InquiryLab

15 min

What Is Your System?

Often, more than one way exists to organize or group things. In this lab, you will work with others to decide on a system.

Procedure

1. Work with a partner. Examine the **assortment of objects** provided by your teacher.
2. Sort your objects into groups of “related” objects. Try to get every object into a group with at least one other object.
3. Choose a name for each group.
4. Choose one object from your collection, and trade it with an object from another pair of students.
5. Try to fit the new object into one of your groups.

Analysis

1. **List** and define each of your group names from step 3.
2. **Describe** how you classified the new object in step 4.
3. **Predict** whether another person would be able to “correctly” classify one of your objects by using your list of groups. Explain your reasoning.

READING TOOLBOX

These reading tools can help you learn the material in this chapter. For more information on how to use these and other tools, see **Appendix: Reading and Study Skills.**

Using Words

Word Origins Many scientific words derive their parts from Greek or Latin words. Learning the meanings of some Greek and Latin word parts can help you understand the meaning of many scientific words.

Your Turn Answer the following questions.

1. What do taxonomists probably do?
2. What role might nomenclature have in taxonomy?

Word Parts

Word part	Origin	Meaning
tax	Greek	arrangement, order, movement
nom	Greek; Latin	law, order, system; name
clatur	Latin	calling, naming
clad	Greek	shoot, branch, twig
phyl	Greek	tribe, race, class, clan
gram	Greek	write, a written record
gen	Greek, Latin	birth, descent, origin, creation
morph	Greek	shape, form, appearance

Using Language

Mnemonics Mnemonic devices are tools that help you remember lists or parts in their proper order. Use the first letter of every word that you want to remember as the first letter of a new word in a memorable sentence. You may be more likely to remember the sentence if the sentence is funny.

Your Turn Create mnemonic devices that could help you remember all of the parts of the following groups of items.

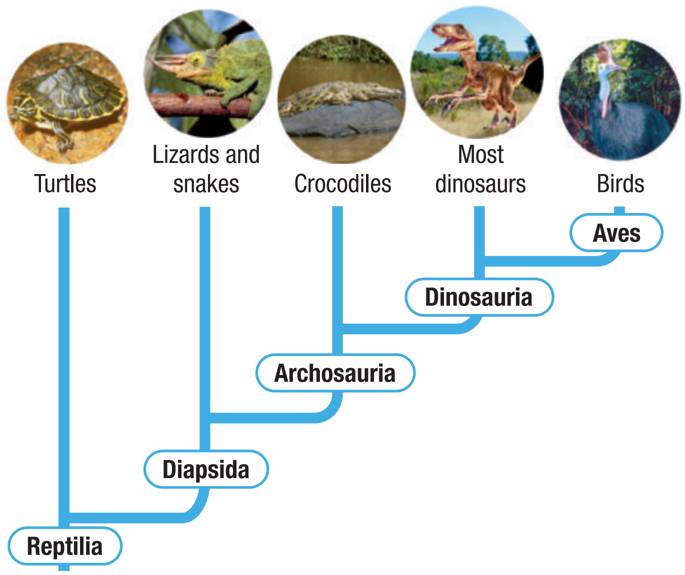
1. the names of all of your teachers
2. the 12 months of the year

Using Science Graphics

Phylogenetic Tree A phylogenetic tree shows the relationships of different groups of organisms to each other. The groups that are most closely related appear on branches that lie close together. Branch points represent a point in time where groups became separated and speciation began. Time is represented as moving forward from the bottom (or trunk) toward the top (or branches) of the tree.

Your Turn Use this phylogenetic tree to answer the following questions.

1. Which group is most closely related to extinct dinosaurs?
2. Which group existed before the other groups did?



Section 1

The Importance of Classification

Key Ideas	Key Terms	Why It Matters
Why do biologists have taxonomic systems? What makes up the scientific name of a species? What is the structure of the modern Linnaean system of classification?	taxonomy genus binomial nomenclature	In order to study and make use of living things, we need a name for each specific thing.

The number of species that exist in the world is much greater than the number known. About 1.7 million species have been named and described by scientists. But scientists think that millions more are undiscovered. We have little knowledge of Earth's variety of species.

The Need for Systems

In biology, the practice of naming and classifying organisms is called **taxonomy.** Scientists use a logical system of classification to manage large amounts of information. Similarly, a library uses a system for organizing books. **Biologists use taxonomic systems to organize their knowledge of organisms. These systems attempt to provide consistent ways to name and categorize organisms.**

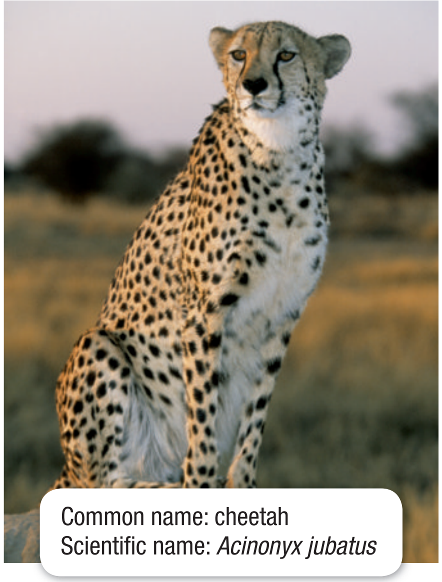
Common names of organisms are not organized into a system. One species may have many common names, and one common name may be used for more than one species. For example, the bird called a *robin* in Great Britain is a different bird from the bird called a *robin* in North America. To avoid confusion, biologists need a way to name organisms that does not depend on language or location.

Biologists also need a way to organize lists of names. A system that has categories is more efficient than a simple list. So, biologists group organisms into large categories as well as smaller and more specific categories. The general term for any one of these categories is a *taxon* (plural, *taxa*).

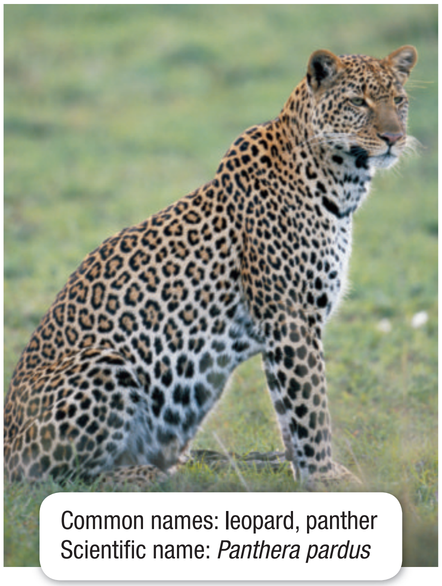
Reading Check *What is the problem with common names of species? (See the Appendix for answers to Reading Checks.)*

taxonomy (taks AHN uh mee) the science of describing, naming, and classifying organisms

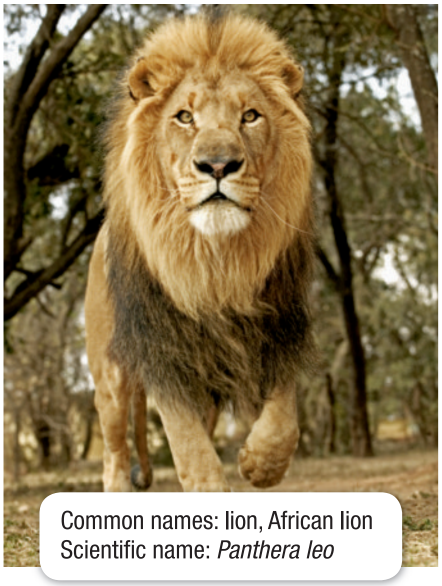
Figure 1 Museums are full of biological specimens, yet only a fraction of Earth's species have been scientifically named.



Common name: cheetah
Scientific name: *Acinonyx jubatus*



Common names: leopard, panther
Scientific name: *Panthera pardus*



Common names: lion, African lion
Scientific name: *Panthera leo*

Figure 2 Each species may have many common names but only one scientific name. The scientific name is made up of a genus name and a species identifier. Each genus is a group of closely related species. **To what genus do both lions and leopards belong?**

genus (JEE nuhs) a level of classification that contains similar species

binomial nomenclature (bie NOH mee uhl NOH muhn KLAY chuhr) a system for giving each organism a two-word scientific name that consists of the genus name followed by the species name

Scientific Nomenclature

As biology became established as a science, biologists began to create systems for naming and classifying living things. A major challenge was to give each species a unique name.

Early Scientific Names In the early days of European biology, various naming systems were invented. Some used long, descriptive Latin phrases called *polynomials*. Names for taxa were inconsistent between these systems. The only taxon that was somewhat consistent was the **genus,** which was a taxon used to group similar species.

A simpler and more consistent system was developed by the Swedish biologist Carl Linnaeus in the 1750s. He wanted to catalog all known species. He wrote books in which he used the polynomial system but added a two-word Latin name for each species. His two-word system is called **binomial nomenclature.** For example, his two-part name for the European honeybee was *Apis mellifera*, the genus name followed by a single descriptive word for each species. **Figure 2** shows the binomial names of three other animals.

Naming Rules In the years since Linnaeus created his system, his basic approach has been universally adopted. The unique two-part name for a species is now called a *scientific name*. Scientific names must conform to rules established by an international commission of scientists. No two species can have the same scientific name.

All scientific names for species are made up of two Latin or Latin-like terms. All of the members of a genus share the genus name as the first term. The second term is called the *species identifier* and is often descriptive. For example, in the name *Apis mellifera,* the term *mellifera* derives from the Latin word for "honey." When you write the scientific name, the genus name should be capitalized and the species identifier should be lowercased; both terms should be italicized.

Reading Check ***Why did Linnaeus devise a new naming system?***

The Linnaean System

In trying to catalog every known species, Linnaeus devised more than just a naming system. He devised a system to classify all plants and animals that were known during his time. His system formed the basis of taxonomy for centuries. **❯ In the Linnaean system of classification, organisms are grouped at successive levels of a hierarchy based on similarities in their form and structure.** Since Linnaeus's time, many new groups and some new levels have been added, as **Figure 3** shows. **❯ The eight basic levels of modern classification are domain, kingdom, phylum, class, order, family, genus, and species.**

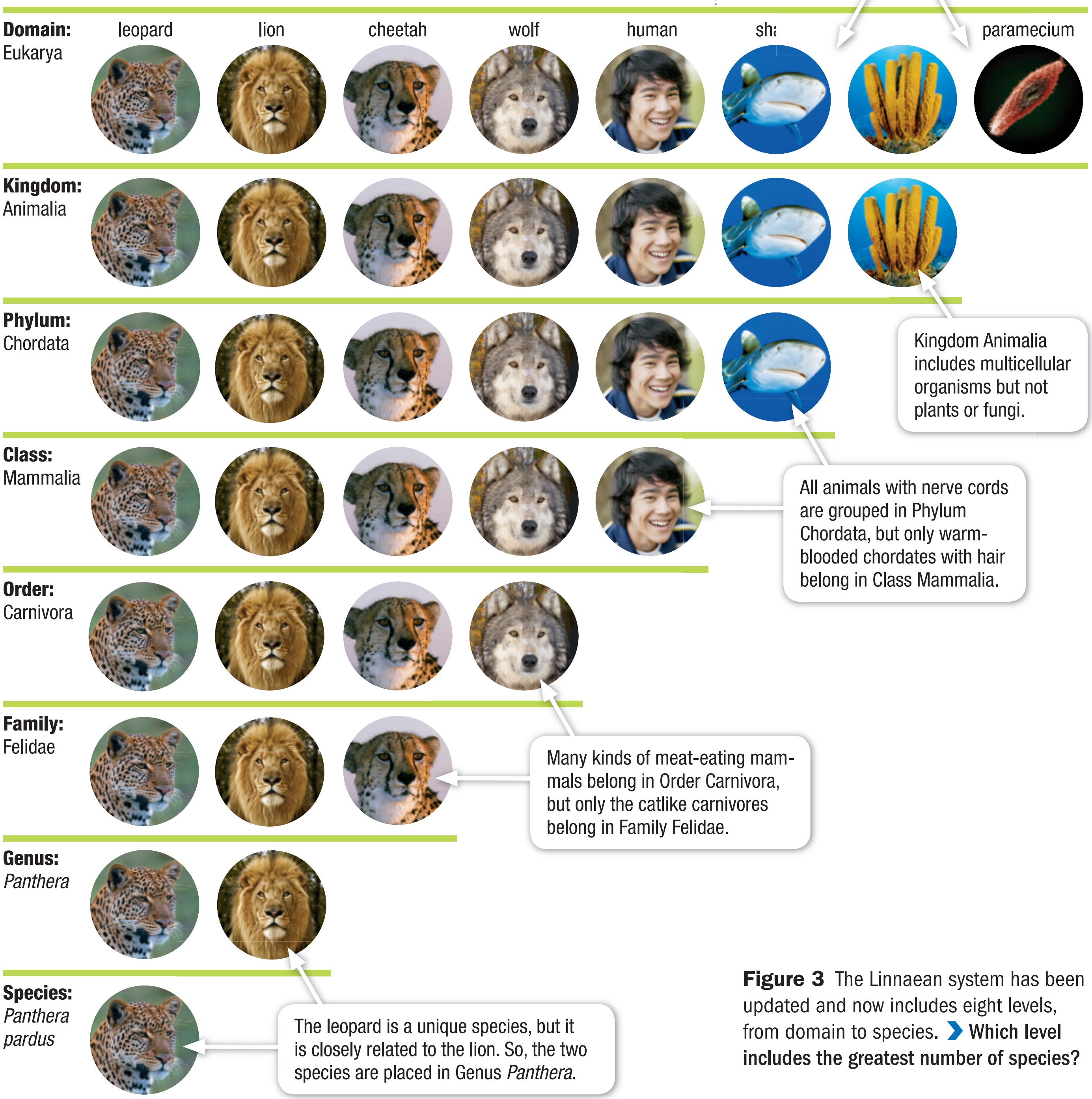


Figure 3 The Linnaean system has been updated and now includes eight levels, from domain to species. **❯ Which level includes the greatest number of species?**

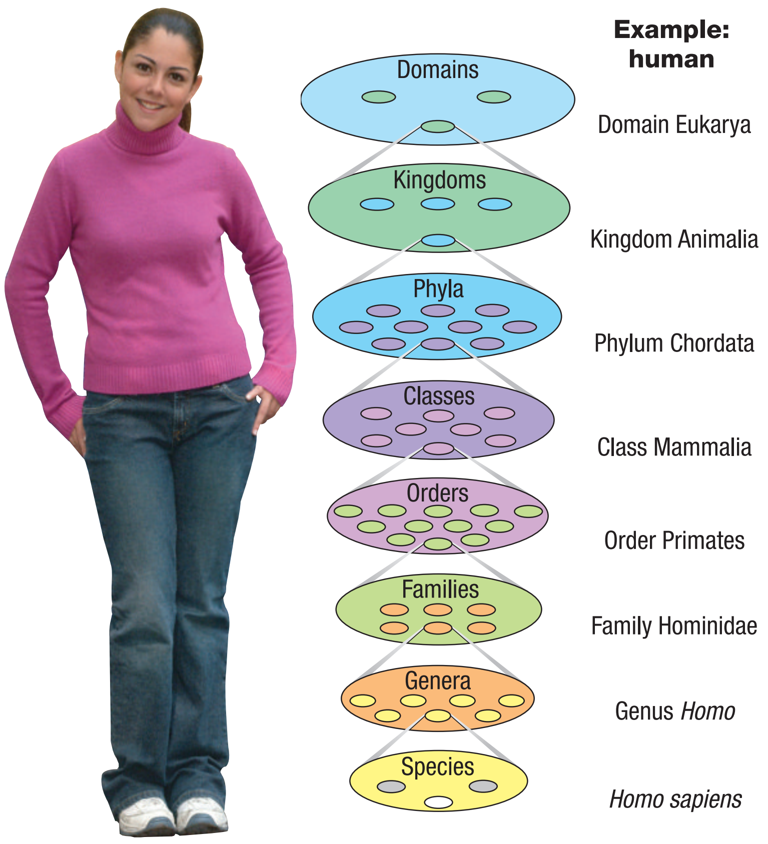


Figure 4 A species can be classified at each level of the Linnaean system.

Levels of the Modern Linnaean System

Each level has its own set of names for taxa at that level. Each taxon is identified based on shared traits. Similar species are grouped into a genus; similar genera are grouped into a family; and so on up to the level of domain. **Figure 4** shows the classification of humans in this system.

- **Domain** Since Linnaeus's time, the category *domain* has been invented in order to recognize the most basic differences among cell types. All living things are now grouped into one of three domains. For example, humans belong to the domain Eukarya.
- **Kingdom** The category *kingdom* encompasses large groups such as plants, animals, or fungi. Six kingdoms fit within the three domains.
- **Phylum** A *phylum* is a subgroup within a kingdom. Many phyla exist within each kingdom. Humans belong to the phylum Chordata.
- **Class** A *class* is a subgroup within a phylum.
- **Order** An *order* is a subgroup within a class.
- **Family** A *family* is a subgroup within an order. Humans belong to the family Hominidae.
- **Genus** A *genus* (plural, *genera*) is a subgroup within a family. Each genus is made up of species with uniquely shared traits, such that the species are thought to be closely related. Humans belong to the genus *Homo*.
- **Species** A *species* is usually defined as a unique group of organisms united by heredity or interbreeding. But in practice, scientists tend to define species based on unique features. For example, *Homo sapiens* is recognized as the only living primate species that walks upright and uses spoken language.

Reading Check ***How many kingdoms are in the Linnaean system?***

READING TOOLBOX

Mnemonics To remember the eight levels in their proper order, use a phrase, such as "Do Kindly Pay Cash Or Furnish Good Security," to represent *Domain, Kingdom, Phylum, Class, Order, Family, Genus,* and *Species*.

Section 1 Review

KEY IDEAS

1. **Explain** why biologists have systems for naming and grouping organisms.
2. **Describe** the structure of a scientific name for a species.
3. **List** the categories of the modern Linnaean system of classification in order from general to specific.

CRITICAL THINKING

4. **Logical Reasoning** Describe additional problems that might occur for biologists without a logical taxonomic system.
5. **Anticipating Change** Although the basic structure of the system that Linnaeus invented is still in use, many aspects of this system have changed. Suggest some possible ways that the system may have changed.

ALTERNATIVE ASSESSMENT

6. **Classification Poster** Create a poster that shows the major levels of classification for your favorite organism. Write a description of the general characteristics of the organism at each level. For each level, include a list of other organisms that belong to the same taxon.

Section 2

Modern Systematics

Key Ideas	Key Terms	Why It Matters
❯ What problems arise when scientists try to group organisms by apparent similarities? ❯ Is the evolutionary past reflected in modern systematics? ❯ How is cladistics used to construct evolutionary relationships? ❯ What evidence do scientists use to analyze these relationships?	phylogeny cladistics	Modern systematics unites evolutionary science with traditional studies of anatomy.

Have you ever wondered how scientists tell one species from another? For example, how can you tell a mushroom that is harmless from a mushroom that is poisonous? Identification is not easy, even for experts. The experts often revise their classifications as well as their procedures. This field of expertise is known as *systematics*.

Traditional Systematics

Linnaeus's system was based on his judgment of the importance of various similarities among living things. ❯ **Scientists traditionally have used similarities in appearance and structure to group organisms. However, this approach has proven problematic.** Some groups look similar but turn out to be distantly related. Other groups look different and turn out to be closely related. Often, new data or new analyses suggest relationships between organisms that were not apparent before.

For example, dinosaurs were once seen as a group of reptiles that became extinct millions of years ago. And birds were seen as a separate, modern group that was not related to any reptile group. However, fossil evidence has convinced scientists that birds evolved from one of the many lineages of dinosaurs. Some scientists now classify birds as a subgroup of dinosaurs, as described in **Figure 5.**

❯ **Reading Check** *What is systematics?*

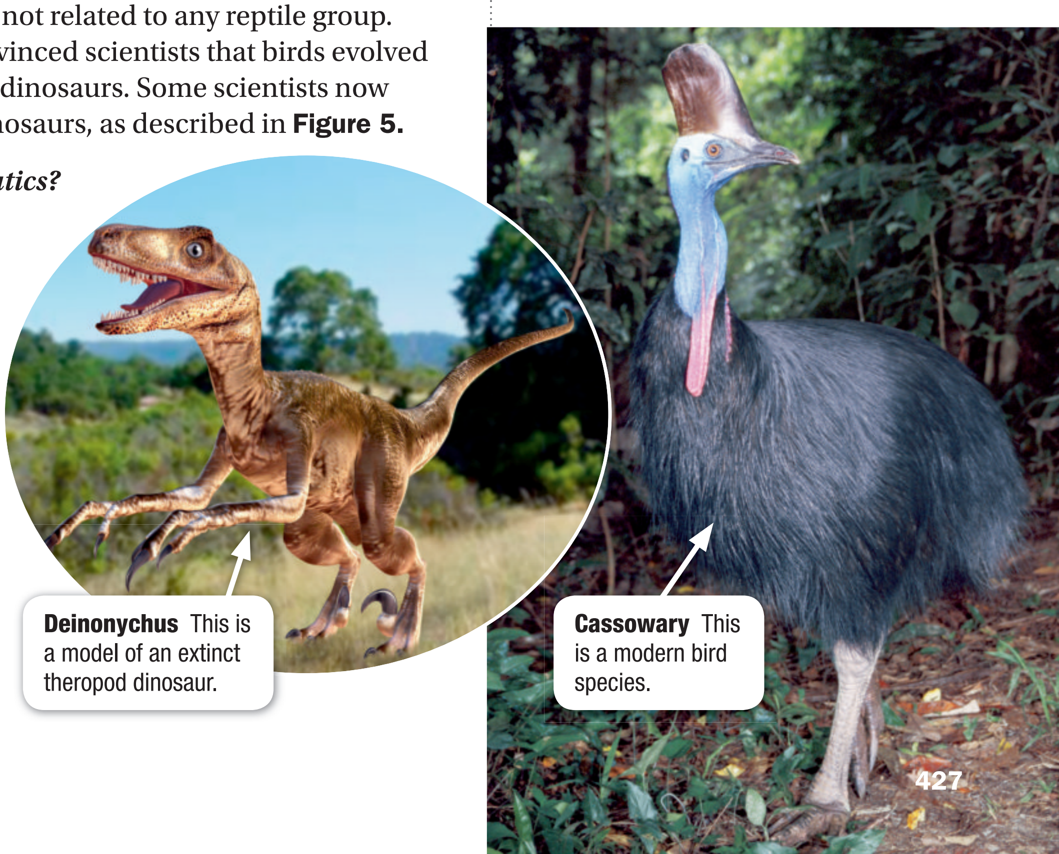


Figure 5 In a sense, birds are dinosaurs. Scientists think that modern birds are descended from a subgroup of dinosaurs called *theropods*. This inference is based on thorough comparisons of modern birds and fossilized theropods.

Deinonychus This is a model of an extinct theropod dinosaur.

Cassowary This is a modern bird species.

Phylogenetics

Today, scientists who study systematics are interested in **phylogeny,** or the ancestral relationships between species. **Grouping organisms by similarity is often assumed to reflect phylogeny, but inferring phylogeny is complex in practice.** Reconstructing a species' phylogeny is like trying to draw a huge family tree that links ancestors and descendants across thousands or millions of generations.

phylogeny the evolutionary history of a species or taxonomic group

cladistics a phylogenetic classification system that uses shared derived characters and ancestry as the sole criterion for grouping taxa

Misleading Similarities Inferring phylogenies from similarities can be misleading. Not all similar characters are inherited from a common ancestor. Consider the wings of a bird and of an insect. Both types of wings enable flight, but the structures of the two kinds of wings differ. Moreover, fossil evidence shows that insects with wings existed long before birds with wings appeared. Through the process called *convergent evolution,* similarities may evolve in groups that are not closely related to one another, often because the groups become adapted to similar habitats or lifestyles. Similarities that arise through convergent evolution are called *analogous* characters.

Judging Relatedness Another problem is that grouping organisms by similarities is subjective. Are all characters equally important, or are some more important than others? Often, different scientists may give different answers to these questions.

For example, systematists historically placed birds in a separate class from reptiles, giving importance to characters such as feathers, as **Figure 6** shows. But more recently, fossil evidence and detailed studies of bird and dinosaur anatomy have changed the view of these groups. **Figure 6** shows that birds are now considered part of the "family tree" of dinosaurs. This family tree, or *phylogenetic tree,* represents a hypothesis of the relationships between several groups.

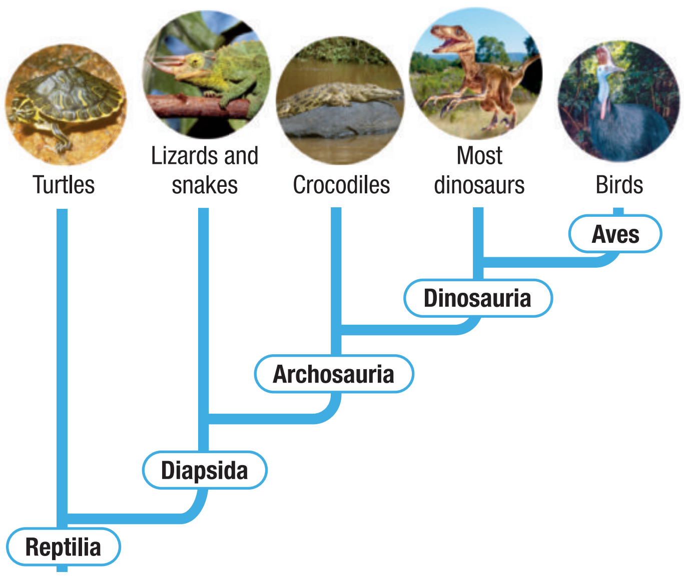
Figure 6 Traditional systematics grouped birds separately from other reptiles by emphasizing the unique features of birds. However, modern phylogenetics places birds as a subgroup of reptiles on a phylogenetic tree. **How do these two systems differ in structure?**

Linnaean Classification

Classes of Animals

Class Reptilia	Class Aves
egg-laying, exothermic, scales	egg-laying, endothermic, feathers
lizards, snakes, turtles, crocodiles, and dinosaurs	birds

Modern Phylogeny



Cladistics

To unite systematics with phylogenetics, scientists need an objective way to sort out relatedness. Today, the preferred method is cladistics. **Cladistics** is a method of analysis that infers phylogenies by careful comparisons of shared characters. **Cladistic analysis is used to select the most likely phylogeny among a given set of organisms.**

ACADEMIC VOCABULARY

objective independent of the mind; without bias

Comparing Characters Cladistics focuses on finding characters that are *shared* between different groups of organisms because of shared ancestry. With respect to two groups, a shared character is defined as *ancestral* if it is thought to have evolved in a common ancestor of both groups. In contrast, a *derived* character is one that evolved in one group but not in the other group. Cladistics infers relatedness by identifying shared derived and shared ancestral characters among groups while avoiding the use of analogous characters.

For example, consider the relationship between flowering plants and conifers. The production of seeds is a character that is present in all living conifers and flowering plants and in some prehistoric plants. So, it is a shared ancestral character among these groups. The production of flowers, however, is a derived character that is shared only among flowering plants. Flowers evolved in some ancestor of flowering plants but did not evolve in the group that led to conifers.

READING TOOLBOX

Word Origins The word root *clad* means "shoot, branch or twig" and the word root *gram* means "to write or record." Use this information to analyze the meaning of the term *cladogram.*

Constructing Cladograms Cladistics uses a strict comparison of many characters among several groups in order to construct a cladogram. A *cladogram* is a phylogenetic tree that is drawn in a specific way, as **Figure 7** shows. Organisms are grouped together through identification of their shared derived characters. All groups that arise from one point on a cladogram belong to a clade. A *clade* is a set of groups that are related by descent from a single ancestral lineage.

Each clade in a tree is usually compared with an *outgroup,* or group that lacks some of the shared characters. For example, **Figure 7** shows that flowering plants and conifers share a character with each other that they do not share with ferns. So, conifers and flowering plants form a clade, and ferns form the outgroup.

Reading Check *What does a cladogram show?*

Characters in Plants

Type of plants	Vascular tissue	Seeds	Flowers
Mosses	no	no	no
Ferns	yes	no	no
Conifers	yes	yes	no
Flowering plants	yes	yes	yes

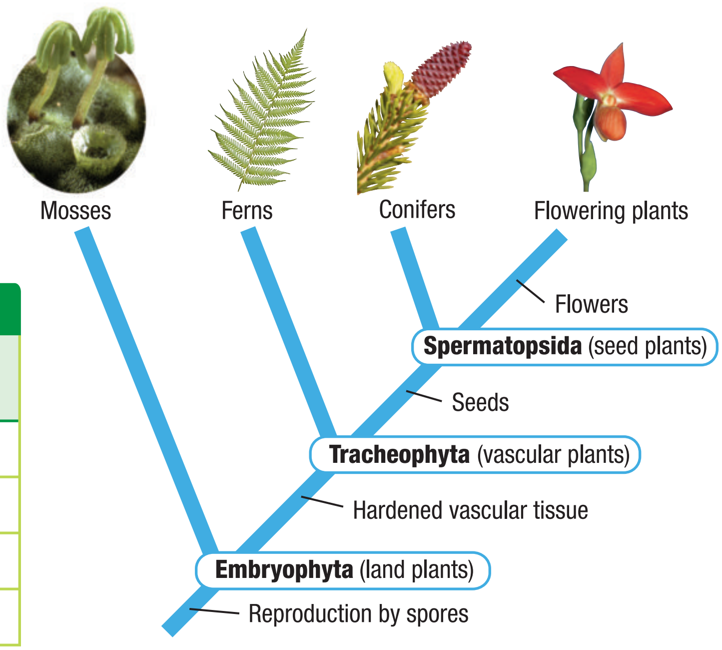


Figure 7 This cladogram organizes plants by using a strict comparison of the characters shown in the table. Each clade is united by a specific shared derived character. **Which groups are united by having seeds?**

Data

QuickLab

10 min

Cladogram Construction

Use this table of shared characters to construct a cladogram. Use the other cladograms in this section to help you draw your cladogram.

Characters in Vertebrates

	Four legs	Amniotic egg	Hair
Tuna	no	no	no
Frog	yes	no	no
Lizard	yes	yes	no
Cat	yes	yes	yes

Analysis

1. **Identify** the outgroup. The outgroup is the group that does not share any of the characters in this list. Draw a diagonal line and then a single branch from its base. Write the outgroup at the tip of this first branch.
2. **Identify** the most common character. Just past the "fork" of the first branch, write the most common derived character. This character should be present in all of the subsequent groups added to the tree.
3. **Complete** the tree. Repeat step 2 for the second most-common character. Repeat until the tree is filled with all of the groups and characters from the table.
4. CRITICAL THINKING **Applying Concepts** What is a shared derived character of cats and lizards?
5. CRITICAL THINKING **Applying Concepts** What character evolved in the ancestor of frogs but not in that of fish?

Inferring Evolutionary Relatedness

As you have seen, phylogenetics relies heavily on data about characters that are either present or absent in taxa. But other kinds of data are also important. **Biologists compare many kinds of evidence and apply logic carefully in order to infer phylogenies.** They constantly revise and add details to their definitions of taxa.

SCILINKS.
www.scilinks.org
Topic: Phylogenetic Tree
Code: HX81141

Morphological Evidence *Morphology* refers to the physical structure or anatomy of organisms. Large-scale morphological data are most obvious and have been well studied. For example, the major characters used to define plant groups—vascular tissue, seeds, and flowers—were recognized long ago. But because convergent evolution can lead to analogous characters, scientists must consider many characters and look carefully for similarities and differences. For example, many animals have wings that are merely analagous.

An important part of morphology in multicellular species is the pattern of development from embryo to adult. Organisms that share ancestral genes often show additional similarities during the process of development. For example, in all vertebrate species, the jaw of an adult develops from the same part of an embryo. In many cases, studies of embryos bring new information to phylogenetic debates.

Molecular Evidence In recent decades, scientists have used genetic information to infer phylogenies. Recall that as genes are passed on from generation to generation, mutations occur. Some mutations may be passed on to all species that descend from a common ancestor. So, DNA, RNA, and proteins can be compared in the same manner as morphology is compared to infer phylogenies.

Reading Check *What is an example of morphological data?*

Sequence Data Today, genetic sequence data are widely used for cladistic analysis. First, the sequence of DNA bases in a gene (or of amino acids in a protein) is determined for several species. Then, each letter (or amino acid) at each position in the sequence is compared. Such a comparison can be laid out in a large table, but computers are best able to calculate the relative similarity of many sequences.

Genomic Data At the level of genomes, alleles may be added or lost over time. So, another form of molecular evidence is the presence or absence of specific alleles—or the proteins that result from them. Finally, the relative timing between genetic changes can be inferred.

Evidence of Order and Time Cladistics can determine only the relative order of divergence, or branching, in a phylogenetic tree. To infer the actual time when a group may have begun to "branch off," extra information is needed. Often, this information comes from the fossil record. For example, by using cladistics, scientists have identified lancelets as the closest relative of vertebrates. The oldest known fossils of vertebrates are about 450 million years old, but the oldest lancelet fossils are 535 million years old. So, these two lineages must have diverged more than 450 million years ago.

More recently, scientists have noticed that most DNA mutations occur at relatively constant rates. So, genetic change can be used as an approximate "molecular clock," as **Figure 8** shows. Scientists can measure the genetic differences between taxa and then estimate the time at which the taxa began to diverge.

Inference Using Parsimony Modern systematists use the *principle of parsimony* to construct phylogenetic trees. This principle holds that the simplest explanation for something is the most reasonable, unless strong evidence exists against the simplest explanation. So, given two possible cladograms, the one that implies the fewest character changes between branch points is preferred.

Reading Check *What kinds of molecular data inform cladistics?*

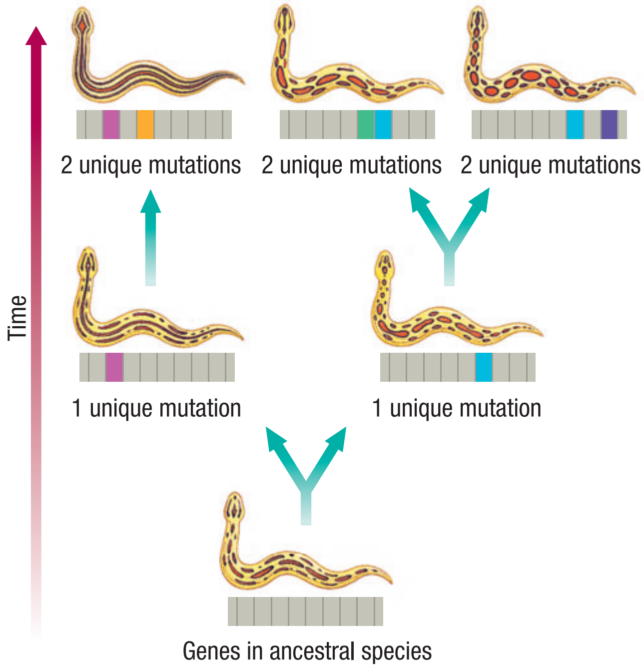


Figure 8 Because mutation occurs randomly at any time, an average rate of mutation can be measured and used as a "clock" to estimate the time any two species took to accumulate a number of genetic differences.

Section 2 Review

KEY IDEAS

1. **Identify** the kinds of problems that arise when scientists try to group organisms by similarities.
2. **Relate** classification to phylogeny.
3. **Describe** the method of cladistics.
4. **Identify** the kinds of evidence used to infer phylogenies.

CRITICAL THINKING

5. **Justifying Reasoning** Some scientists who study dinosaurs have stated that dinosaurs are not extinct. How could this statement be justified?
6. **Analyzing Relationships** Explain how the outgroup in a cladogram relates to the difference between ancestral and derived characters.

METHODS OF SCIENCE

7. **Taxonomic Challenge** In the past, mammals were identified as animals that have fur and give birth to live offspring, and reptiles were identified as animals that have scales and lay eggs. Then, an animal was found that has fur and lays eggs. How might this problem have been resolved?

Why It Matters

New Species

The work of biology is never finished. Indeed, the work of finding, naming, and classifying all living species has barely begun. Scientists have estimated that 1 km^2 of rain forest may contain hundreds or thousands of species, most of which are currently unknown to science. In fact, new species are "discovered" all of the time, all around the world.

Mantophasmatodea—
a new order of insects

When is a species "new"?

What does discovering a new species mean? Typically, it means collecting a specimen, giving it a name, and classifying it for the first time by using modern taxonomy. Although truly new species may be evolving at any time, most new species are simply new to science.

Big, Small, Far, Near
Undiscovered species are everywhere! Even mammals, such as this monkey, are still being discovered. Of course, we may never find all of the tiny bugs and microbes in the world.

Biodiversity Hot Spots
Some parts of the world, such as tropical rain forests, contain an extreme diversity of species. This frog is from a region of Sri Lanka that is home to many amphibian species.

Undiscovered Worlds
In 2005, an expedition went into a "lost world" of rain forest in New Guinea that was previously unexplored by scientists. The expedition quickly found dozens of new species, such as this honeyeater bird.

Lemur from
Madagascar

Quick Project Find out if any new species have been discovered in your local area in the last few decades. Try to find the name of the new species, the story behind the name, and a photo of the species.

Section 3

Kingdoms and Domains

Key Ideas	Key Terms	Why It Matters
❯ Have biologists always recognized the same kingdoms? ❯ What are the domains and kingdoms of the three-domain system of classification?	bacteria archaea eukaryote	The three-domain system is one of the latest revolutions in biology.

If you read old books or stories, you might read about plants and animals, or “flora and fauna,” but probably not “fungi” or “bacteria.”

Updating Classification Systems

For many years after Linnaeus created his system, scientists recognized only two kingdoms: Plantae (plants) and Animalia (animals). Relatively few of Earth’s species were known, and little was known about them. ❯ **Biologists have added complexity and detail to classification systems as they have learned more.** Throughout history, many new taxa have been proposed and some groups have been reclassified.

For example, **Figure 9** shows sponges, which were first classified as plants. Then, the invention of the microscope allowed scientists to look at cells. Scientists learned that sponges have cells that are much more like animal cells than like plant cells. So today, sponges are classified as animals. The microscope prompted many such changes.

From Two to Five Kingdoms In the 1800s, scientists added Kingdom Protista as a taxon for unicellular organisms. Soon, they noticed the differences between prokaryotic cells and eukaryotic cells. So, scientists created Kingdom Monera for prokaryotes and left single-celled eukaryotes in Kingdom Protista. By the 1950s, five kingdoms were used: Monera, Protista, Fungi, Plantae, and Animalia.

Six Kingdoms In the 1990s, Kingdom Monera came into question. Genetic data suggested two major groups of prokaryotes. So, Kingdom Monera was split into two new kingdoms: Eubacteria and Archaebacteria.

❯ **Reading Check** *What were the original Linnaean kingdoms?*

Sponge cells with flagella

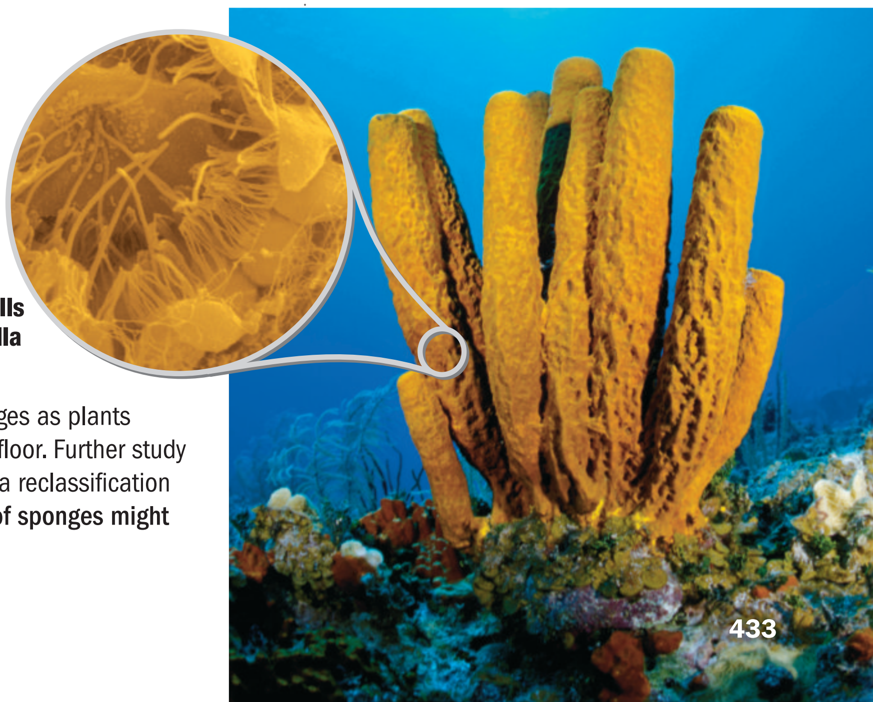


Figure 9 Early scientists classified sponges as plants because sponges are attached to the sea floor. Further study and microscopic views in particular led to a reclassification of sponges as animals. ❯ **What features of sponges might have led to this reclassification?**

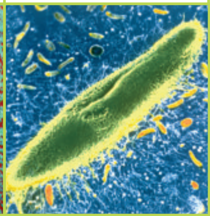
Characteristics of Domains and Kingdoms						
Domain	Bacteria	Archaea	Eukarya			
Kingdom	Eubacteria	Archae-bacteria	Protista	Fungi	Plantae	Animalia
Example	*Streptococcus pneumoniae*	*Staphylo-thermus marinus*	paramecium	spore cap mushroom	Texas paintbrush	white-winged dove
						
Cell type	prokaryote		eukaryote			
Cell walls	cell walls with peptidoglycan	cell walls with unique lipids	some species with cell walls	cell walls with chitin	cell walls with cellulose	no cell walls
Number of cells	unicellular		unicellular or multicellular	mostly multicellular	mostly multicellular	multicellular
Nutrition	autotroph or heterotroph			heterotroph	autotroph	heterotroph

Figure 10 This table shows the major characteristics used to define the domains and kingdoms of the modern Linnaean system. **What other kind of characteristic differs between kingdoms?**

The Three-Domain System

As biologists began to see the differences between the two kinds of prokaryotes, they also saw the similarities among all eukaryotes. So, a new system was proposed that divides all organisms into three domains: Bacteria, Archaea, and Eukarya. **Today, most biologists tentatively recognize three domains and six kingdoms. Figure 10** shows the major characteristics of these taxa.

Major Characteristics Major taxa such as kingdoms are defined by major characteristics. These characteristics include:

- **Cell Type** The cells may be either *prokaryotic* or *eukaryotic*.
- **Cell Walls** The cells may either have a cell wall or lack a cell wall.
- **Body Type** An organism is either *unicellular* or *multicellular*.
- **Nutrition** An organism is either an *autotroph* (makes nutrients from inorganic materials) or a *heterotroph* (gets nutrients from other organisms). Some taxa have unique means of nutrition.
- **Genetics** As you have learned, related groups of organisms will have similar genetic material and systems of gene expression. So, organisms may have a unique system of DNA, RNA, and proteins.

Domain Bacteria **Domain Bacteria is equivalent to Kingdom Eubacteria.** The common name for members of this domain is *bacteria*. **Bacteria** are prokaryotes that have a strong exterior cell wall and a unique genetic system. However, bacteria have the same kind of cell membrane lipid as most eukaryotes do.

Hands-On

QuickLab

Field Guides

Have you ever used field guides to identify animals or plants? Do you know how these guides are organized? Take a few guides outside, and take a closer look.

20 min

Procedure

1. Gather **several different field guides** for plants or other organisms in your area. Also gather a **magnifying glass** and a **specimen jar.** Take these items with you to a **local natural area.**
2. **CAUTION: Do not touch or disturb any organisms without your teacher's permission; leave all natural items as you found them.** Try to find and identify at least two organisms that are listed in your field guides. Make notes to describe each organism.

Analysis

1. **Analyzing Methods** How difficult was identifying your organisms? How certain are you of your identification?
2. **Comparing Systems** How are the field guides organized? What other ways could they be organized?

All bacteria are similar in physical structure, with no internal compartments. Traditionally, bacteria have been classified according to their shape, the nature of their cell wall, their type of metabolism, or the way that they obtain nutrients. Bacteria are the most abundant organisms on Earth and are found in almost every environment.

Domain Archaea › **Domain Archaea is equivalent to Kingdom Archaebacteria.** The common name for members of this domain is *archaea.* **Archaea** have a chemically unique cell wall and membranes and a unique genetic system. The genetic systems of archaea share some similarities with those of eukaryotes that they do not share with those of prokaryotes. Scientists think that archaea began to evolve in a separate lineage from bacteria early in Earth's history and that some archaea eventually gave rise to eukaryotes.

Archaea were first found by scientists in extreme environments, such as salt lakes, the deep ocean, or hot springs that exceed 100°C. These archaea are called *extremophiles*. Other archaea called *methanogens* live in oxygen-free environments. However, some archaea live in the same environments as many bacteria do.

Domain Eukarya › **Domain Eukarya is made up of Kingdoms Protista, Fungi, Plantae, and Animalia.** Members of the domain Eukarya are **eukaryotes,** which are organisms composed of eukaryotic cells. These cells have a complex internal structure. This structure enabled the cells to become larger than the earliest cells and enabled the evolution of multicellular life. While eukaryotes vary in many fundamental respects, they share several key features.

› **Reading Check** *Which kingdoms are prokaryotic?*

bacteria (bak TIR ee uh) extremely small, single-celled organisms that usually have a cell wall and that usually reproduce by cell division; members of the domain Bacteria

archaea (ahr KEE uh) prokaryotes that are distinguished from other prokaryotes by differences in their genetics and in the makeup of their cell wall; members of the domain Archaea

eukaryote an organism made up of cells that have a nucleus enclosed by a membrane, multiple chromosomes, and a mitotic cycle; members of the domain Eukarya

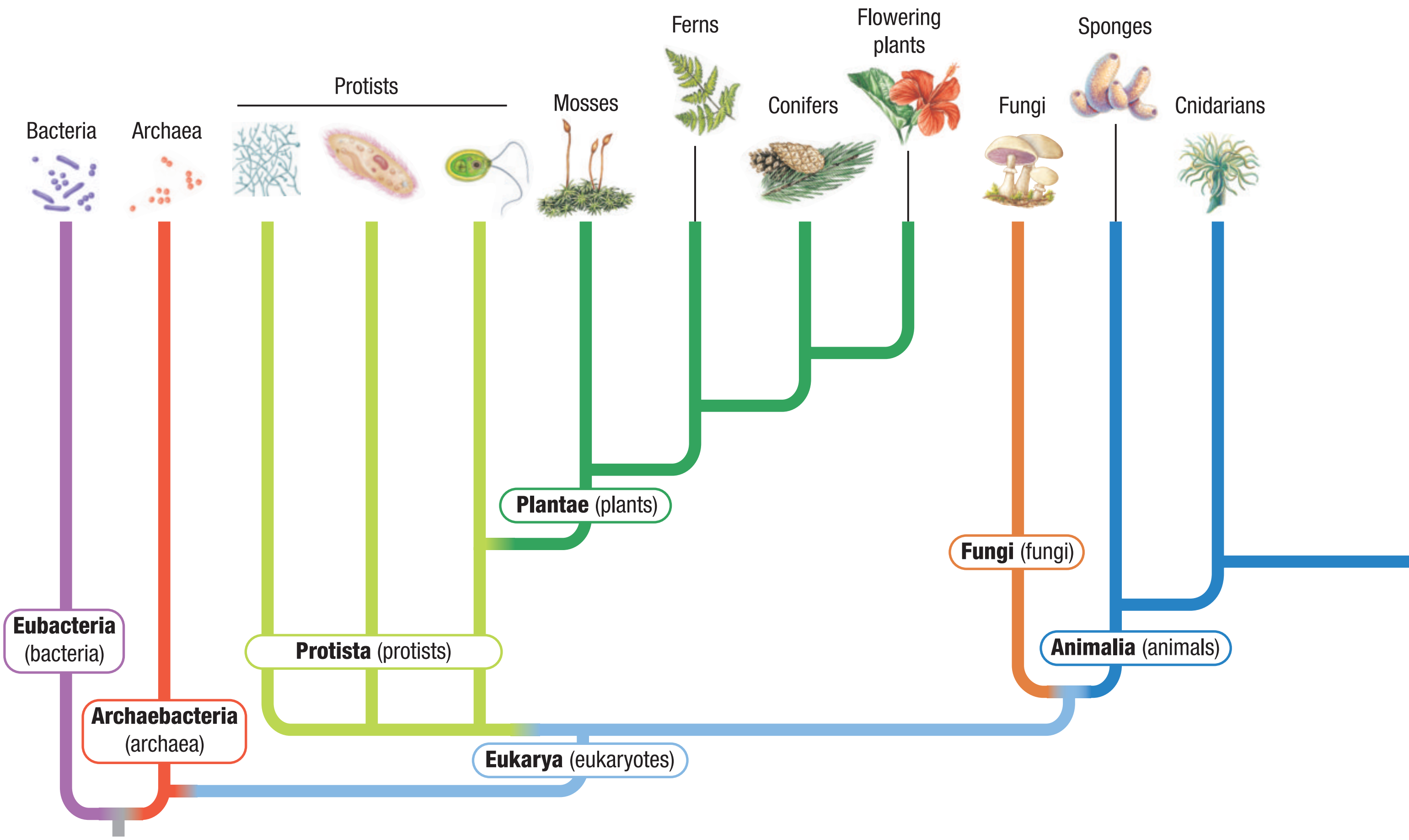


Figure 11 This tree of life shows current hypotheses of the relationships between all major groups of organisms. For updates on phylogenetic information, visit **go.hrw.com** and enter the keyword **HX8 Phylo.** **❯ Why might this type of model be revised?**

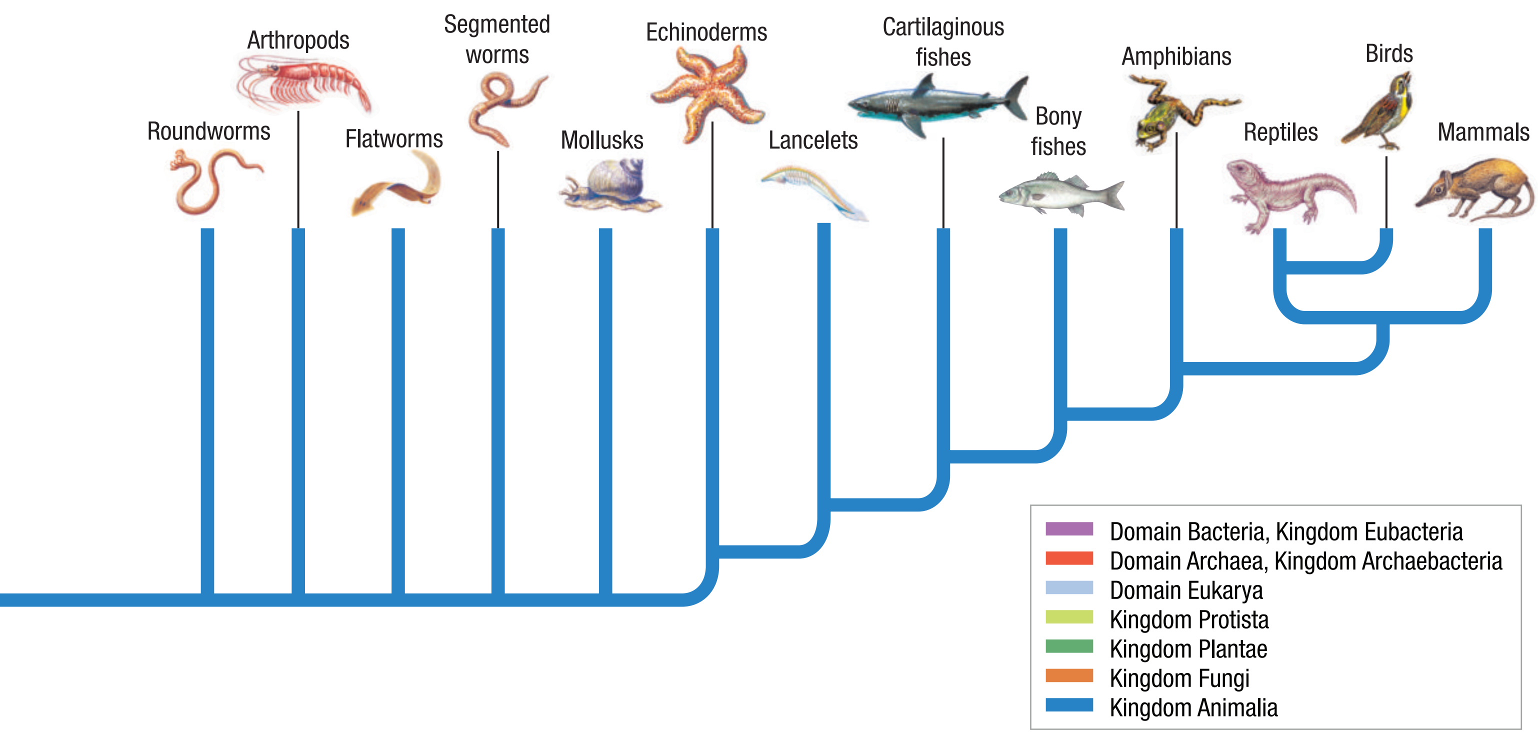
READING TOOLBOX

Phylogenetic Tree Look carefully at **Figure 11.** Try to identify which groups are most closely related to each other. Which label includes lineages that do not share a unique common ancestor?

Characteristics of Eukaryotes Eukaryotes have highly organized cells. All eukaryotes have cells with a nucleus and other internal compartments. Also, true multicellularity and sexual reproduction occur only in eukaryotes. True multicellularity means that the activities of individual cells are coordinated and the cells themselves are in contact. Sexual reproduction means that genetic material is recombined when parents mate. Sexual reproduction is an important part of the life cycle of most eukaryotes.

Kinds of Eukaryotes The major groups of eukaryotes are defined by number of cells, body organization, and types of nutrition.

- **Plantae** Almost all plants are autotrophs that produce their own food by absorbing energy and raw materials from their environment. This process is *photosynthesis,* which occurs inside chloroplasts. The cell wall is made of a rigid material called *cellulose*. More than 270,000 known species of plants exist.
- **Animalia** Animals are multicellular heterotrophs. Their bodies may be simple collections of cells or highly complex networks of organ systems. Animal cells lack the rigid cell walls that plant cells have. More than 1 million known species of animals exist.
- **Fungi** Fungi are heterotrophs and are mostly multicellular. Their cell wall is made of a rigid material called *chitin*. Fungi are considered to be more closely related to animals than to any other kingdom. More than 70,000 known species of fungi exist.



- **Protista** Kingdom Protista is a diverse group. Unlike the other three Kingdoms of Eukarya, Protista is not a natural group but rather a "leftover" taxon. Any single-celled eukaryote that is *not* a plant, animal, or fungi can be called a *protist*. Protists did not descend from a single common ancestor.

  For many years , biolgists recognized four major groups of protists: flagellates, amoebas, algae, and parasitic protists. More recently, biologists have proposed to replace Protista with several new kingdoms. These kingdoms would classify protists that seem to be unrelated to any other groups. However, some protists are being reclassified into other kingdoms. For example, algae that have chloroplasts are thought to be most closely related to plants, as shown in **Figure 11.** Biologists have not yet agreed how to resolve all of these issues.

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Reading Check *Which kingdoms contain only heterotrophs?*

Section 3 Review

KEY IDEAS

1. **Outline** how biologists have changed the major levels of the Linnaean system over time.
2. **List** the three domains, identify the kingdoms that align with each domain, and list the major characteristics of each kingdom.

CRITICAL THINKING

3. **Finding Evidence** The *theory of endosymbiosis* proposes that eukaryotes descended from a primitive combination of both archaea and bacteria. What evidence supports this theory?
4. **Science and Society** Microscopes led scientists to recognize new kingdoms. What other technology has impacted classification?

ALTERNATIVE ASSESSMENT

5. **Tree of Life Poster** Make a poster of the tree of life. At appropriate places on the tree, add images of representative organisms, along with labels. Include all domains and kingdoms as well as at least three major taxa within each kingdom.

Skills Practice

Chapter 18 Lab

Objectives

- Identify objects by using a dichotomous key.
- Design a dichotomous key for a group of objects.

Materials

- objects, common (6 to 10)
- labels, adhesive
- pencil

Safety

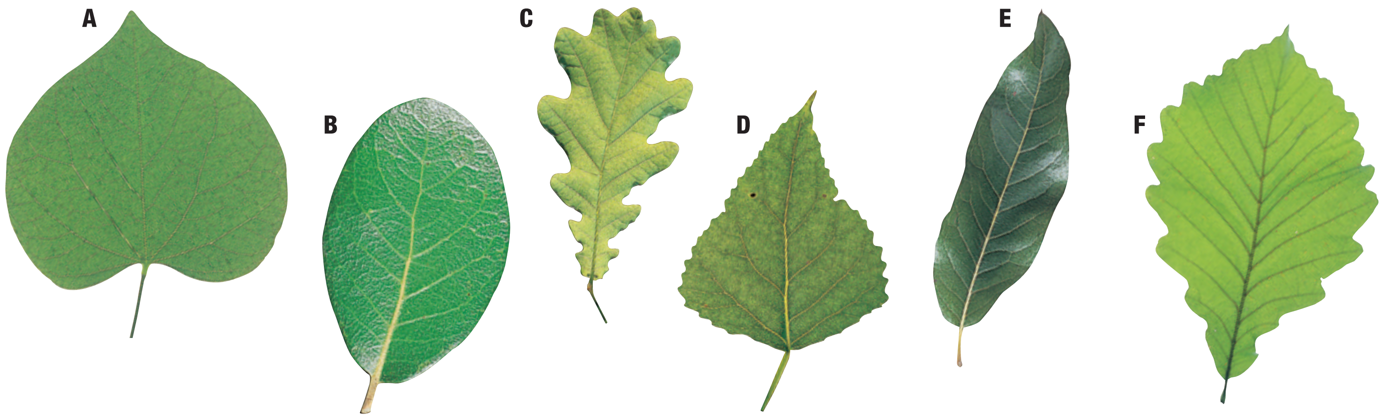
Dichotomous Keys

One way to identify an unknown organism is to use an identification key, which contains the major characteristics of groups of organisms. A dichotomous key is an identification key that contains pairs of contrasting descriptions. After each description, a key either directs the user to another pair of descriptions or identifies an object. In this lab, you will design and use a dichotomous key. A dichotomous key can be written for any group of objects.

Procedure

Use a Dichotomous Key

1. Work with a small group. Use the dichotomous key to identify the tree that produced each of the leaves shown here. Identify one leaf at a time. Always start with the first pair of statements (1a and 1b). Follow the direction beside the statement that describes the leaf.
2. Proceed through the key until you get to the name of a tree. Record your answer for each leaf shown.



Key to Forest Trees

1a	Leaf edge is smooth or barely curved.	go to 2
1b	Leaf edge has teeth, waves, or lobes.	go to 3
2a	Leaf has a sharp bristle at its tip.	shingle oak
2b	Leaf has no bristle at its tip.	go to 4
3a	Leaf edge has small, shallow teeth.	Lombardy poplar
3b	Leaf edge has deep waves or lobes.	go to 5
4a	Leaf is heart shaped.	eastern redbud
4b	Leaf is not heart shaped.	live oak
5a	Leaf edge has less than 20 large lobes.	English oak
5b	Leaf edge has more than 20 waves.	chestnut oak

Design a Dichotomous Key

3. Put on safety goggles, gloves, and a lab apron.Choose 6 to 10 objects from around the classroom or from a collection supplied by your teacher. Before you go to the next step, have your teacher approve the objects your group has chosen.

4. Study the structure and organization of the dichotomous key, which includes pairs of contrasting descriptions that form a "tree" of possibilities. Use this key as a model for the next step.

5. Work with the members of your group to design a new dichotomous key for the objects that your group selected. Be sure that each part of the key leads to either a definite identification of an object or another set of possibilities. Be sure that every object is included.

6. Test your key by using each one of the objects in your collection.

Exchange and Test Keys

7. After each group has completed the steps above, exchange your key and your collection of objects with another group. Use the key you receive to identify each of the new objects. If the new key does not work, return it to the group so that corrections can be made.

Cleanup

8. Clean up your work area and return or dispose of materials as directed by your teacher. Wash your hands thoroughly before you leave the lab and after you finish all of your work.

SCILINKS
www.scilinks.org
Topic: Classification
Code: HX80295

Analyze and Conclude

1. **Summarizing Data** List the identity of the tree for each of the leaves that you analyzed in step 2.
2. SCIENTIFIC METHODS **Critiquing Procedures** What other characteristics might be used to identify leaves by using a dichotomous key?
3. **Analyzing Results** What challenges did your group face while making your dichotomous key?
4. **Evaluating Results** Were you able to use another group's key to identify the group's collection of objects? Describe your experience.
5. SCIENTIFIC METHODS **Analyzing Methods** Does a dichotomous key begin with general descriptions and then proceed to more specific descriptions, or vice versa? Explain your answer by using examples.
6. SCIENTIFIC METHODS **Evaluating Methods** Is a dichotomous key the same as the Linnaean classification system? Explain your answer.

Extension

7. **Research** Do research in the library or media center to find out what types of methods, other than dichotomous keys, are used to identify organisms.

Chapter 18 Summary

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SUPER SUMMARY
Keyword: HX8CLSS

Key Ideas	Key Terms

1 The Importance of Classification

- Biologists use taxonomic systems to organize their knowledge of organisms. These systems attempt to provide consistent ways to name and categorize organisms.
- All scientific names for species are made up of two Latin or Latin-like terms.
- In the Linnaean system of classification, organisms are grouped at successive levels of a hierarchy based on similarities in their form and structure. The eight levels of modern classification are domain, kingdom, phylum, class, order, family, genus, and species.

Key Terms

taxonomy (423)
genus (424)
binomial nomenclature (424)

2 Modern Systematics

- Scientists traditionally have used similarities in appearance and structure to group organisms. However, this approach has proven problematic.
- Grouping organisms by similarity is often assumed to reflect phylogeny, but inferring phylogeny is complex in practice.
- Cladistic analysis is used to select the most likely phylogeny among a given set of organisms.
- Biologists compare many kinds of evidence and apply logic carefully in order to infer phylogenies.

Key Terms

phylogeny (428)
cladistics (429)

3 Kingdoms and Domains

- Biologists have added complexity and detail to classification systems as they have learned more.
- Today, most biologists tentatively recognize three domains and six kingdoms. Domain Bacteria is equivalent to Kingdom Eubacteria. Domain Archaea is equivalent to Kingdom Archaebacteria. Domain Eukarya is made up of Kingdoms Protista, Fungi, Plantae, and Animalia.

Key Terms

bacteria (434)
archaea (435)
eukaryote (435)

Chapter 18 Review

READING TOOLBOX

1. **Word Parts** Use the table of word parts at the beginning of this chapter to analyze the word *phylogeny*.

2. **Concept Map** Make a Venn diagram that shows the relationships between all major levels of the modern Linnaean classification system.

Using Key Terms

For each pair of terms, explain how the meanings of the terms differ.

3. *genus* and *species*

4. *bacteria* and *archaea*

Complete each of the following sentences by choosing the correct term from the word bank.

cladistics *taxonomy*

phylogeny *binomial nomenclature*

5. Scientists use ___ to name and classify organisms.

6. All modern scientific names are based on Linnaeus's original system of ___.

7. Today, biologists use ___ to analyze evolutionary relationships between groups of organisms.

8. Looking at obvious similarities is not always enough to infer ___.

Understanding Key Ideas

9. Which language is used for each scientific name?
   a. Greek
   b. Latin
   c. English
   d. French

10. Which classification level contains subgroups within orders?
   a. family
   b. class
   c. phylum
   d. domain

11. Which of the following pairs of characters are analogous but not homologous?
   a. eggs of a lizard and eggs of a snake
   b. feet of a dinosaur and feet of a bird
   c. wings of a butterfly and wings of a bat
   d. beak of a bluebird and beak of a blue jay

12. When constructing a cladogram, systematists use the principle of parsimony. This principle leads to cladograms that contain
   a. very few branch points.
   b. a few large branches, each with many smaller branches.
   c. the greatest number of character changes between branch points.
   d. the fewest number of character changes between branch points.

13. How do scientists use DNA sequences to infer which organisms share the most recent ancestry?
   a. They re-create fossil DNA to model ancient organisms.
   b. They compare all of the genes of every organism that exists.
   c. They look for organisms that share the most similar DNA sequences.
   d. They look for any organisms that have differences in DNA sequences.

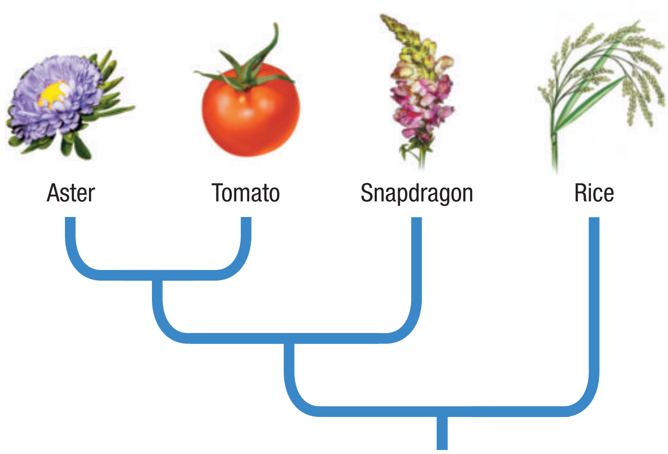
Explaining Key Ideas

14. **Justify** the need for scientific nomenclature.

15. **Explain** why analogous characters, such as wings, should not be used to classify organisms.

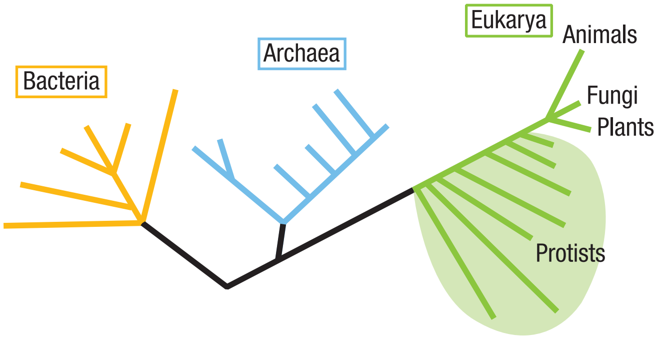
16. **Differentiate** between the major characteristics of organisms in the domains Bacteria and Eukarya.

17. **Describe** this diagram. What does it represent? What does it tell us about an aster plant and a tomato plant as compared with a snapdragon?



Using Science Graphics

This phylogenetic tree represents recent hypotheses about the major lineages of all life and relationships between each of these groups. In this diagram, the length of each branch represents the relative amount of divergence over time for each lineage. Use the diagram below to answer the following questions.



18. According to this model, which of the following two groups are most closely related?
- **a.** bacteria and plants
- **b.** animals and fungi
- **c.** archaea and eukarya
- **d.** fungi and protists

19. Which of the following statements is in agreement with this model?
- **a.** Protists do not make up a clade.
- **b.** Bacteria are descended from protists.
- **c.** Fungi should be reclassified as plants.
- **d.** Animals and protists form their own clade.

This table compares characters of several animals. Use the table to answer the following question.

Characters in Vertebrates

	Amniotic sac	Mammary glands	Placenta
Trout	no	no	no
Hummingbird	yes	no	no
Koala	yes	yes	no
Gray squirrel	yes	yes	yes

20. Which organism in the table would be used as the outgroup in a cladogram that unites the other three organisms?
- **a.** trout
- **b.** hummingbird
- **c.** koala
- **d.** gray squirrel

Critical Thinking

21. Using Logical Systems In practice, taxonomists have invented many "in-between" levels for the Linnaean system, such as "subclass" or "superorder." Why might they have done this?

22. Analyzing Concepts Explain why ancestral characters are associated with the outgroup in a cladogram.

23. Constructing Explanations How could the presence of extra bones and a tail on a chicken embryo help scientists understand the evolutionary history of chickens?

24. Justifying an Opinion Given the the current characteristics of each kingdom in the six-kingdom system, would you split any of the kingdoms into new kingdoms? Explain your reasoning.

25. Comparing Features What similarities and differences exist between animals and fungi?

Why It Matters

26. New Species Will scientists ever finish classifying all species? Explain your answer.

Writing for Science

27. Lyrics Choose one of the six kingdoms, and write a song or poem about it.

Alternative Assessment

28. Linnaean Album Use library or Internet resources to make a picture album representing the six kingdoms. Find a picture of one species from each kingdom, and mount a copy of the picture in your album. Add a listing of each species' classification, using as many taxonomic levels as possible.

Math Skills

29. Rates Suppose that the amino acid sequence for gene Z of plant A has 10 bases that differ from those in the sequence for the same gene in plant B. Assume that mutations in this kind of gene occur at a rate of 2 mutations every 10,000 years. Estimate how long ago these two plants diverged from a common ancestor.

Chapter 18 Standardized Test Prep

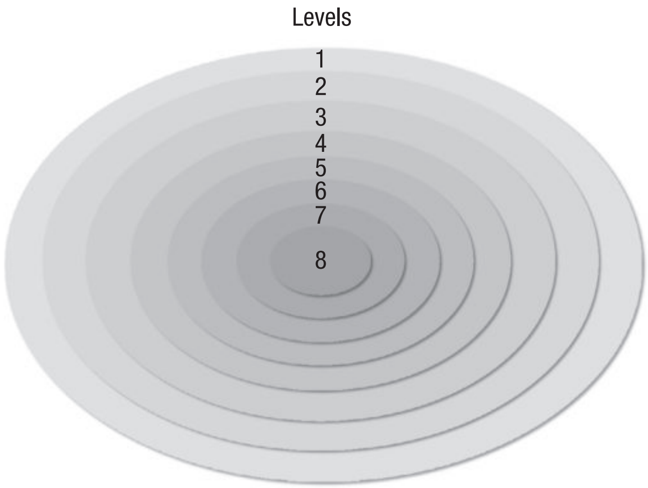
TEST TIP After you finish writing your answer to a short-response item, proofread it for errors in spelling, grammar, and punctuation.

Science Concepts

1. Why do biologists have taxonomic systems?
- **A** to provide descriptive Latin names
- **B** to maintain a small number of taxa
- **C** to provide consistent ways to identify and classify organisms as they are being studied
- **D** to construct a family tree that predicts how many species may be discovered in the future

2. Which taxonomic system was developed by Carl Linnaeus in the 1750s and is used today?
- **F** cladistics
- **G** taxonomic phylogeny
- **H** the polynomial system
- **J** binomial nomenclature

This diagram shows the major levels of taxonomy in the modern Linnaean system. Use the diagram to answer the following questions.

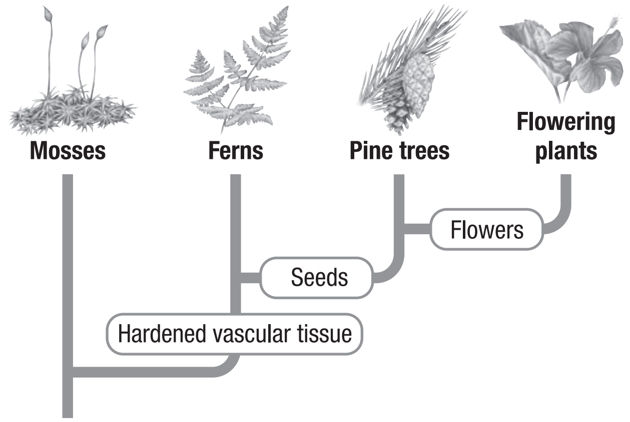


3. Which level represents the genus category?
- **A** level 1
- **B** level 2
- **C** level 7
- **D** level 8

4. Which level represents the kingdom category?
- **F** level 1
- **G** level 2
- **H** level 7
- **J** level 8

Using Science Graphics

This diagram shows the relationship between several types of plants. Use the diagram to answer the following questions.



5. Which derived character is shared by pine trees and flowering plants but not ferns?
- **A** seeds
- **B** flowers
- **C** mosses
- **D** vascular tissue

6. Which of the following pairs of plant groups form a clade that is exclusive of all other plants?
- **F** mosses and ferns
- **G** ferns and pine trees
- **H** mosses and flowering plants
- **J** pine trees and flowering plants

7. What is the name of the domain that contains all of the organisms shown in the diagram?
- **A** Algae
- **B** Plantae
- **C** Eukarya
- **D** Bacteria

Writing Skills

8. Short Response Describe the origins of the modern Linnaean system of taxonomy.

9. Extended Response Write an essay that summarizes the historical development of scientific naming and classification systems. Include the reasons why such systems were invented, and describe the ways that modern systematics differs from earlier systems.

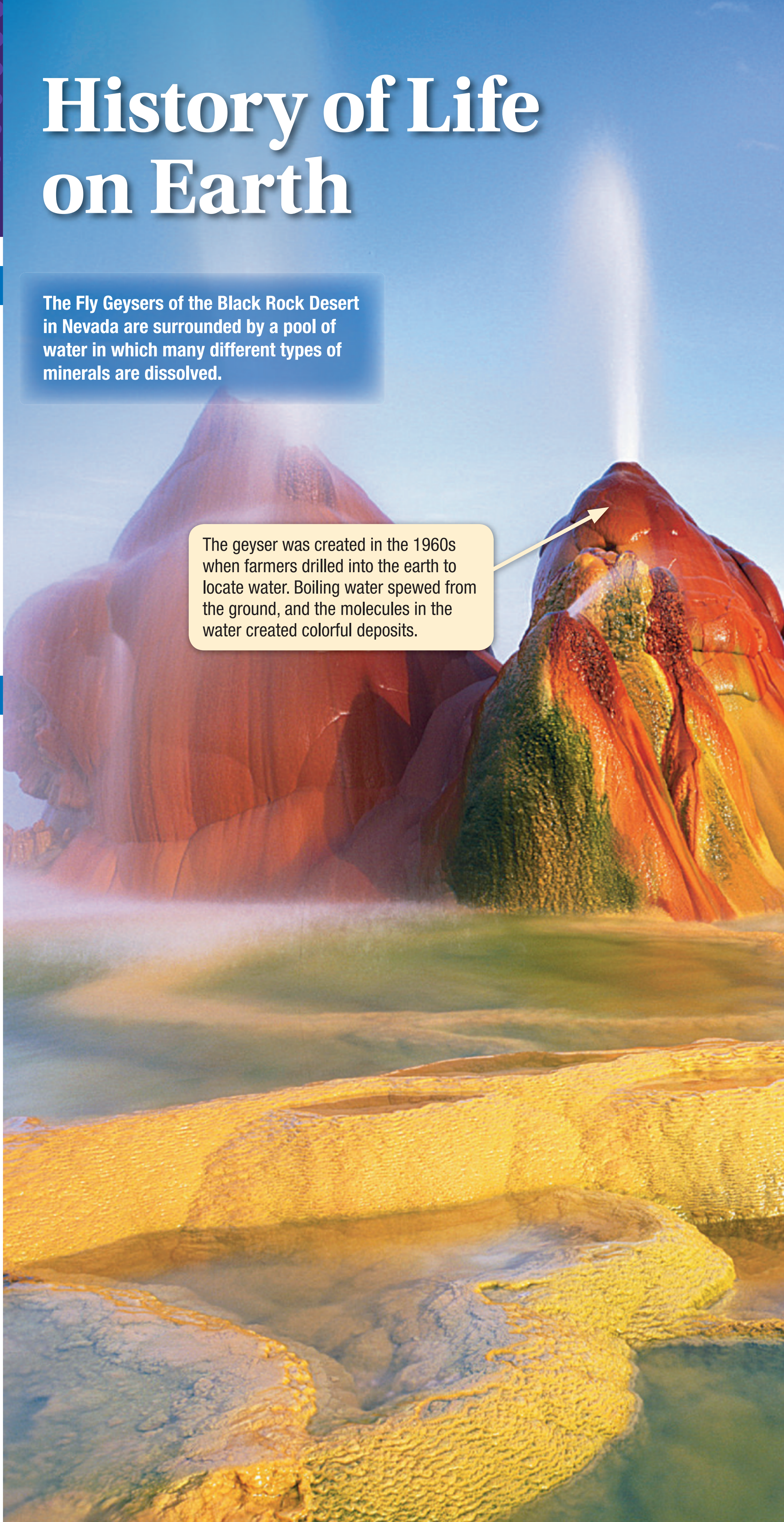
Chapter 19

History of Life on Earth

Preview

Why It Matters

The history of life on Earth is like a puzzle; scientists continue to search for evidence and to put it together into a cohesive theory.



The Fly Geysers of the Black Rock Desert in Nevada are surrounded by a pool of water in which many different types of minerals are dissolved.

The geyser was created in the 1960s when farmers drilled into the earth to locate water. Boiling water spewed from the ground, and the molecules in the water created colorful deposits.