

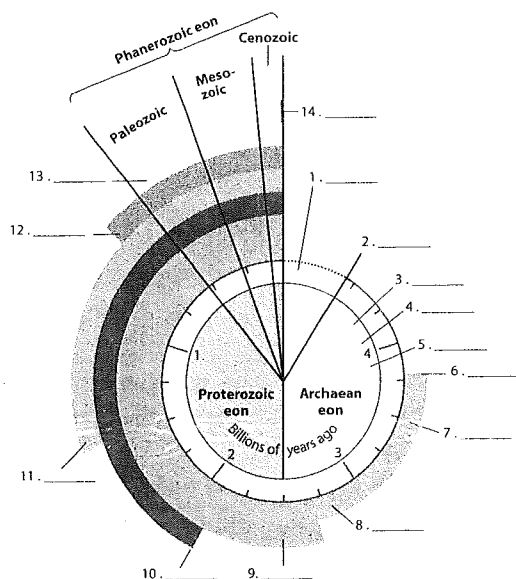
- Molecules reflect evolutionary relationships. The more recently two species have branched from a common ancestor, the more similar their DNA base sequences. Some regions of the genome mutate rapidly and track rapid, recent change, while other parts change more slowly and reveal more ancient relationships. 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)

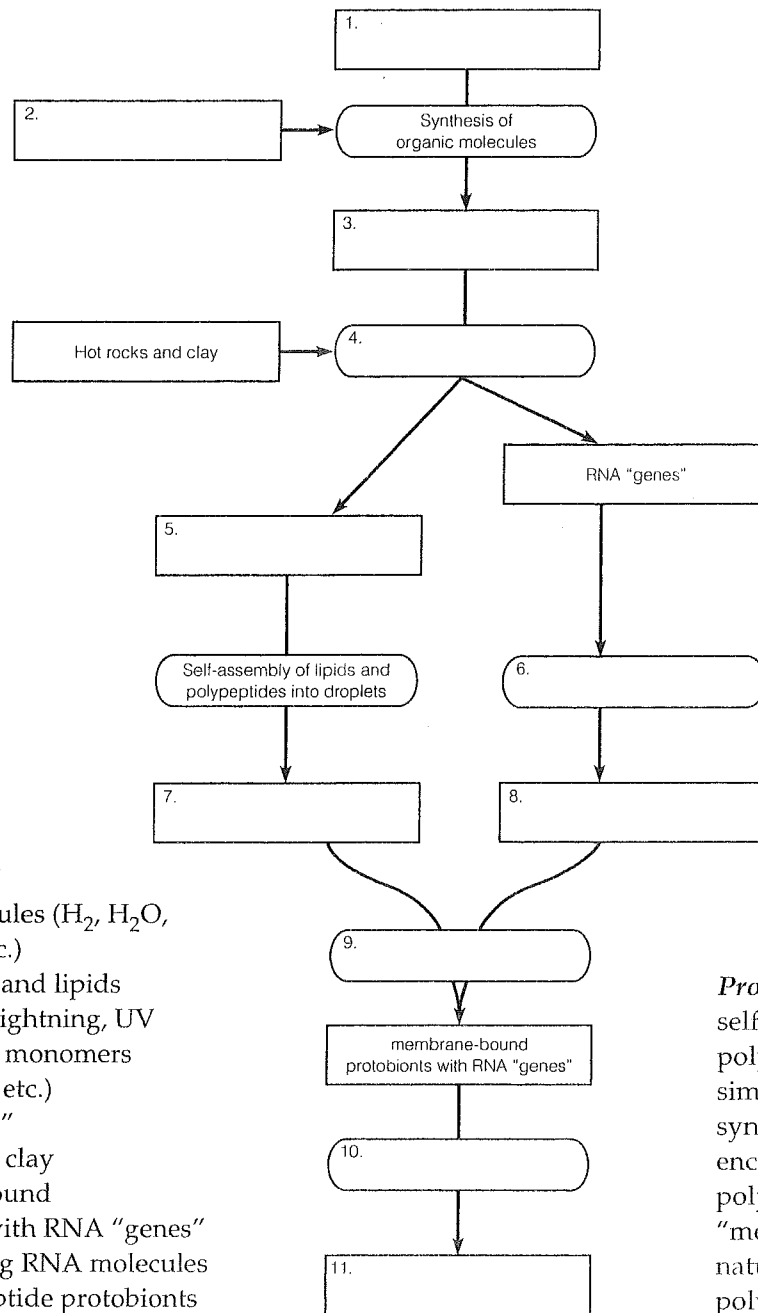
Summarize the early history of Earth and some major milestones in the history of life by finding each of the following events on the evolutionary “clock.” Some of the events are described in the module and some in Figure 15.4. (Note that it is more important to know the *order* of events than exactly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



- Age of oldest known fossils—stromatolites
- Molten Earth, followed by formation of core and crust
- Origin of the solar system and Earth
- First single-celled eukaryotes
- Formation of the oceans
- Appearance of humans
- Buildup of oxygen in atmosphere
- First land plants
- Prokaryotes dominant organisms
- Appearance of animals
- Appearance of the first living things
- Volcanoes belch out atmosphere of H_2O , H_2 , NH_3 , CO_2 , etc.
- The “Big Bang”—formation of the universe
- 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 (H₂, H₂O, CH₄, NH₃, 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.)

<i>Sequence</i>	<i>Eon</i>	<i>Era</i>	<i>Event</i>
_____	_____	_____	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. Flowering 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.

- 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?
- 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 |
| _____ 20. Mass extinctions that had a significant impact on the history of life | T. Mammals |
| _____ 21. Underwent dramatic adaptive radiation after the Cretaceous extinction | U. Iridium |
| _____ 22. Movement resulting from forces at plate edges | V. Plate edges |
| _____ 23. Place where plates slide along one another | W. A new supercontinent |
| _____ 24. Continent formed from the eastern part of Laurasia | X. Yucatan |
| _____ 25. Mass extinction that occurred 250 million years ago | Y. "Big Five" |
| _____ 26. Hot layer that lies beneath the crust | Z. Wings, rigid stems, pollination |

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 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 in-group, 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, mtDNA 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

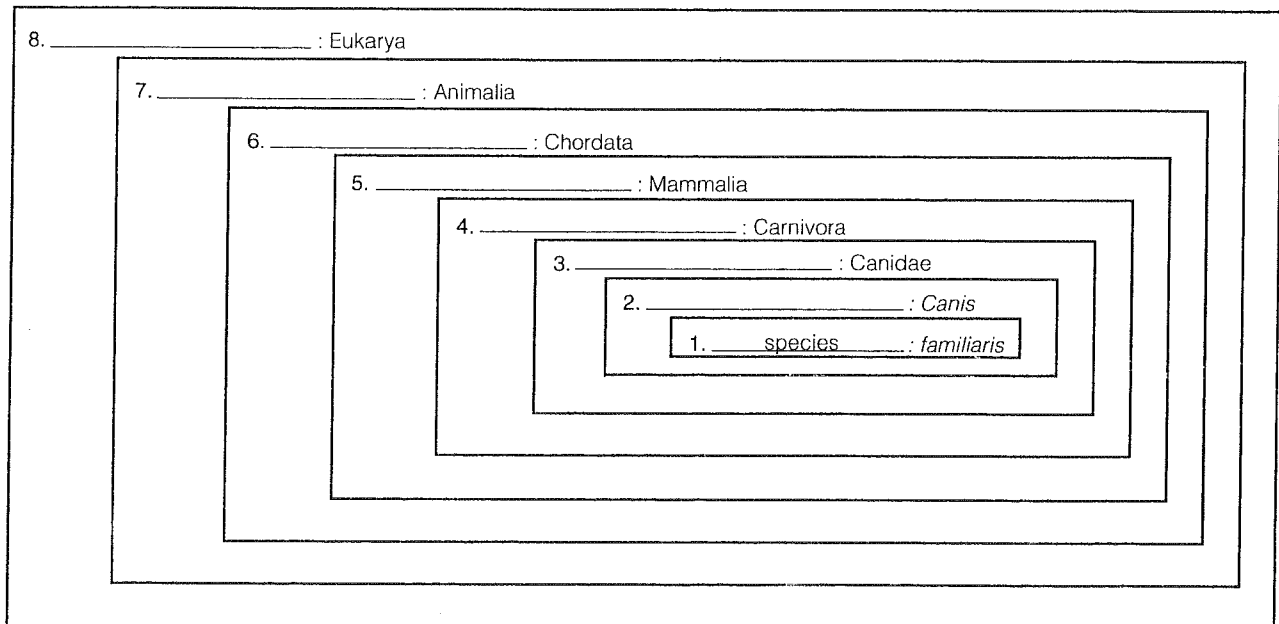
eukaryotes! Genomics has revealed that gene ³⁴ _____ has had an important role in evolution, because it increases the number of genes in the genome and provides “raw material” for evolutionary change.

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.

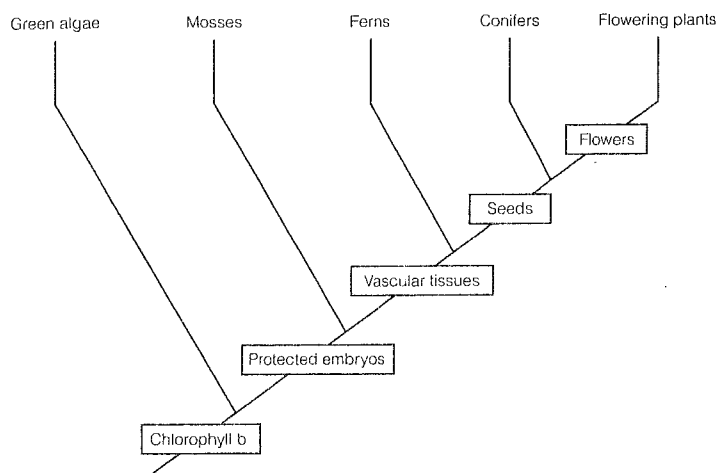
Exercise 8 (Module 15.15)

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.