Tracing Evolutionary History

15

Focus on the Concepts

This chapter considers the subject of macroevolution—large-scale changes in living things over vast spans of time. Focus on the following concepts:

- Earth formed about 4.6 billion years ago, and the first fossils of microorganisms date from about 3.5 billion years ago. Biologists believe that physical and chemical processes on the early Earth gave rise to simple cells perhaps 3.9 billion years ago. Experiments suggest that this happened in four stages: (1) abiotic synthesis of organic monomers such as amino acids, (2) joining of monomers to form simple polymers, such as polypeptides and nucleic acids, (3) packaging of these molecules into "protobionts," droplets with simple biological activity, and (4) origin of self-replicating (probably RNA) molecules that made inheritance possible.
- The geologic and fossil records, along with radiometric dating, outline the history of life. Prokaryotes possessed Earth for a billion years. As photosynthesis added O_2 to the atmosphere, cellular respiration and more complex eukaryotic cells appeared. Multicellular eukaryotes first evolved about 1.5 billion years ago, but more complex forms don't appear in the fossil record until about 600 million years ago. Fungi, plants, and animals first colonized land about 500 million years ago.
- Geologic changes and catastrophes have shaped the history of life. Earth's crust is divided into huge plates that "float" on the hot mantle. Circulation of the mantle causes continental drift, resulting in geologic shifts along plate boundaries. About 250 million years ago, all the continents joined to form Pangaea, which later broke up. These changes altered climate, habitats, and distribution of organisms and may have caused mass extinctions. The Cretaceous Mass Extinction, the end of the line for the dinosaurs, may have been caused by an asteroid impact.
- Various biological mechanisms contribute to macroevolution. Major adaptive radiations have followed mass extinctions. Changes in genes (duplication, timing, regulation) that control growth and development, such as homeotic genes, may drastically reshape body parts. Complex structures, such as eyes, may develop step-by-step. Features such as feathers may take on new uses in a new context. Natural selection may "prune" the multibranched tree of life, shaping evolutionary trends.
- Phylogeny is the evolutionary history of a group of organisms. Biologists reconstruct phylogeny by studying fossils and anatomical and molecular homologies. Cladistics is a method that groups organisms into branches called clades. A clade includes an ancestral species and all its descendants that possess shared derived characters.

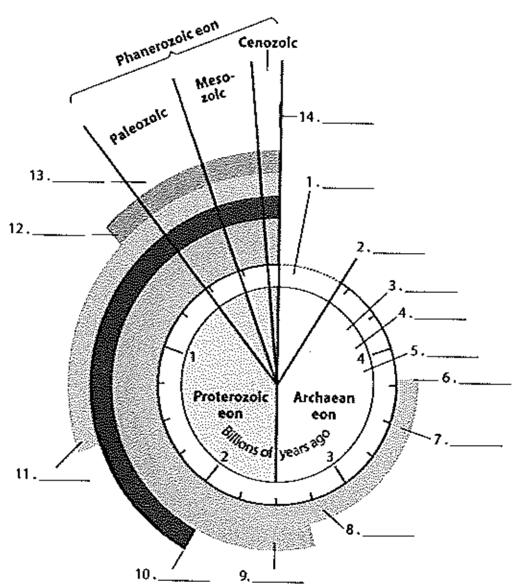
- Molecules reflect evolutionary relationships. The more recently two species have branched form a common ancestor, the more similar their DNA base sequences. Some regions of the genome mutate rapidly and track rapid, recent change, while other parts change more slowly and reveal more ancient relationships. Some change at known rates and can be used as a "clock." Whole genome comparisons demonstrate the importance of gene duplications, the large number of homologies among very different organisms, and the unity of all life.
- Taxonomists give each organism a binomial (two-part) name and group organisms into genera, families, and larger categories such as phyla and kingdoms, all the way up to one of three domains: Bacteria, Archaea, and Eukarya. Ideally, classification reflects evolutionary relationships, and each grouping is a clade—a branch or twig on the tree of life. Horizontal gene transfer early in the history of life makes the branches of the tree more twisted and intertwined than once thought.

Review the Concepts

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

Exercise 1 (Modules 15.1 and 15.4)

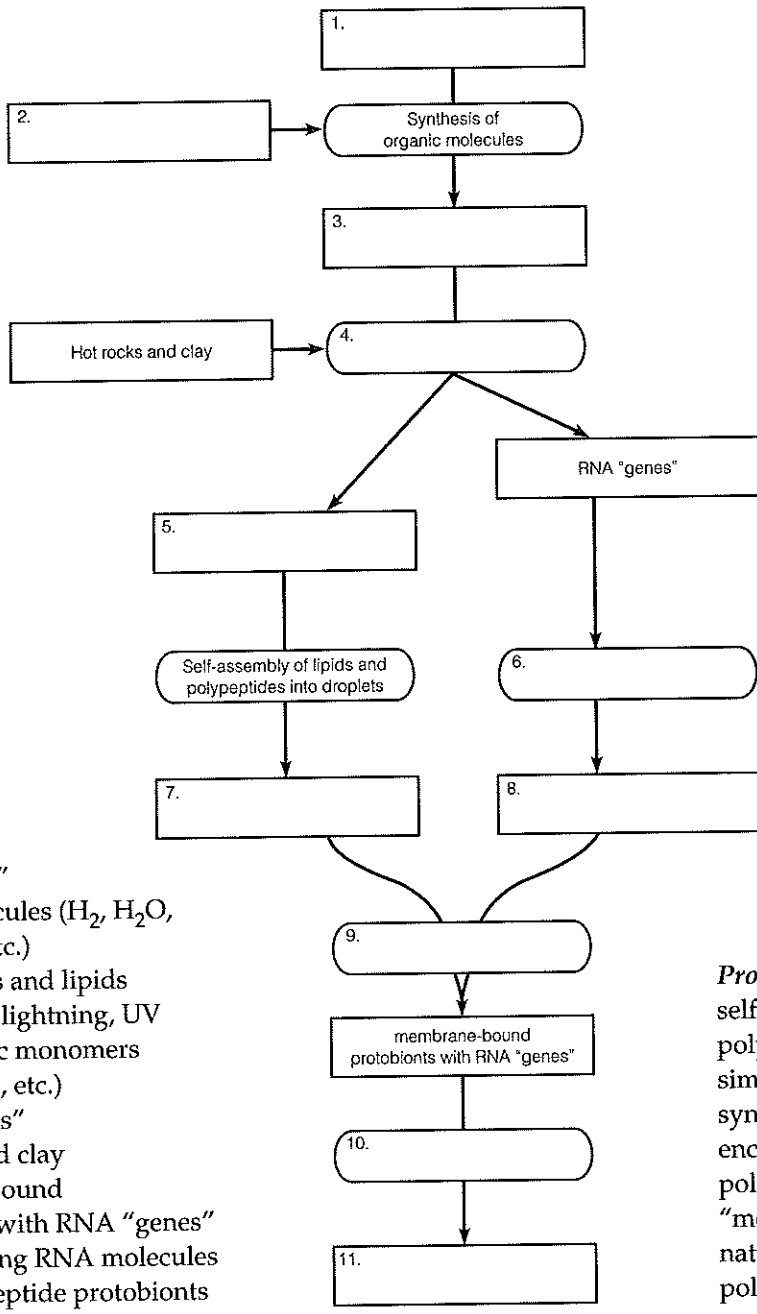
Summarize the early history of Earth and some major milestones in the history of life by finding each of the following events on the evolutionary "clock." Some of the events are described in the module and some in Figure 15.4. (Note that it is more important to know the *order* of events than exactly *when* they occurred.)



A. Age of oldest known fossils—stromatolites
B. Molten Earth, followed by formation of core and crust
C. Origin of the solar system and Earth
D. First single-celled eukaryotes
E. Formation of the oceans
F. Appearance of humans
G. Buildup of oxygen in atmosphere
H. First land plants
I. Prokaryotes dominant organisms
J. Appearance of animals
K. Appearance of the first living things
L. Volcanoes belch out atmosphere of H_2O, H_2, NH_3, CO_2, etc.
M. The "Big Bang"—formation of the universe
N. Multicellular eukaryotes

Exercise 2 (Modules 15.2–15.3)

The geological record and laboratory experiments suggest how life may have arisen from inorganic chemicals on the early Earth. This flowchart summarizes experiment and theory concerning the origin of life. Fill in the boxes by choosing from the list of components. Fill in the ovals by choosing from the list of processes. Some are done for you.



Components

RNA "genes"
simple molecules (H_2, H_2O, CH_4, NH_3, etc.)
polypeptides and lipids
energy from lightning, UV
small organic monomers (amino acids, etc.)
the first "cells"
hot rocks and clay
membrane-bound protobionts with RNA "genes"
self-replicating RNA molecules
lipid/polypeptide protobionts

Processes

self-assembly of lipids and polypeptides into droplets
simple RNA replication
synthesis of organic monomers
enclosure of RNA by lipid/polypeptide protobiont "membrane"
natural selection
polymerization

Exercise 3 (Modules 15.4–15.6)

Review the major events in the history of life by numbering each of the following events in sequence (1, 2, 3 . . .) and naming the geologic eon and era (if applicable) when each occurred. (Note once again that it is more important to know the order in which events occurred than the dates or names of the era.)

Sequence	*Eon*	*Era*	*Event*
______	__________	__________	A. Cone-bearing plants and dinosaurs dominant
______	__________	__________	B. Humans appear
______	__________	__________	C. Diverse soft-bodied animals
______	__________	__________	D. Prokaryotes dominant
______	__________	__________	E. Diversification of fishes
______	__________	__________	F. First eukaryotes
______	__________	__________	G. Radiation of mammals
______	__________	__________	H. Invasion of land by plants and arthropods
______	__________	__________	I. Origin of reptiles
______	__________	__________	J. First animals
______	__________	__________	K. First living things
______	__________	__________	L. Permian mass extinction of marine and terrestrial life
______	__________	__________	M. Flowing plants appear, dinosaurs go extinct
______	__________	__________	N. "Explosion" of animal phyla

Exercise 4 (Module 15.5)

Use the concept of half-life to answer these questions about the ages of fossils.

1. The half-life of carbon-14 is 5,730 years. If a mammoth has 1/8 the ^{14}C-to-^{12}C ratio that it was thought to have when it was frozen in a Siberian glacier, how old is the mammoth? With a margin of error of plus or minus 10%, what are the maximum and minimum ages of the fossil?

2. The half-life of potassium-40 is 1.3 billion years. If a rock specimen contained 1 g of potassium-40 when it was formed, how much potassium-40 would be left if the rock is 2.6 billion years old?

Exercise 5 (Modules 15.7–15.10)

Review some of the geologic processes that reshape the surface of Earth—and their macroevolutionary consequences—by matching each of the phrases on the left with a word on the right. The illustrations in the textbook will help.

_______ 1. The surface of Earth, broken into plates	A. Pangaea
_______ 2. Animals that evolved when Pangea was still intact	B. Tsunamis
_______ 3. Southern land mass formed when Pangaea broke up	C. Cretaceous
_______ 4. A very small plate	D. Earthquake
_______ 5. This ocean grows as North America and Eurasia split apart.	E. Himalayas
_______ 6. New adaptations that led to adaptive radiations	F. Continental drift
_______ 7. Supercontinent formed 250 million years ago	G. Gondwana
_______ 8. May have caused Permian mass extinction	H. Mantle
_______ 9. Any large, moving segment of Earth's crust	I. Australia
_______ 10. "Fallout" from asteroid impact	J. Nazca
_______ 11. Formed by collision of Indo-Australian and Eurasian plates	K. Laurasia
_______ 12. Movement of continents over Earth's surface	L. Siberian volcanoes
_______ 13. Mass extinction probably caused by an asteroid impact	M. Fault
_______ 14. Northern land mass formed when Pangaea broke up	N. Atlantic
_______ 15. Many marsupials evolved here, isolated from other continents	O. Lungfishes
_______ 16. Caused by undersea earthquakes	P. Eurasia
_______ 17. Where most important geological processes occur	Q. Permian
_______ 18. Predicted to form 250 million years in the future	R. Plate
_______ 19. Site of crater that perhaps is related to Cretaceous mass extinction	S. Crust
	T. Mammals
_______ 20. Mass extinctions that had a significant impact on the history of life	U. Iridium
	V. Plate edges
_______ 21. Underwent dramatic adaptive radiation after the Cretaceous extinction	W. A new supercontinent
	X. Yucatan
_______ 22. Movement resulting from forces at plate edges	Y. "Big Five"
_______ 23. Place where plates slide along one another	Z. Wings, rigid stems, pollination
_______ 24. Continent formed from the eastern part of Laurasia	
_______ 25. Mass extinction that occurred 250 million years ago	
_______ 26. Hot layer that lies beneath the crust	

Exercise 6 (Modules 15.11–15.13)

Scientists are beginning to understand the biological mechanisms responsible for large-scale evolutionary changes. Review the biological mechanisms underlying macroevolution by matching each of the descriptions on the left with the best evolutionary example on the right.

______ 1. Changes in body form often result from changes in gene regulation, not in the genes themselves.	A. The horse family
______ 2. Complex structures often evolve step-by-step.	B. Eyes
______ 3. A structure that evolves in one context and takes on a new role is called an exaptation.	C. Human and chimp skulls
______ 4. Slight changes in the relative rates of growth in different body parts can make big changes in the appearance of adults.	D. Feathers
______ 5. Changes in homeotic genes can radically alter the timing of development and the shape of body parts.	E. Fins to legs
______ 6. Selection among different species may result in large-scale evolutionary trends or apparent "trends."	F. Salamanders with gills
______ 7. Paedomorphosis is a change in timing of development, causing juvenile features to be retained by adults.	G. Stickleback spines

Exercise 7 (Modules 15.14–15.19)

Review the principles, methods, and vocabulary of phylogeny and systematics by inserting the correct terms into the following essay.

The evolutionary history of a species or group of species is termed [1]________________. Scientists look to the [2]________________ record to reconstruct phylogeny. Evolutionary history can also be reconstructed by comparing morphological (structural) and molecular features among living species. The teeth and skeletons of lions and bobcats show many [3]________________ that indicate that these animals share a common ancestry. But anatomical comparisons can sometimes be misleading. A process called [4]________________ evolution sometimes causes unrelated organisms to look alike because they have adapted independently to similar environments. The extinct Tasmanian "tiger" (see Chapter 19, Introduction) looks like a cat, but it is actually a marsupial, more closely related to a kangaroo! Such similarity due to convergence is called [5]________________; it can be misleading in reconstructing phylogenies. Often, molecular comparisons allow us to see beyond outward appearance; the DNA of the Tasmanian tiger is very different from the DNA of the two big cats.

[6]________________ is the field of biology that focuses on classifying organisms and finding their evolutionary relationships. An important goal of systematics is to name and classify organisms. Biologists called [7]________________ use morphological and molecular comparison to name and group species. Each species is given a two-part name, called a [8]________________. For example, the African lion is *Panthera leo*. The first part of the name is the [9]________________ to which the lion belongs. The second part identifies a particular [10]________________ within that genus.

Naming is only a starting point. The ultimate goal of taxonomy is to place each organism into a hierarchy of taxonomic categories from [11]________________ (the smallest) to [12]________________ (the largest and most inclusive). Ideally, these categories reflect evolutionary history. Biologists depict these relationships in the form of

[13]________________ trees. Species are the twigs of such a tree. The limbs of the tree are larger groupings such as orders, classes, and phyla.

The most widely used method in systematics is called [14]________________. It is a method that that seeks to identify [15]________________—branches that include an ancestral species and all its descendants. Such an inclusive group—a genus, family, or kingdom—is said to be [16]________________. Cladistics makes it possible to construct a classification scheme that reflects the branching of the tree of life.

Cladistics is based on the idea that the evolutionary tree forks when a new heritable trait develops and is passed on to descendants. Groups of organisms that share the new trait are more [17]________________ related than those that have only ancestral traits. For example, the Tasmanian tiger, the lion, and the bobcat all have hair and mammary glands. These are shared [18]________________ characters. But the Tasmanian tiger gives birth to its young very early and nurses them within a pouch. The lion and bobcat retain their young for a much longer period of gestation, nourishing them via a structure called the placenta; this is an added trait, a shared [19]________________ character, that sets the lion and bobcat apart from the Tasmanian tiger. The bobcat and lion are placed in a separate clade, a separate subclass of Class Mammalia, reflecting this evolutionary history. If we are comparing the two cats with the Tasmanian tiger, the cats constitute an ingroup, and the Tasmanian tiger represents an [20]________________, a group known to have diverged before the cat lineage.

The principle of [21]________________, the quest for the simplest explanation, guides cladistics, but this has shaken some branches of the "traditional" evolutionary tree. For example, this approach places [22]________________ within the reptile clade. Several shared [23]________________ characters, such as a four-chambered heart, show that birds and crocodiles are more closely related to each other than crocs are to other reptiles. Similarly, cladistics separates humans and chimps from other apes.

Molecular comparisons can clarify evolutionary relationships. Comparing nucleic acids, proteins, or other molecules to determine relatedness is called molecular [24]________________. Researchers use computers to search through and compare nucleic acid [25]________________ sequences from different species. In general, the more similar the base sequences, the more [26]________________ related the organisms in question. Some nucleic acids, such as the DNA in [27]________________, evolve rather rapidly. Thus, mDNA can be used to trace recent evolutionary events, such as the divergence of various human groups. Other nucleic acids, such as the DNA coding for [28]________________ RNA, change more slowly, so they can track changes occurring over hundreds of millions of years. Because some genes appear to change at a known rate, they allow us to calibrate a molecular [29]________________ that can be used to date evolutionary branch points. Because a good fossil record goes back only about [30]________________ million years, we can use molecular clocks to date divergences thought to have occurred before that time. Returning to the more recent divergence of our cats and the Tasmanian tiger, we would expect that homologous genes of a lion and a bobcat would be more alike than homologous genes of a lion and a Tasmanian tiger. Thus, cladistics and molecular systematics enable us to form testable [31]________________.

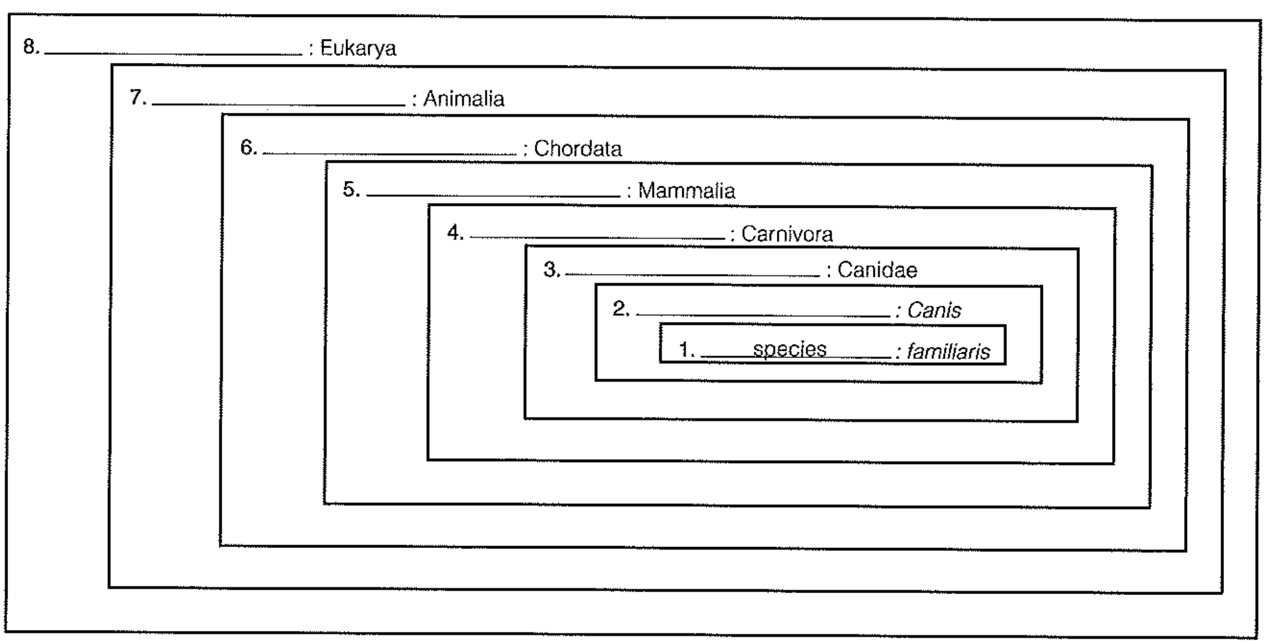
Comparing whole genomes has given us some surprising insights into evolutionary relationships. On a molecular level, the genes of humans and chimps are 96% identical. Amazingly [32]________________ of human genes are homologous with genes in mice, and about half our genes are homologous with genes in [33]________________—single-celled eukaryotes! Genomics has revealed that gene [34]______________ has had an important role in evolution, because it increases the number of genes in the genome and provides "raw material" for evolutionary change.

Looking at the larger picture, molecular systematics has catalyzed rethinking the entire tree of life. Back in the day, all life was divided into two kingdoms—[35]______________ and [36]______________. But where did this leave bacteria or photosynthetic organisms that swim? By the 1960s, it looked like the tree of life had five main branches, but soon enough, molecular comparisons showed that that scheme was flawed too. More recently, biologists have adopted a three-[37]______________ system, with two groups of prokaryotes, called [38]______________ and [39]______________, and one group of eukaryotes, the [40]______________. Plants, [41]______________, fungi, and protists (like those swimming green guys) are [42]______________ within Domain Eukarya.

The most recent discoveries suggest that the tree of life might not be a tree at all! During the early history of life, there appear to have been substantial exchanges of genes among the different domains. This took place via [43]______________ gene transfer, a process carried out by exchange of plasmids, [44]______________ infection, or even fusion of whole organisms. Your mitochondria, for example, were once free-living [45]______________. The tree of life thus becomes a tangled thicket of intertwining vines, or even a ring.

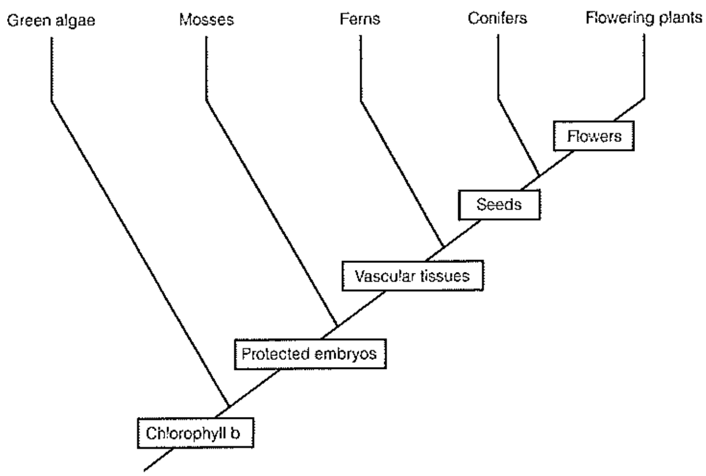
Exercise 8 (Module 15.15)

The system of taxonomic categories used by biologists is like a set of boxes into which organisms are sorted. A cocker spaniel—*Canis familiaris*—for example, is first placed in a small box, the specific name *familiaris* that separates it from all other species. This is placed in a slightly larger box, the genus *Canis*, which also holds *Canis lupus* (the wolf) and *Canis latrans* (the coyote). This genus box is placed in a larger box, along with other genera of doglike animals, and so on, all the way up to the last box that separates eukaryotes from prokaryotes. Imagine that the nested boxes below represent the taxonomic categories, starting with species (omitting subphylum). Label the boxes to show the relationships among the categories.



Exercise 9 (Module 15.16)

Cladistics, the most widely used method of systematics, seeks to clarify evolutionary and taxonomic relationships by grouping organisms into clades. A clade is a group of organisms made up of an ancestor and all its descendants. This simplified phylogenetic tree uses cladistics (based on anatomy, but backed up by molecular data) to reconstruct the relationships among four groups of plants and their closest relatives, the green algae. Read Module 15.16, examine the trees in the module and below, and then answer the following questions. This exercise is rather difficult, so take your time.

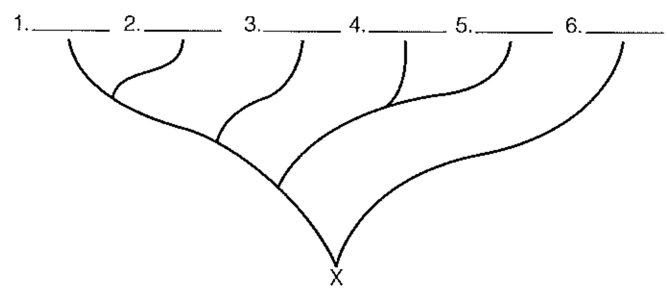


1. Which four groups of organisms above make up the in-group?
2. Which organisms constitute the out-group?
3. Which is more useful in cladistics, analogies or homologies?
4. Which characters are unique to a lineage of organisms, shared derived characters or shared ancestral characters? Which are more useful in differentiating among (separating out) distinct lineages?
5. What is a shared ancestral character common to all plants?
6. What is a shared derived character common to all plants?
7. What is a shared ancestral character common to all plants with seeds?
8. What is a shared derived character common to all plants with seeds?
9. Which characters are most useful in deciding whether an organism is in the out-group or the in-group, shared ancestral characters or shared derived characters?
10. If we are interested in focusing on all plants that have vascular tissues, which groups on the phylogenetic tree constitute the out-group? The in-group?
11. What is the name of a taxonomic group consisting of an ancestor and all its descendants?
12. What other organisms are in the clade that includes the first plants with seeds?
13. Name or describe nine different clades shown on the phylogenetic tree above.

Exercise 10 (Module 15.17)

Homologous structures—similar structures derived from the same structure in a common ancestor—tell us about phylogenetic relationships among organisms. But convergent evolution can make unrelated organisms look alike; their similarities may be analogous, not homologous. Fortunately, we can dig beneath surface similarities and compare biological molecules to measure relatedness between species. For example we can compare protein amino acid sequences, RNA base sequences, or DNA base sequences—even whole genomes. Imagine that you have sequenced mitochondrial DNA (mDNA) for six species of rodents, A through F. All the rodents are thought to have evolved from a common ancestor, X. The number of differences in mDNA sequence are compiled in the table below, which reads like a road map mileage chart. For example, there are four differences between A and C, and nine differences between A and D. Use the differences in sequence to place species A through F on the phylogenetic tree. (Hint: Don't get too mathematical; just "eyeball" overall numbers.)

A						
B	10					
C	4	11				
D	9	5	10			
E	14	16	15	15		
F	10	2	10	6	16	
	A	B	C	D	E	F



Test Your Knowledge

Multiple Choice

1. The science of naming and classifying organisms is called
   a. biology.
   b. polyploidy.
   c. genetics.
   d. taxonomy.
   e. parsimony.

2. Large-scale changes in the history of life, such as mass extinctions, the development of walking legs from fins, and the appearance of new groups of organisms such as birds, are termed:
   a. macroevolution.
   b. adaptation.
   c. exaptation.
   d. microevolution.
   e. paedomorphosis.

3. Which of the following is thought to have been the first step in the origin of life?
   a. cooperation among molecules
   b. formation of protobionts
   c. formation of organic monomers
   d. replication of primitive "genes"
   e. formation of organic polymers

4. Systematics is concerned with
   a. naming organisms.
   b. studying biological diversity.
   c. taxonomy.
   d. tracing phylogeny.
   e. all of the above.

5. If you want to see a dinosaur, it would be best to set the controls of your time machine for the
   a. Mesozoic era.
   b. Paleozoic era.
   c. Cenozoic era.
   d. Paleozoic era.
   e. Precambrian.

6. Which of the following taxonomic categories contains all the others?
   a. genus
   b. class
   c. family
   d. subclass
   e. order

7. The three domains of life are
   a. bacteria, plants, and animals
   b. prokaryotes, eukaryotes, and plants
   c. plants, animals, and fungi
   d. eukaryotes and two kinds of prokaryotes
   e. bacteria, protists, and eukaryotes

8. Organisms that survive mass extinctions
   a. often diversify, taking advantage of new opportunities.
   b. usually are so reduced in numbers that they soon go extinct.
   c. are often "living fossils" that have existed unchanged for long periods.
   d. usually cannot cope with the new conditions that follow.
   e. usually lack exaptations for their new environment.

9. The ideal taxonomic grouping includes
   a. all known species with shared ancestral characters.
   b. an out-group and an in-group
   c. a group of species that all evolved at about the same time.
   d. species that do not share any derived characters.
   e. an ancestor species and all its descendants.

10. Pangaea
    a. was a land mass that broke up to form the present-day continents.
    b. is the idea that all life on Earth is related.
    c. was an animal common in ancient seas but now extinct.
    d. is the evolutionary history of a species, family, or phylum.
    e. is the theory that crustal plates can move relative to one another.

11. Continental drift is responsible for all of the following except
    a. volcanoes.
    b. formation of river systems.
    c. distribution of animals and plants.
    d. mountain ranges such as the Himalayas.
    e. earthquakes.

12. Which of the following most strongly suggests that an impact by an asteroid may have caused the extinction of the dinosaurs?
    a. Fossils show that dinosaurs suffered from cold and starvation.
    b. There have been several near misses in recent years.
    c. Sedimentary rocks contain a layer of mineral uncommon on Earth.
    d. The dinosaurs disappeared rather abruptly—virtually overnight.
    e. Fossils indicate that most dinosaurs were looking up when they died.

13. Which of the following is least useful in tracing phylogeny?
    a. mitochondrial DNA
    b. convergent evolution
    c. fossils
    d. homologous genes
    e. gene duplications

Essay

1. Describe Stanley Miller's experiment that simulated conditions on the ancient Earth. How was the experiment carried out? What was its purpose? Its result? Looking back, what was the experiment's biggest flaw?

2. Explain how the formation of Pangaea may have led to mass extinctions at the end of the Permian period, about 250 million years ago. How did this lead to new evolutionary developments?

3. Place the following events in the history of life in the proper order: Appearance of humans, origin of eukaryotes, dominance of dinosaurs and cone-bearing plants, origin of animals, appearance of first vertebrates, diversification of mammals, origin of flowering plants, first prokaryotes, movement of plants and animals onto land.

4. Describe two different ways in which continental drift causes mountains to form.

5. The following list shows the levels of classification of a human being, *Homo sapiens*. Name the category that corresponds to each of the taxa listed. (Hint: Vertebrata is a subphylum.)

   Eukarya Animalia Chordata Vertebrata Mammalia Primates Hominidae *Homo sapiens*

6. What is a clade? Explain how cladistics connects phylogeny and taxonomy. How has cladistics shaken up traditional taxonomy?

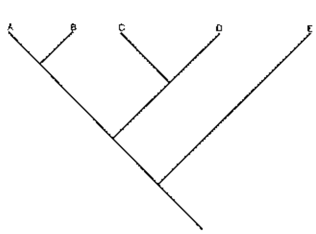
Apply the Concepts

Multiple Choice

1. Drastic reductions in the number of body segments and pairs of legs may have been responsible for the evolution of the first insects from millipede-like ancestors. This example might illustrate
   a. parsimony.
   b. paedomorphsis.
   c. species selection.
   d. horizontal gene transfer.
   e. changes in homeotic genes.

2. Which of the following discoveries would force scientists to revise their present theories regarding the origin of life on Earth?
   a. Earth is found to be 6 billion years old, rather than 4.6 billion.
   b. Polypeptides can catalyze replication of small RNA molecules.
   c. There was a lot of oxygen gas in the atmosphere 4 billion years ago.
   d. Minerals in lava catalyze formation of polypeptides from amino acids.
   e. Lipids spontaneously form selectively permeable membranes.

3. This phylogenetic tree represents the relationships among several species—A, B, C, D, and E. Which of the following groups of species is a clade?
   a. A, B, C
   b. A, B, C, D
   c. B, C, D
   d. C, D, E
   e. B, C, D, E



4. The following are some major events in the early history of life.
   P. first cells
   Q. first genes
   R. first eukaryotes
   S. first photosynthetic prokaryotes
   T. first animals

   Which answer below places these events in the correct order?
   a. PQSRT
   b. QSPTR
   c. QPSRT
   d. QSPRT
   e. SPQRT

5. Which of the following would cast doubt on the asteroid-impact hypothesis for the Cretaceous extinction?
   a. finding a crater 200 million years old
   b. finding fossil dinosaur bones beneath a layer of iridium
   c. determining that birds are closely related to dinosaurs
   d. finding fossil dinosaur bones above a layer of iridium
   e. finding that many forms of marine life disappeared at the same time as the dinosaurs

6. The wings of birds and insects have similar functions, but they do not have the same evolutionary origin. Bird and insect wings are
   a. homologous.
   b. phylogenetic.
   c. analogous.
   d. binomial.
   e. monophyletic.

7. Which of the following might be a shared derived character that could be used to classify different kinds of mammals (mice, monkeys, deer, bears, cats, etc.)?
   a. whether or not they have hair
   b. kinds of teeth they possess
   c. presence or absence of a backbone
   d. whether or not they produce milk
   e. analogous skeletal structures

8. Two animals in the same family would not have to be in the same
   a. genus.
   b. domain.
   c. order.
   d. phylum.
   e. class.

9. A phylogenetic tree of bird families would most clearly show which of the following?
   a. characteristics shared by all bird families
   b. evolutionary relationships among families
   c. families that look most alike
   d. analogous structures shared by various species
   e. relative ages of living species of birds

10. Fossils of an ancient reptile called *Lystrosaurus* have been found in Africa, India, and Antarctica. Which of the following best explains this distribution?
    a. They were able to move between continents before the oceans filled.
    b. Movement of India due to continental drift carried them from place to place.
    c. These areas were once next to each other and have since drifted apart.
    d. They were able to migrate over frozen seas during the Ice Ages.
    e. Changes in climate forced them to migrate from place to place.

11. A species of fruit fly is thought to have diverged from another species less than a thousand years ago. Study of which of the following would best clarify these fruit fly relationships?
    a. mitochondrial DNA
    b. the fossil record
    c. ribosomal RNA
    d. comparison of analogous structures
    e. radiometric dating

12. Which of the following taxa is *least* closely related to the others?
    a. Archaea
    b. Plantae
    c. Bacteria
    d. Eukarya
    e. Animalia

13. According to Figure 15.17, which of the following are most closely related?
    a. raccoon and lesser panda
    b. giant panda and raccoon
    c. giant panda and lesser panda
    d. sloth bear and spectacled bear
    e. brown bear and sloth bear

14. In a detailed phylogenetic tree showing the evolutionary relationships within a class, the "trunk" of the tree might represent the ______, while the ends of individual "twigs" might represent ______.
    a. phylum . . . classes
    b. class . . . species
    c. genus . . . species
    d. species . . . families
    e. class . . . phyla

Essay

1. When a tree was buried in a swamp, it contained 400 mg of carbon-14. The half-life of carbon-14 is 5,730 years. How long ago was the tree buried if it now contains 100 mg of carbon-14?

2. Ultraviolet light breaks chemical bonds in large organic molecules. (That is why it is dangerous to unprotected skin.) Does this fact lend support to hypotheses about the possible role of UV radiation in the origin of life, or does it present problems for these hypotheses? Explain.

3. The dinosaurs perished in a mass extinction at the end of the Cretaceous period, 65 million years ago. Briefly describe alternative hypotheses that have been suggested to explain the extinction of the dinosaurs. Did other forms of life disappear during the same period? Does this cast doubt on any of the hypotheses? Why?

4. Biologists like to look at fossils to trace evolutionary relationships. Birds are very delicate and unlikely to be fossilized; only a handful of old bird fossils are known. How might the molecules in the cells of living birds be compared to determine how ducks, sparrows, and hawks are related? Briefly name the molecules, what characteristic of the molecules would be compared, and how this would indicate how closely related the birds are.

5. Molecular comparisons indicate that the vultures of Africa and America are more closely related to separate nonvulture ancestors than they are to each other. If the two groups of vultures are not closely related, why do you think they look so much alike?
6. Are "vultures" a clade? Explain.
7. Advocates of "intelligent design" say that a structure as complex as the eye could not have evolved, but must have been designed by an "intelligent agent." How do biologists counter this assertion?

Put Words to Work

Correctly use as many of the following words as possible when reading, talking, and writing about biology:

analogy, binomial, clade, cladistics, class, continental drift, convergent evolution, domain, "evo-devo," family, genus (plural, *genera*), *geologic record, horizontal gene transfer, in-group, kingdom, macroevolution, molecular clock, molecular systematics, monophyletic, order, out-group, Pangaea, parsimony, phyla, phylogenetic tree, phylogeny, radiometric dating, shared ancestral characters, shared derived characters, species, systematics, taxon, three-domain system*

Use the Web

For further review on the history of life, mechanisms of macroevolution, and the principles of systematics, see the activities and questions at www.mybiology.com.