Chapter 3

Organisms and Evolutionary Relationships

Standards:
SB4.a, c

Chapter 3 • Lesson 10

Classifying Organisms

Key Terms • taxonomy • species • clade • domain • kingdom • prokaryote • eukaryote • heterotroph • autotroph • endosymbiosis • virus

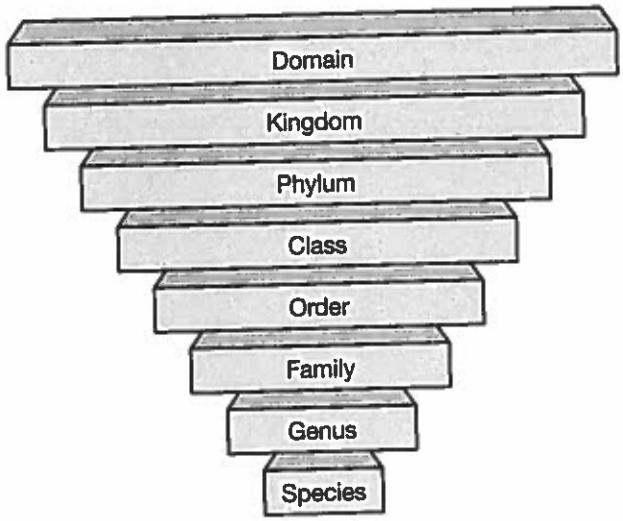
Getting the Idea

Earth is home to millions of different kinds of organisms. Each one shares some features with all other organisms. Even so, there is great diversity in their forms and structures. To bring order to this diversity, scientists have devised a system for grouping organisms, which helps us organize and understand these diverse lifeforms. This system changes as scientists learn more about the evolutionary relationships among living things.

Classification

Taxonomy is the field of biology that deals with classifying organisms—that is, grouping them based on their similarities. Early taxonomists classified organisms based solely on similarities that were easy to observe. Today's taxonomists classify organisms based on analysis and comparison of their physical structures, embryological development, chemical processes, and DNA. These data are used to group organisms and classify newly discovered organisms in ways that reflect evolutionary relationships. A recent change, based on DNA analysis and other comparisons, is the reclassification of organisms that were previously placed into a group called Protista.

In modern taxonomy, there are eight major levels of classification, as shown below.



As you move from the top to the bottom of this hierarchy, each classification is more specific, so groups at each level are smaller than at the level above it. That is, organisms within each category are more closely related as you move from the domain toward the species level. A **species** is a group of organisms that share most characteristics and can interbreed to produce fertile offspring. A species contains only one kind of organism. For example, the coyote belongs to the species *Canis latrans*, while the wolf—a close relative of the coyote—belongs to the species *Canis lupus*.

A **clade** is a group of organisms thought to have evolved from a common ancestor. You can think of a kingdom as a very large clade, with many smaller clades within it.

Domains and Kingdoms

A **domain** is the largest group in the modern biological classification system. Domains organize all living things into three groups based on fundamental differences in their cells. The three domains are Bacteria, Archaea, and Eukarya. **Kingdoms** are the next level of classification under domain. The domains Bacteria and Archaea each include only one kingdom, bacteria and archaea. The domain Eukarya is made up of three kingdoms: plants, animals, and fungi.

Bacteria and Archaea

All bacteria are single-celled prokaryotes. Recall that a **prokaryote** is an organism that lacks a membrane-bound nucleus and organelles. Bacteria have cell walls that contain a substance called peptidoglycan. Bacteria include both disease-causing and beneficial organisms.

Like bacteria, archaea are single-celled prokaryotes. However, the cell walls of archaea do not contain peptidoglycan. Also, the cell membranes of archaea are made up of different lipids than the cell membranes of other organisms. Most archaea live in extreme environments, such as thermal vents and salt lakes.

Bacteria and archaea were once classified in the same kingdom, but increased knowledge about archaea led scientists to develop the domain level of classification. Scientists now recognize that bacteria and archaea are as different from each other as they are from eukaryotes. Many scientists think that archaea evolved before bacteria, but there is disagreement on this point.

Eukarya

The domain Eukarya contains the kingdoms fungi, plants, and animals. All members of these kingdoms are eukaryotes. Recall that a **eukaryote** is an organism whose cells contain a nucleus and other membrane-bound organelles. Fungi may be unicellular or multicellular. All plants and animals, however, are multicellular.

The kingdoms of fungi, plants, and animals are thought to have evolved from organisms in what was previously the fourth eukaryotic kingdom—protists. Organisms that were previously classified as protists can be unicellular, multicellular, or colonial (organisms of the same species functioning together). These organisms do not have complex organ systems. This varied group of organisms contains all types of algae, amoebas, paramecia, and euglenas. All of these organisms live in wet or moist environments. The term *protist* is often still used to describe eukaryotes that are not fungi, plants, or animals.

Fungi (singular: *fungus*) are organisms that have cell walls made of chitin but lack vascular tissue and chloroplasts. Fungi are heterotrophs. A **heterotroph** is an organism that cannot make its own food and must instead feed on other organisms. Fungi live in all environments and include important decomposers and parasites. Fungi can be single-celled or multicellular. Yeasts, molds, mildews, rusts, and mushrooms are found in this kingdom.

Plants are multicellular autotrophs. An **autotroph** is an organism that makes its own food. All plants have rigid cell walls made of cellulose. Plants are a major group of living things, including trees, grasses, herbs, ferns, mosses, and others.

Animals are multicellular heterotrophs whose cells lack cell walls. Most animals have interior digestive tracts, body symmetry, and nerve tissue. The animal kingdom contains more species than any other kingdom in the domain Eukarya.

The table below summarizes the major characteristics of the kingdoms in domain Eukarya.

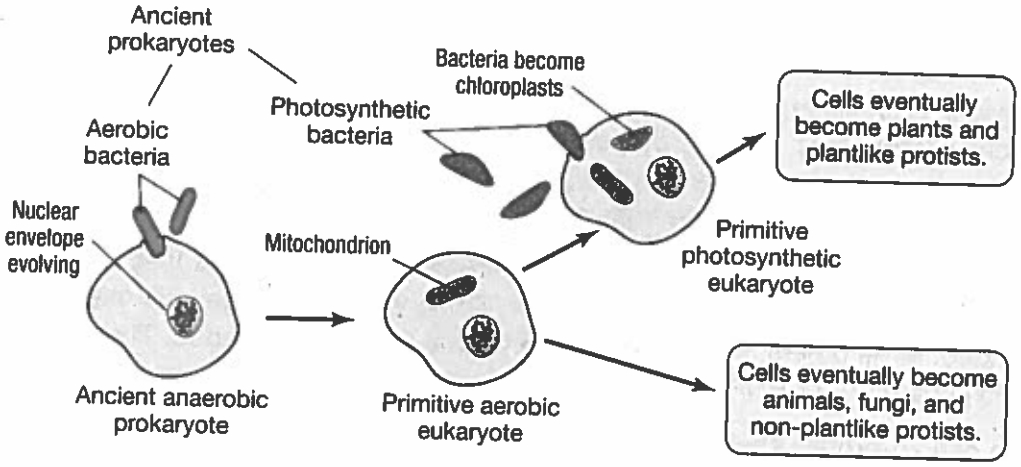
Kingdoms in the Domain Eukarya

Kingdom	Characteristics	Examples
Fungi	Unicellular or multicellular; have a nucleus (sometimes more than one per cell), cell membrane, and cell wall; lack chloroplasts; include only heterotrophs that absorb nutrients from other organisms and from wastes in their environments	Yeasts, mushrooms, molds, mildews
Plants	Multicellular; have a nucleus, cell membrane, cell wall, and chloroplasts; tissues organized into organs and organ systems; include only autotrophs that carry out photosynthesis	Mosses, ferns, trees, grasses
Animals	Multicellular; have a nucleus and cell membrane; do not have cell wall or chloroplasts; tissues organized into complex systems, such as skeletal, nervous, and circulatory systems; include only heterotrophs	Sponges, worms, insects, fish, amphibians, birds, reptiles, mammals

The Theory of Endosymbiosis

Prokaryotes existed on Earth for at least one billion years before any members of the domain Eukarya appeared. Recall that prokaryotic cells do not contain membrane-bound organelles, such as mitochondria and chloroplasts. Scientists have developed the scientific theory of **endosymbiosis**, which explains how organelles of eukaryotic cells evolved from prokaryotes.

According to this theory, free-living bacteria were engulfed, or taken in, by anaerobic prokaryotes (prokaryotes that do not use oxygen). Some of these bacteria were photosynthetic. Other bacteria were aerobic (bacteria that use oxygen). The engulfed bacteria and the host cell formed a relationship in which each organism benefited from the other. (*Endo-* means "inside"; *symbiosis* means "living together.") Over time, the bacteria inside the cell evolved into the organelles of modern eukaryotic cells. The diagram below shows this process



Recall that scientific arguments are supported by evidence. Visit websites to research the observations and data biologists have collected that support the theory of endosymbiosis. Describe three kinds of evidence that support the theory, and explain why they do so. Include your sources (URLs).

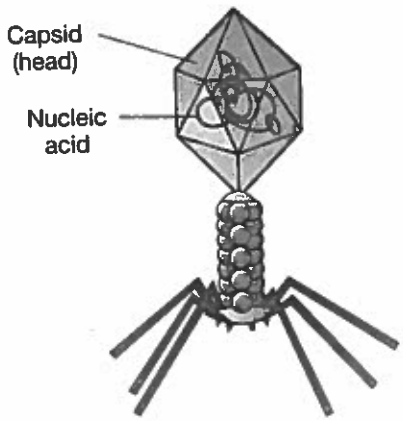
Viruses and Organisms: A Comparison

You might have noticed that viruses are not included in any of the groups of living things that have been discussed in this lesson. A **virus** is an infectious, nonliving particle made up of a nucleic acid enclosed in a protein or lipid-protein shell. Viruses share a few characteristics with living things. Both viruses and organisms contain nucleic acids and proteins. Both organisms and viruses have the ability to respond to the environment and to change over time. Like organisms, viruses reproduce using their nucleic acids. Also, some viruses and some organisms cause disease in other organisms.

Despite these similarities, most scientists do not consider viruses to be living things. Viruses lack most cell components, such as cytoplasm, ribosomes, and other organelles. Without cell structures, viruses cannot use energy, grow, or develop. In addition, viruses do not divide to reproduce. They can only reproduce from within a living cell, which is referred to as the *host cell.*

Viruses are much smaller than prokaryotic cells. Viruses are so small that they are usually measured in nanometers, or billionths of a meter. Some viruses have genetic material that is single stranded, while others have genetic material that is double stranded. The nucleic acid in a virus can be either DNA or RNA.

The protein or lipid-protein shell that surrounds a virus is called a capsid. The shape of a virus is determined by the arrangement of the proteins in its capsid. The diagram below shows the shape and key structures of one kind of virus.



In addition to a capsid, some viruses also have a protective coating called an envelope. Viral envelopes are formed from the host cell membrane. They may contain lipids and proteins from both the virus and its host cell. Tiny spikes may also cover a viral envelope. The virus uses these spikes both to identify and to attach to the cells it infects.

Empirical evidence is evidence that is gathered by experimentation, investigation, or observation. Empirical evidence does not include opinions or inferences. Scientific arguments should always be supported by empirical evidence.

For nearly a century, scientists debated how to classify viruses. In fact, some scientists continue to debate this issue today. Use a library or the Internet to do research into the arguments for and against classifying viruses as living things. Use recent research as much as possible. Then use evidence from your research as well as this lesson to construct your own argument comparing and contrasting viruses and organisms. State whether you agree with classifying viruses as nonliving, and explain why.

Lesson Review

1. Which feature is common to **both** living cells and viruses?

   A. capsid

   B. cytoplasm

   C. nucleic acid

   D. ribosome

2. Which group is made up of organisms that are the **most** similar genetically?

   A. class

   B. order

   C. phylum

   D. species

3. Which feature distinguishes bacteria from archaea?

   A. being multicellular

   B. the presence of a true nucleus

   C. the composition of the cell wall

   D. the presence of membrane-bound organelles

4. An organism is multicellular and made up of eukaryotic cells. The organism can move from one place to another. Its cells do not have cell walls or chloroplasts. In which kingdom should the organism be classified?

   A. animals

   B. fungi

   C. plants

   D. viruses

Standard:
SB4.b

Cladograms and Phylogenetic Trees

Key Terms • theory of evolution • cladogram • phylogenetic tree • phylogeny • divergence

Getting the Idea

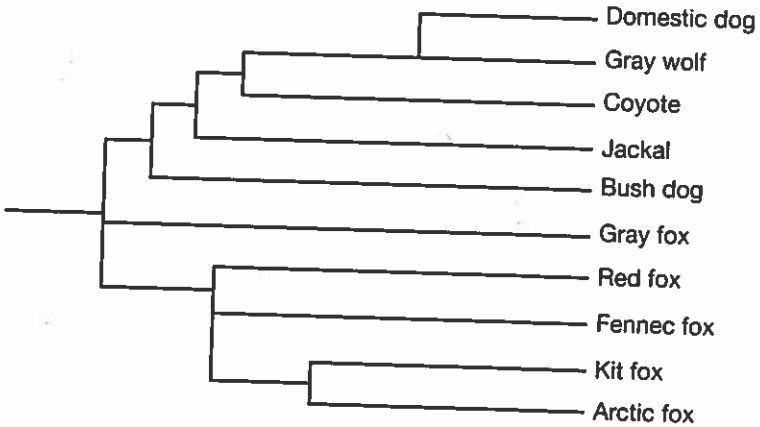
Scientists have constructed a variety of diagrams that show how species—both living and extinct—are related and how organisms can be grouped based on their characteristics. The diagrams are models that represent how life on Earth has changed over time and how groups of organisms share patterns of common ancestry.

Modeling Evolutionary Relationships

The **theory of evolution** is a scientific theory that explains how species develop from preexisting species. Scientists agree that Earth's biodiversity has resulted from evolution, and they use models to show the patterns of common ancestry among species. Cladograms and phylogenetic trees are models that depict the evolutionary relationships among groups of organisms.

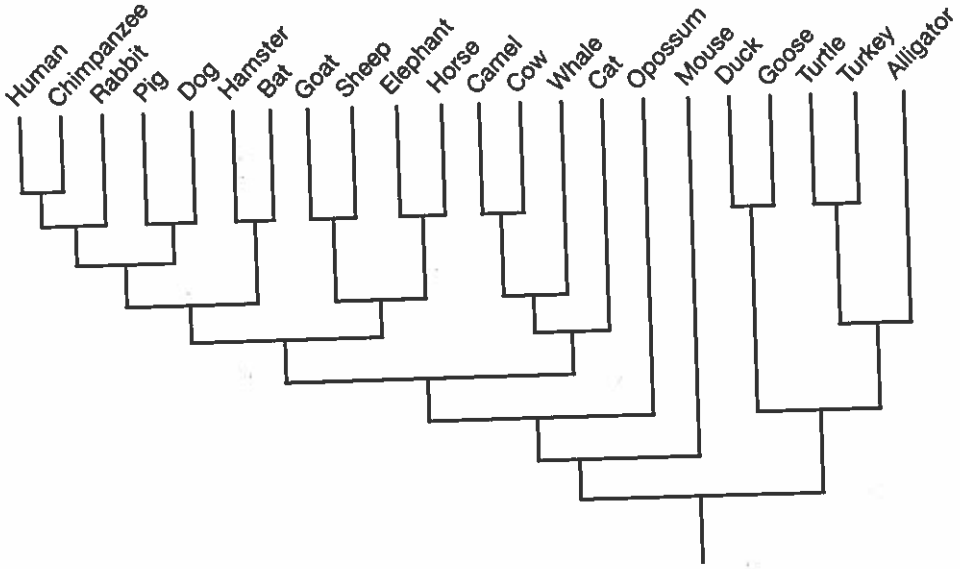
A **cladogram** or **phylogenetic tree** is a branching diagram that shows the relationships among organisms or groups of organisms. The names of these diagrams come from the terms *clade* and *phylogeny*. Recall that a clade is a group of organisms thought to have evolved from a common ancestor. A **phylogeny** is the evolutionary history of a species. Many scientists use *cladogram* and *phylogenetic tree* interchangeably. For others, the lengths of the branches in a phylogenetic tree indicate the length of time or amount of change, while branch length in a cladogram has no meaning.

The cladogram below shows several living species of the family Canidae.



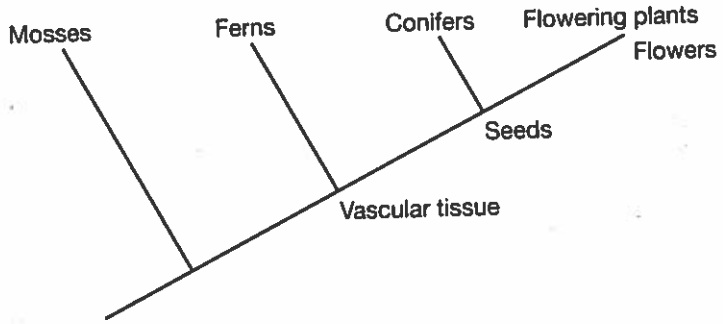
The tree on the preceding page indicates that Canidae developed from a single ancestor into a group that includes the domestic dog, the arctic fox, and other species. The line at the far left of the diagram represents the ancestral species. The points at which a line splits into two are called *nodes*. The nodes represent a splitting of the groups of organisms from the ancestral species.

The cladogram below was developed using biochemical analysis of insulin. Many animals produce the hormone insulin. The degree of similarity among the different forms of insulin helped scientists determine the evolutionary relationships of the various animal groups.



Divergence is the process of evolutionary separation. In the cladogram above, find the first divergence from the common ancestor and follow those two branches to the top of the tree. Notice that one branch leads to mammals, while the other leads to birds and reptiles.

The simple cladogram below shows the features that differentiate the main groups of plants. Such features are called *derived traits*. They are shared by members of a clade but not by ancestors of the clade. Vascular tissue, seeds, and flowers are all derived traits. Ferns, conifers, and flowering plants all have vascular tissue, but only conifers and flowering plants have seeds.



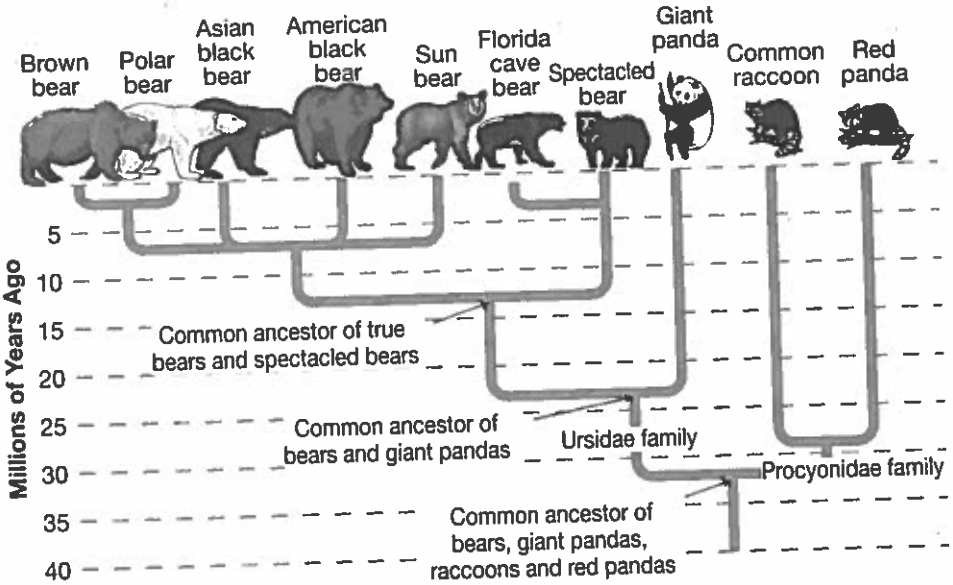
The first step in constructing a cladogram is analyzing and interpreting data. Analyze and interpret the data in the table below to determine how derived traits can be used to construct a cladogram.

Species	Derived Trait				
	A	B	C	D	E
1	Present	Present	Present	Absent	Absent
2	Absent	Absent	Absent	Absent	Absent
3	Present	Absent	Absent	Absent	Absent
4	Present	Present	Present	Present	Present
5	Present	Present	Absent	Absent	Absent
6	Present	Present	Present	Present	Absent

In the space below, develop a cladogram using the information in the table. Model your diagram on the cladogram of plant groups on the preceding page.

Which two species are most closely related? Which two are least closely related? Explain your answers.

In the phylogenetic tree below, the length of a branch represents the amount of time that has passed since the species diverged from a common ancestor. The diagram includes a timescale to show the estimated times at which groups diverged. Each new branch indicates an instance of speciation, or formation of a new species. Observe that the line for the Florida cave bear does not extend to the present. This indicates that the Florida cave bear is an extinct species.



Ultimately, all organisms share a common ancestor. If a phylogenetic tree could be drawn for all life that has ever existed on Earth, its branches would lead back to a single stem. Evidence of this common ancestor comes from both fossils and living organisms.

Evidence of Phylogenetic Relationships

Scientists combine many kinds of evidence, such as evidence from fossils and comparisons of anatomy, embryos, and DNA and proteins, to understand phylogenetic relationships. A hypothesis about the evolutionary history of a species becomes more reliable as more pieces of evidence are gathered that support it. Phylogenies are also revised as new information is gathered. For example, recent DNA data have changed the phylogenetic tree for birds.

Sometimes two species have similar structures, but other data show that the species are not closely related. Convergence is the development of similar structures and other features in species that evolved independently. This is one reason why scientists use many pieces of evidence to develop a phylogeny.

Scientists' understanding of evolutionary relationships is constantly growing and changing, as research continues in paleontology, anatomy, embryology, and biochemistry. You will learn more about the evidence for biological evolution in Lesson 20.

Lesson Review

1. What are the names of the three domains?

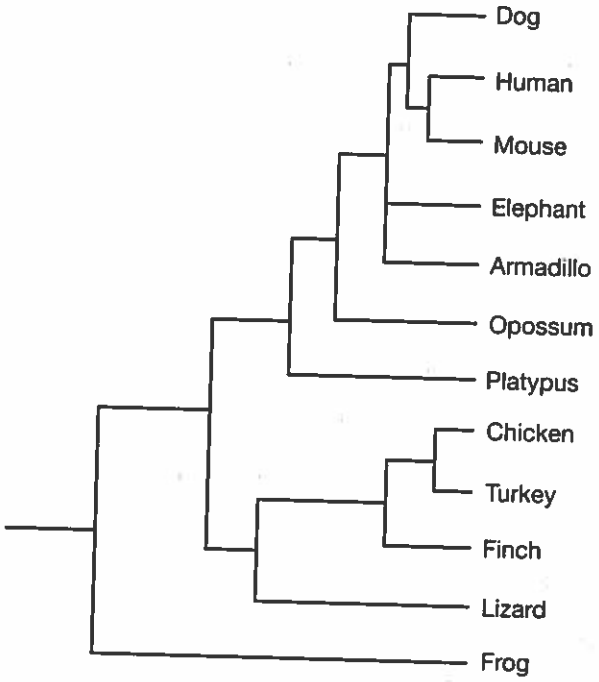
   A. Animalia, Eukarya, and Bacteria

   B. Plantae, Animalia, and Protista

   C. Eukarya, Archaea, and Bacteria

   D. Protista, Bacteria, and Animalia

2. The diagram below shows the evolutionary relationships of various tetrapods, or vertebrates with two pairs of limbs.



Which of these pairs of organisms are **least** closely related, based on this diagram?

A. human and mouse

B. dog and human

C. elephant and human

D. human and opossum

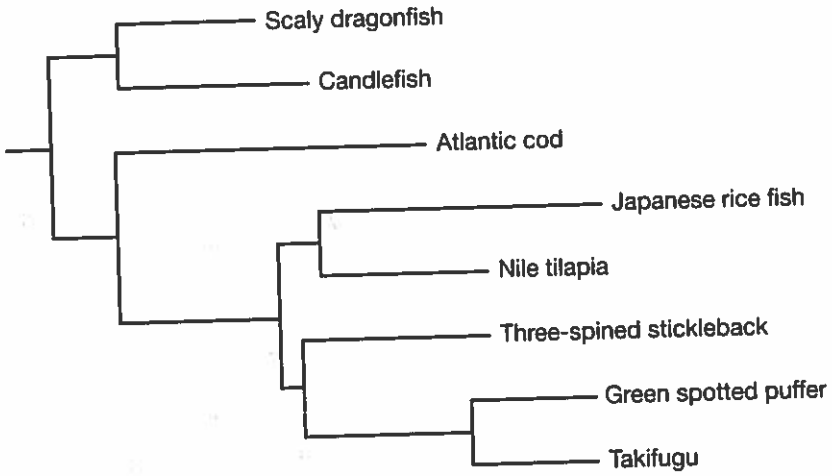
3. As plants diverged from a common ancestor, characteristic features evolved that distinguished the main plant groups from one another. Which statement shows the evolutionary sequence in which these features developed?

   A. vascular tissue, seeds, flowers

   B. seeds, vascular tissue, flowers

   C. flowers, seeds, vascular tissue

4. The diagram below shows the evolutionary relationships among eight types of fish based on biochemical evidence.



Based on this evidence, which of these pairs of species would scientists expect to have the **most** anatomical similarities?

A. Nile tilapia and candlefish

B. scaly dragonfish and takifugu

C. Japanese rice fish and Atlantic cod

D. green spotted puffer and three-spined stickleback

Chapter 3 Review

1. At one time, scientists classified all bacteria in a single kingdom. Today, prokaryotic organisms are instead classified in two domains (Archaea and Bacteria). Assume that a scientist has found several new types of prokaryotes to classify. She argues that all of these prokaryotes should be classified into the domain Archaea. What information BEST supports her argument?

   (a) The prokaryotes lack a nucleus.

   (b) The prokaryotes have cell walls.

   (c) The prokaryotes cause human disease.

   (d) The prokaryotes grow only in hot springs.

2. Scientists once classified fungi as plants. Which statement BEST supports the argument that fungi should be classified in their own kingdom?

   (a) The cells of plants have nuclei, but the cells of fungi do not.

   (b) Fungi are capable of independent movement, but plants are not.

   (c) Plant cells have chloroplasts, but fungal cells do not.

   (d) The cells of fungi have cell walls, but plant cells do not.

3. A student researched the similarities and differences between viruses and organisms. Which statement BEST supports the argument that viruses share some similarities with living things?

   (a) They both get energy from their environment.

   (b) They both contain proteins and nucleic acids.

   (c) They both reproduce on their own.

   (d) They both have a shell called a capsid.

4. A team of scientists is studying fossils of early reptiles and birds. Which aspect of fossil evidence is MOST LIKELY to help the researchers begin to construct a phylogenetic tree?

(a) the average number of offspring produced by each species

(b) the estimated number of reptile or bird species that are now extinct

(c) the number of modern-day reptile and bird species represented by the fossils

(d) the approximate date when each reptile or bird first appeared in the fossil record

5. Brown bears and coyotes are both classified in the Carnivora order. Based on this information, which TWO inferences can be made?

(a) They also belong to the same class of organisms.

(b) They are members of the same species.

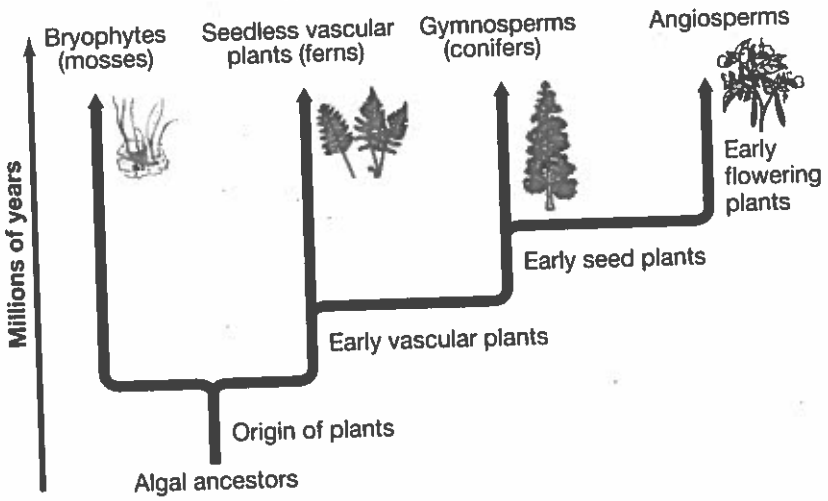
(c) They are members of the same genus.

(d) They also are classified in the same family of organisms.

(e) They both have cells with cell walls.

(f) They are part of the same kingdom.

6. The diagram shows the evolutionary relationships among four types of modern-day plants.



Which statement BEST summarizes the data that were used to develop this diagram?

(a) the number of plant species in each group

(b) the average size of the individual adult plants

(c) the presence or absence of certain plant structures

(d) the global ranges of the plant species in each group

7. Which scientific information would be LEAST useful in constructing an argument supporting the endosymbiotic theory?

   (a) Mitochondria and chloroplasts make copies of themselves by dividing.

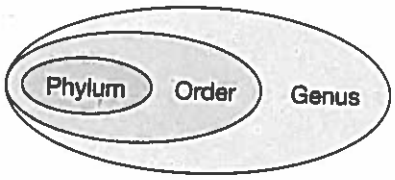
   (b) Some eukaryotic cells have both mitochondria and chloroplasts.

   (c) Mitochondria and chloroplasts are about the same size as bacteria.

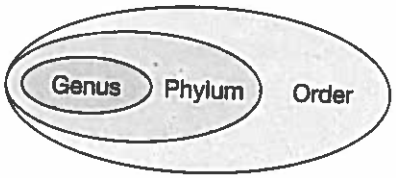
   (d) The ribosomes of mitochondria and chloroplasts are similar to those in prokaryotes.

8. Which diagram BEST shows the relationships among different levels of classification of organisms?

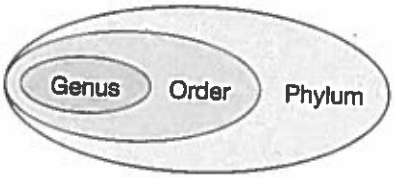
   (a)



   (b)



   (c)



   (d)