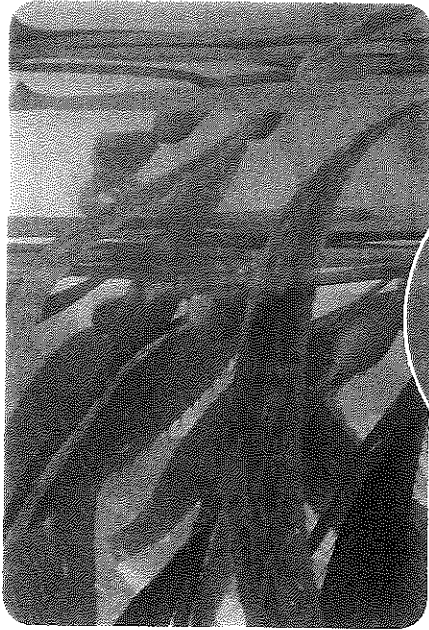
MiniLab 2

Compare Bacteria

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.
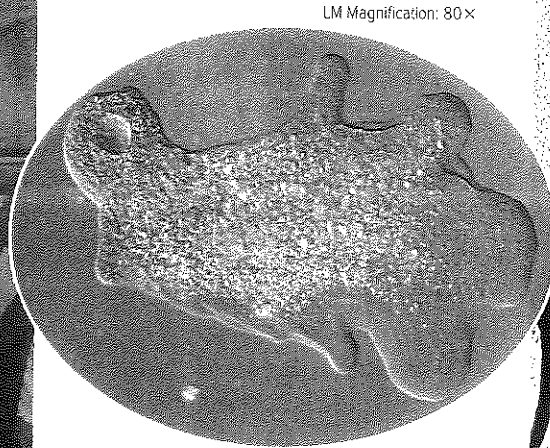
Procedure
1. Read and complete the lab safety form.
2. Observe the prepared **slides of bacteria** with a **compound light microscope.**
3. Create a data table to compare the shapes and features of the bacteria you observe.
4. Compare and contrast the bacteria from the prepared slides. Record your observations 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.
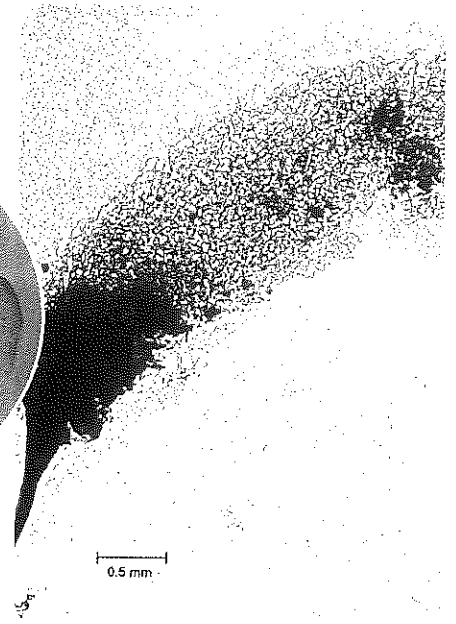
LM Magnification: 80×

Amoeba

Kelp

Slime mold

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.

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.

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.*

▷ BrainPOP

◀**FOLDABLES**
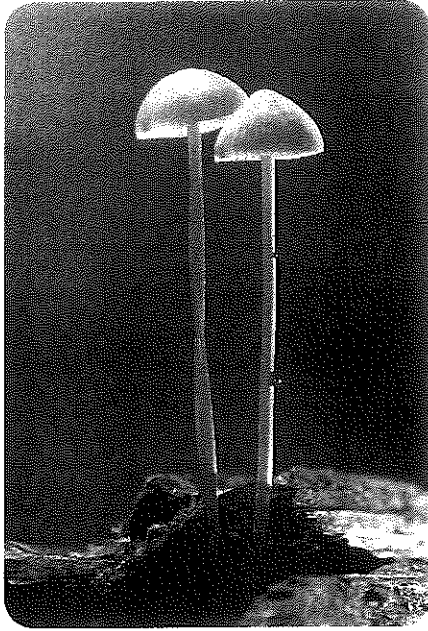Incorporate information from this section into your Foldable.

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					▷ Interactive Table
Domain	Bacteria	Archaea	Eukarya			
Kingdom	Bacteria	Archaea	Protista	Fungi	Plantae	Animalia
Example	*Pseudomonas*	*Methanopyrus*	*Paramecium*	Mushroom	Moss	Earthworm
	SEM Magnification: 5500×	TEM Magnification: 25,000×	LM Magnification: 150×			
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
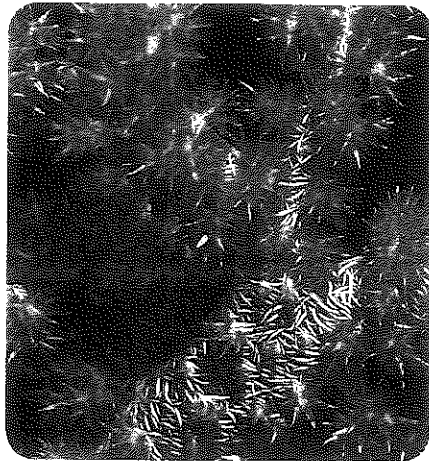
Coral

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. **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.

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.

DNA Sequences

Honeybee

Bumble bee

Robin

Hermit thrush
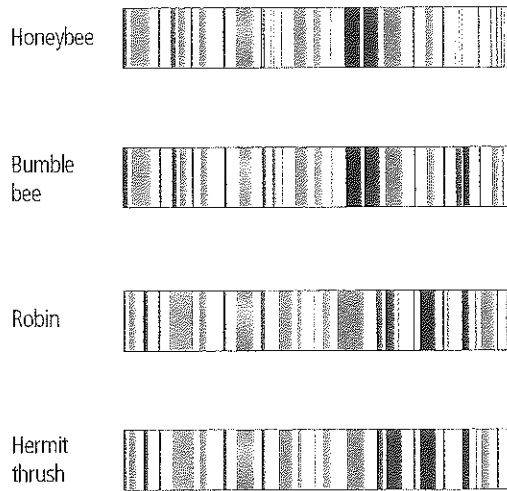
This representation of DNA barcodes shows that more closely related species would have more similar barcodes.

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.

WebQuest

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.

THEME FOCUS Patterns 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.

Vocabulary eGames

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 Patterns** 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?
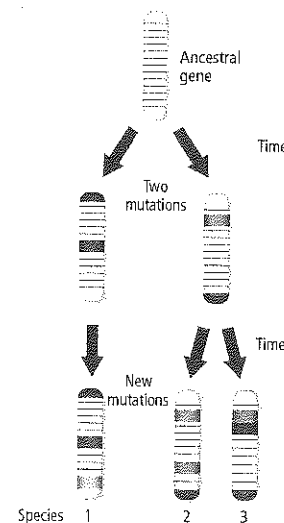
Section 2

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

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.

Crocodilians   Dinosaurs   Birds
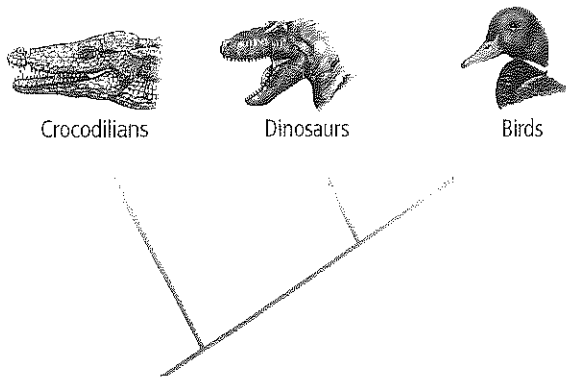
15. According to the figure, which organism diverged last?
    A. alligators
    B. birds
    C. crocodiles
    D. dinosaurs

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. ▬▬◀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.
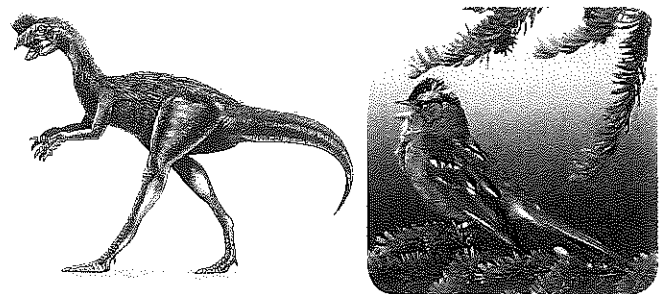
23. **Evaluate** evidence that suggests that the two organisms in the figure are closely related.

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   C. family
    B. phylum   D. domain

28. In which kingdom would prokaryotes found living in acid runoff likely be classified?
    A. Bacteria   C. Fungi
    B. Archaea   D. Protista

✓ Online Test Practice

Use the photograph below to answer question 29.
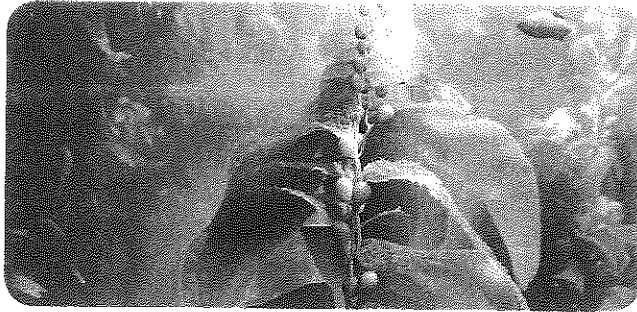
29. In which kingdom would this organism, which has chloroplasts, cell walls, but no organs, be classified?
A. Plantae   C. Protista
B. Animalia   D. Fungi

30. Which substance would most likely be in the cell walls of an organism with chloroplasts and tissues?
A. peptidoglycan   C. hyphae
B. chitin   D. cellulose

Constructed Response

31. ▓▓▓▓▓ 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.
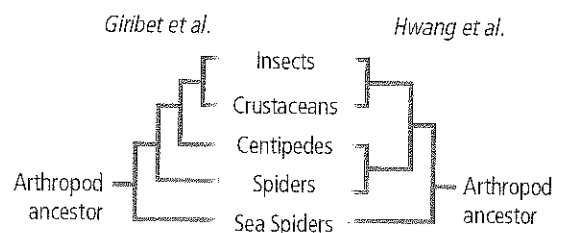

Online Test Practice

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.

 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.

Giribet et al.   Hwang et al.

Insects
Crustaceans
Centipedes
Spiders
Sea Spiders
Arthropod ancestor
Arthropod ancestor

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?

Standardized Test Practice

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.
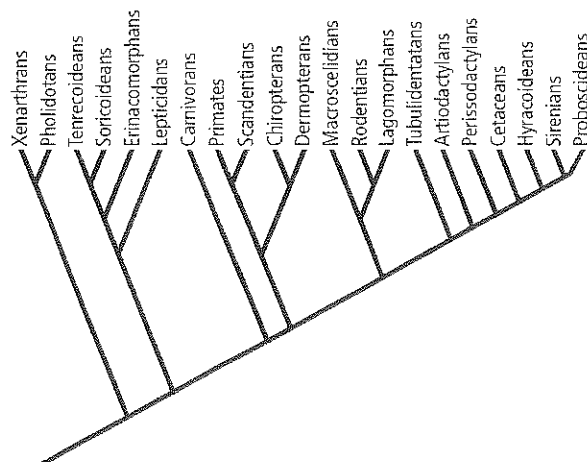
2. According to the cladogram of mammals, which two groups of animals have a more recent common ancestor?
   A. carnivorans and chiropterans
   B. cetaceans and hyracoideans
   C. dermopterans and carnivorans
   D. rodentians and lagomorphans

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.

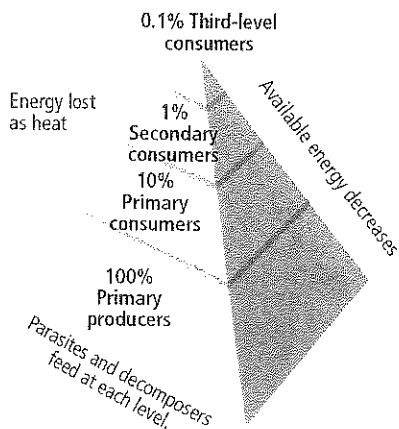*Use the diagram below to answer question 6.*
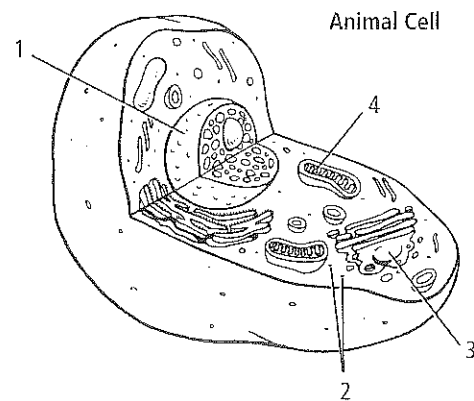
6. Which labeled structure contains the cell's genetic information?
   A. 1
   B. 2
   C. 3
   D. 4

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

Standardized Test Practice

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.

0.1% Third-level consumers

Energy lost as heat

1% Secondary consumers

10% Primary consumers

100% Primary producers

Available energy decreases

Parasites and decomposers feed at each level.

16. How much energy from one trophic level is available to organisms at the next higher trophic level?

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.

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