The Origin and Evolution of Microbial Life: Prokaryotes and Protists

16

A drop of pond water holds a beautiful and fascinating world. Under a microscope, pond scum becomes delicate filaments of green algae, their chloroplasts spiraling inside crystal cell walls. Other algae swim and spin lazily. Golden diatoms glide across the field of view, their intricately etched silica skeletons refracting rainbows of light. Necklaces of simpler cyanobacteria wave gently to and fro. Ciliated cells shaped like funnels suck algae and even smaller bacteria into their mouths, while formless amoebas crawl slowly in search of microscopic prey. Suddenly a huge *Paramecium* darts into view, its cilia beating in rhythm as it vacuums up small food particles. These creatures remind us of a time before there were any plants or animals—before there were any multicellular organisms at all. Some take us back to the very dawn of life on Earth. This chapter concerns the origin of life and the diversity of microbial life forms.

Organizing Your Knowledge

Exercise 1 (Module 16.1)

Web/CD Activity 16A *The History of Life*

Summarize the early history of the Earth and the beginnings of life by numbering the following events in sequence. Some of the events are described in the text and some in Figure 16.1C.

_____ A. Formation of the seas

_____ B. Loss of Earth's original hydrogen (H_2) atmosphere

_____ C. Formation of Earth

_____ D. Melting of Earth, followed by formation of core and crust

_____ E. Oldest known fossils

_____ F. The "Big Bang"—formation of the universe

_____ G. O_2 from photosynthetic prokaryotes produces aerobic atmosphere

_____ H. Origin of eukaryotes

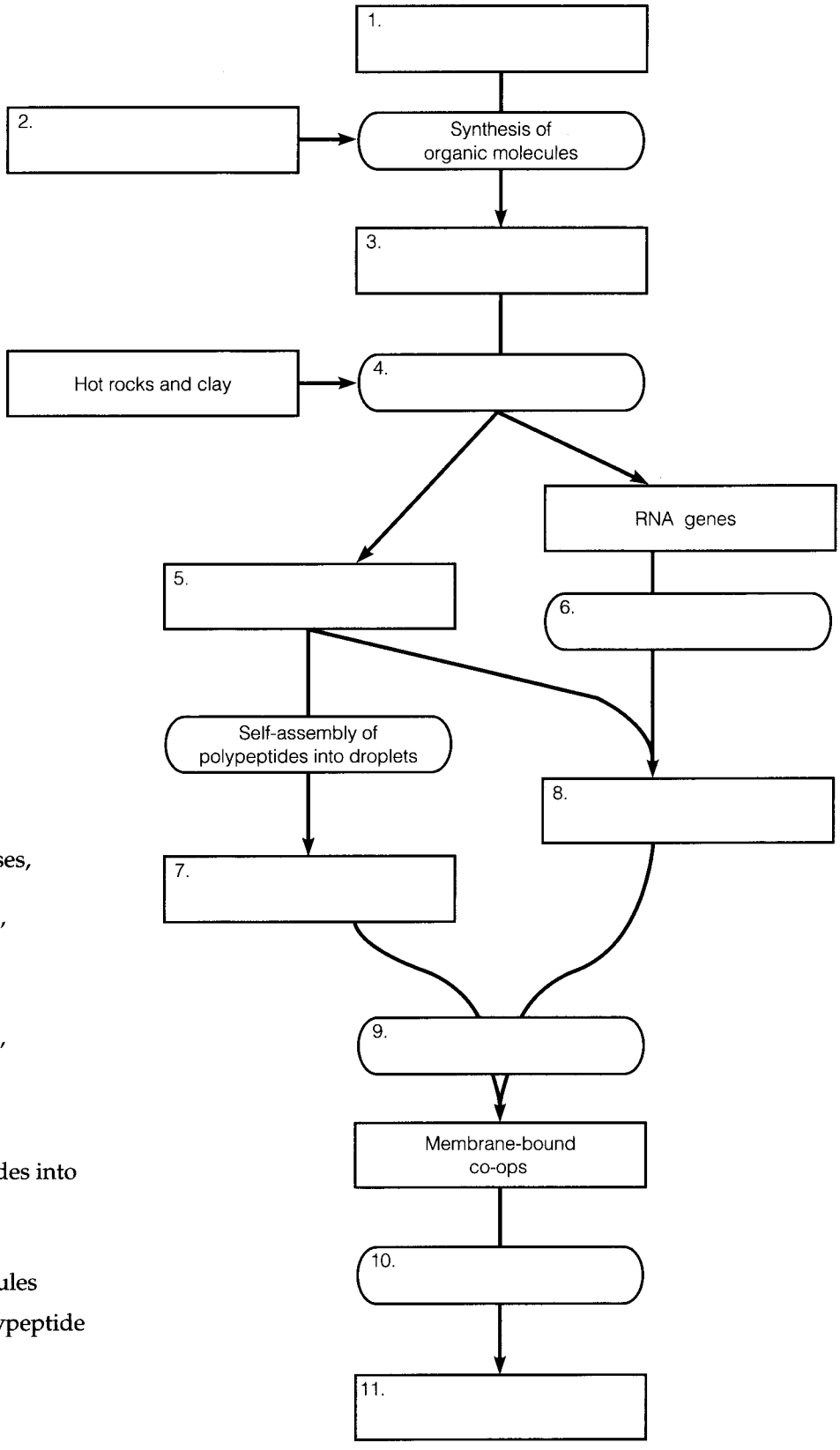
_____ I. Volcanoes belch out atmosphere of H_2O, CO, CO_2, N_2, CH_4, NH_3

_____ J. Origin of life—first prokaryotes

_____ K. Oldest known animals

Exercise 2 (Modules 16.2 - 16.6)

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

polypeptide spheres (with lipids?)

RNA "genes"

simple molecules (CO, CO_2, N_2, H_2O, etc.)

polypeptides

energy from lightning, UV radiation

small organic molecules (amino acids, sugars, bases, ATP)

RNA-polypeptide "co-ops"

the first cells

hot rocks and clay

membrane-bound "co-ops"

Processes

self-assembly of polypeptides into droplets

simple RNA replication

synthesis of organic molecules

enclosure of co-ops by polypeptide spheres

natural selection

polymerization

Exercise 3 (Modules 16.7 - 16.8)

There are two fundamentally different kinds of prokaryotes. State whether each of the following describes bacteria (B) or archaea (A).

_____ 1. genes lack introns

_____ 2. many rRNAs match eukaryote rRNAs

_____ 3. cell walls contain peptidoglycan

_____ 4. uninhibited by streptomycin

_____ 5. some membrane lipids have branched chains

_____ 6. some genes contain introns

_____ 7. complex RNA polymerases

_____ 8. membrane lipids have unbranched chains

_____ 9. simple RNA polymerases

_____ 10. inhibited by streptomycin

_____ 11. cell walls lack peptidoglycan

_____ 12. rRNAs different from eukaryotic rRNAs

_____ 13. more like eukaryotes

Exercise 4 (Module 16.10)

Prokaryotes can be categorized according to their mode of nutrition. Identify whether each of the following prokaryotes is a photoautotroph (as are cyanobacteria), a chemoautotroph, a photoheterotroph, or a chemoheterotroph (as are most prokaryotes).

_____ 1. Energy source—sun; carbon source—organic compounds

_____ 2. Energy source—inorganic chemicals; carbon source—CO_2

_____ 3. Energy source—organic compounds; carbon source—organic compounds

_____ 4. Energy source—sun; carbon source—CO_2

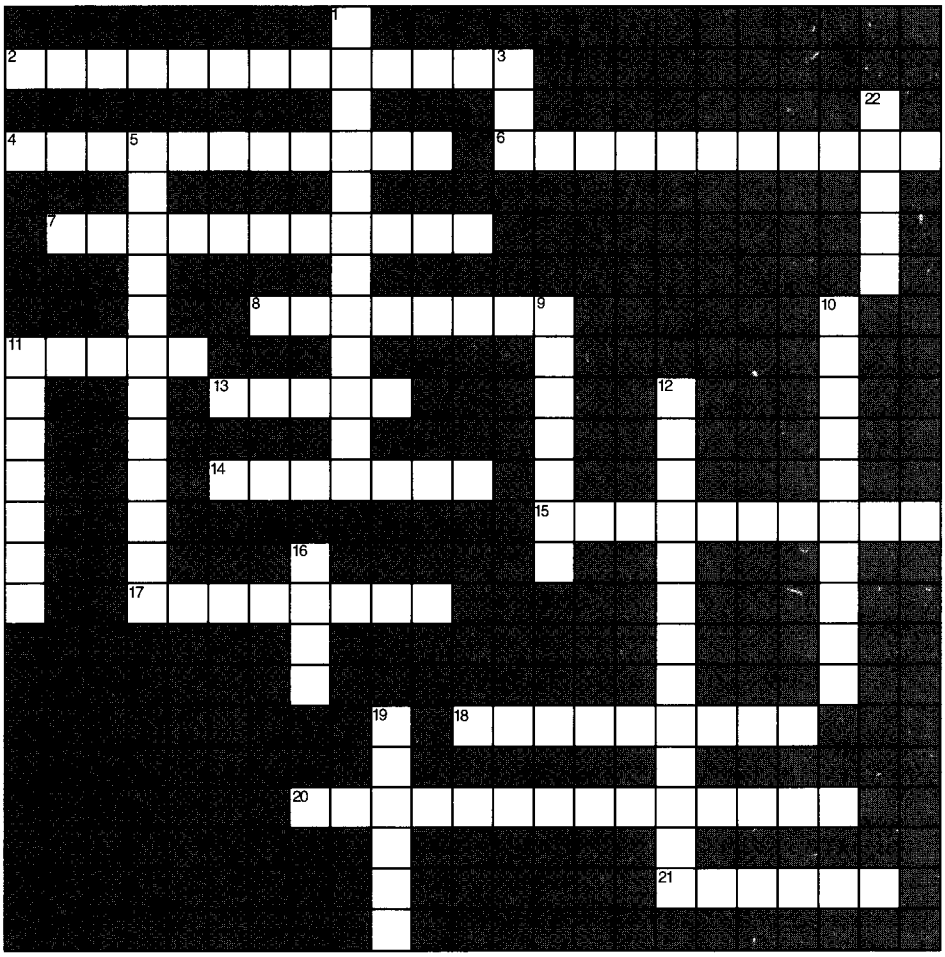
Exercise 5 (Modules 16.9 – 16.13)

Web/CD Activity 16B *Prokaryotic Cell Structure and Function*

These modules review some of the shapes, characteristics, and types of prokaryotes. Review them by completing this crossword puzzle.

Across

2. ____ are blue-green photosynthetic bacteria.
4. Archaea called ____ inhabit your digestive tract.
6. Archaea and bacteria are both ____.
7. Some bacteria produce ____ that inhibit other microbes.
8. The ____ diverged from archaea early in the history of life.
11. A ____ of cyanobacteria may indicate polluted water.
13. Spherical prokaryotes are called ____.
14. Many archaea live in extreme environments such as hot ____.
15. Many bacteria produce dormant, resistant cells called ____.
17. Autotrophic prokaryotes can get energy from ____ .
18. A prokaryote may be able to swim using a propellerlike prokaryotic ____.
20. The earliest life form may have been a ____ that obtained energy from inorganic compounds.
21. Vibrios, spirilla, and spirochetes are curved or ____-shaped.



Down

1. Cocci that occur in chains are called ____.
3. The first prokaryotes probably got energy from ____ from their environment.
5. ____ obtain carbon atoms from organic compounds.
9. The major kinds of prokaryotes are bacteria and ____.
10. ____ make their own organic compounds from inorganic sources.
11. Rod-shaped prokaryotes are called ____.
12. Cyanobacteria formed layered ____ in the ancient seas.
16. ____ enable bacteria to stick to surfaces and to each other.
19. Chemoheterotrophs obtain ____ and carbon from organic compounds.
22. Microbial life may have first arisen around deep-sea hydrothermal ____ .

Exercise 6 (Modules 16.14 - 16.17)

Web/CD Activity 16C *Diversity of Prokaryotes*

These modules outline some of the important roles of prokaryotes. To review them, fill in the blanks in the story below.

"I wish I could get rid of this cold," Matt said, as he wiped his red and swollen nose. "Bacteria are pests that evolved purely to make my life miserable. I wish they'd all disappear."

Alex looked up from his psychology textbook. "Colds are caused by viruses, not bacteria," he said. "And if bacteria disappeared, we'd be in deep trouble. We couldn't live on this planet if it weren't for bacteria."

"Really?"

"The first living things on Earth were [1]_____, the simple kinds of cells that we call bacteria and archaea. Prokaryotes eventually gave rise to creatures with more complex cells—[2]_____. That includes everything from algae to us. Incidentally, they changed the entire Earth. For example, they produced the [3]_____ in the atmosphere."

Matt sniffled. "Maybe they don't cause colds, but they do make people sick."

"Yes, there are many [4]_____, or disease-causing, bacteria," Alex replied. "About [5]_____% of all human diseases are caused by bacteria."

"So how do they make you sick?"

"Most bacteria cause illness by producing [6]_____. *Staphylococcus aureus,* for example, is a common skin bacterium, but it secretes substances called [7]_____ that can cause food poisoning or toxic shock in the body. A strain of *E. coli* bacteria from cattle produces an exotoxin that kills cells lining [8]_____. The deadly [9]_____ bacillus, used as a weapon by bioterrorists, also kills with exotoxins. Some bacteria have poisons called [10]_____ in their cell walls. A species called [11]_____ causes food poisoning that way."

Matt sneezed. "This doesn't feel like a simple cold. It could be pneumonia."

"If it is pneumonia, *then* we're talking *bacteria.* But healthy adults in developed countries don't get many bacterial infections these days. Sanitation measures, like [12]_____ and [13]_____ systems, keep many bacterial diseases from spreading, and—"

"You don't get pneumonia from dirty water, Mr. Know-It-All," Matt interjected.

"Right, but most forms of pneumonia, like most bacterial diseases, can be treated with [14]_____. So you don't have to worry—unless the bacteria have become resistant."

"Say, since you know so much about this, maybe you can tell me how they know that a particular bacterium causes a particular disease. How do microbiologists know that a particular germ causes galloping pneumonia, or food poisoning, or whatever?"

"They use a procedure, a sort of set of rules, called Koch's [15]_____, to prove that a particular bacterium is the cause of a disease. First you have to show that the same bacterium is present in every animal that has the disease. Then you try to isolate the bacterium from an animal and grow it in a [16]_____. Then you [17]_____ experimental hosts with the pure bacteria to see whether they get the disease. Finally, you check to see whether the suspected pathogen is present in the [18]_____. If it is, you can be pretty sure it causes the disease."

Matt changed direction. "Bacteria cause disease all right. That's why I said they should be wiped off the face of the Earth."

Alex said, "We couldn't live without them. Many prokaryotes are involved in the cycling and recycling of various [19]_____ between living things and the nonliving environment. Like the prokaryotes that live in the roots of [20]_____—plants like beans and peas—that take [21]_____ from the air and convert it into forms that plants can use."

"How does that help me?"

"It only helps you if you eat plants or animals that eat plants. I think you do, along with just about every other animal on this planet. By the way, [22]_____ that live in soil and water also trap nitrogen, along with providing some of the oxygen we breathe."

Matt brightened. "I think I understand. There is another kind of recycling that prokaryotes do. They decompose [23]_____ matter, like [24]_____ and [25]_____, and return chemicals to the environment. Then living things can use them again. If it weren't for prokaryotes, in no time we'd be up to our necks in . . . "

"Sewage. That's why prokaryotes are important in sewage-[26]_____ plants. [27]_____ prokaryotes work on solid matter, called [28]_____ and [29]_____ bacteria break down liquid wastes. Some bacteria can even break down oil, and some are used to extract metals, like [30]_____, from low-grade ores, and might help us clean up toxic wastes from old mining sites. Using bacteria to clean up the environment is called [31]"_____".

Matt sneezed. "I could use some to clean up my toxic wastes. This is no ordinary cold. Maybe it's the flu. Maybe it's Lemon disease."

Alex sighed. "You mean Lyme disease? Been bitten by a [32]_____ lately?"

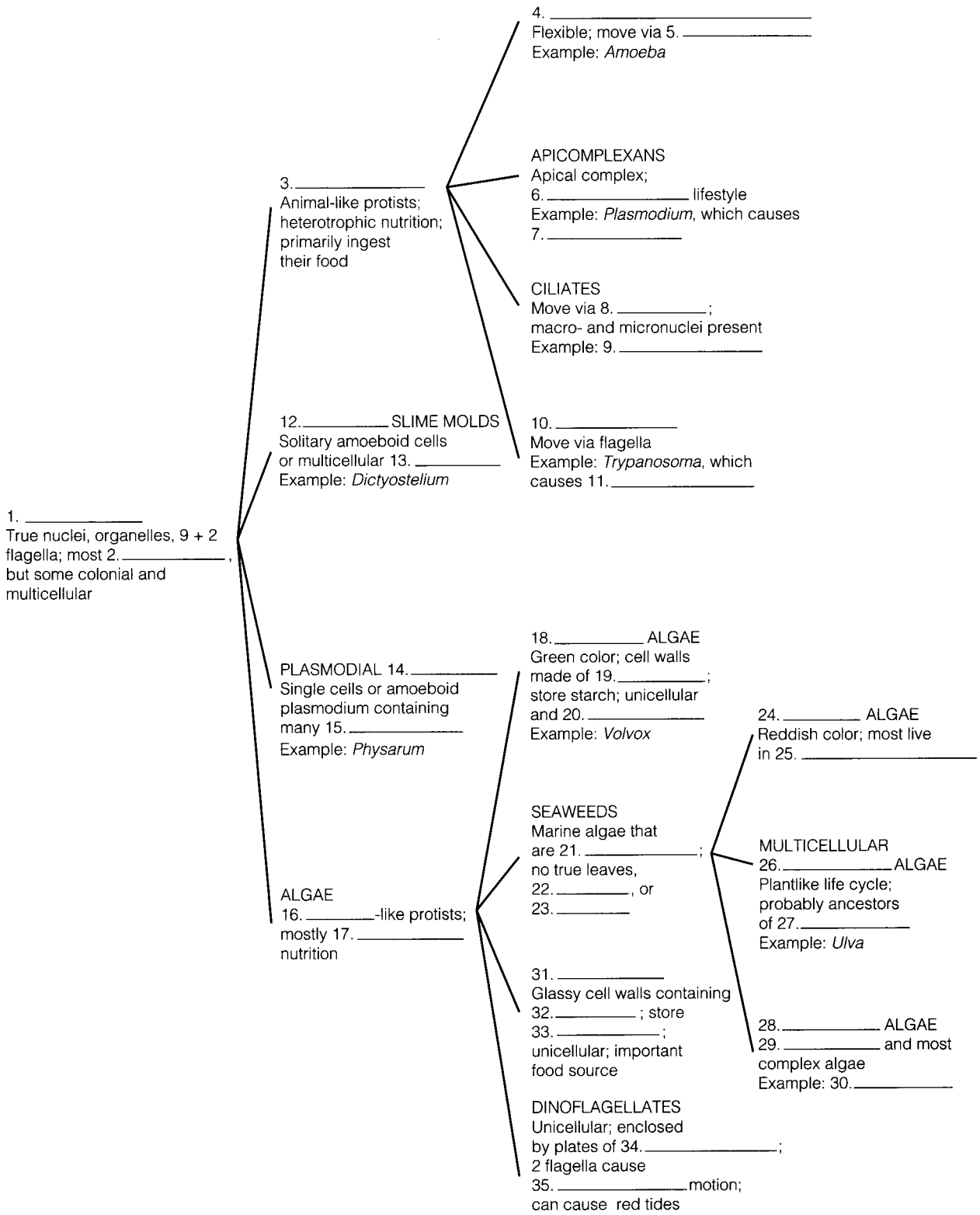
Exercise 7 (Module 16.18)

This module explains how the complex organelles of eukaryotic cells may have arisen through (1) infolding of an ancestral prokaryote's plasma membrane and/or (2) engulfing of smaller prokaryotes by an ancestral prokaryotic cell (endosymbiosis). Review the module by answering the following questions on a separate sheet of paper.

1. Describe the endosymbiotic model.
2. Name two organelles that probably arose via endosymbiosis.
3. What is the evidence for endosymbiosis?
4. How might infolding have occurred?
5. Name two cell structures that probably originated via infolding of the plasma membrane of an ancestral prokaryotic cell.

Exercise 8 (Modules 16.20 – 16.24)

These modules introduce the protists, a diverse group of simple eukaryotes. The diagram below outlines the various groups of protists and the characteristics of each group. Review the protists by writing the missing names or characteristics in the spaces.



Exercise 9 (Modules 16.25 - 16.26)

Multicellular life—seaweeds, plants, animals, and fungi—probably evolved from colonial protists. Test your understanding of this process by completing each sentence on the right with a word on the left. Each answer is used only once.

A. Seaweeds
B. Animals
C. Protists
D. Unicellular organisms
E. Fungi
F. Colonies
G. Multicellular organisms
H. Gametes

1. Cell specialization involved separation of somatic cells and _____.
2. The links between unicellular and multicellular life were _____.
3. The first organisms on land were green algae and associated _____.
4. Three or more different protists may have given rise to _____.
5. Multicellularity probably evolved several times among _____.
6. All life functions happen in one cell in all _____.
7. Different cells do different jobs in _____.
8. The oldest known multicellular organisms include algae and _____ such as corals and worms.

Testing Your Knowledge

Multiple Choice

1. Which of the following was probably *not* present in large amounts in the atmosphere at the time life is thought to have originated?
   a. water (H_2O)
   b. nitrogen (N_2)
   c. carbon monoxide (CO)
   d. oxygen (O_2)
   e. carbon dioxide (CO_2)
2. Prokaryotes called ____ are similar in many ways to eukaryotic organisms.
   a. archaea
   b. bacteria
   c. protozoa
   d. cyanobacteria
   e. dinoflagellates
3. Biologists are interested in the role of clay in the origin of life. They think clay might have
   a. supplied the raw materials for organic compounds.
   b. catalyzed the formation of organic polymers such as proteins and RNA.
   c. formed primitive cell membranes that could grow and divide.
   d. catalyzed the formation of monomers such as amino acids and sugars.
   e. supplied the energy for metabolism in the first simple cells.
4. Which of the following is thought to have been the first step in the origin of life?
   a. cooperation among molecules
   b. formation of polypeptide spheres
   c. formation of organic monomers
   d. replication of primitive "genes"
   e. formation of organic polymers
5. *E. coli* bacteria, which live in human intestines, are shaped like tiny, straight sausages. They are
   a. bacilli.
   b. vibrios.
   c. spirochetes.
   d. cocci.
   e. spirilla.
6. Which of the following is a difference between bacteria and archaea?
   a. Archaea are unicellular, and bacteria are colonial.
   b. The genes of bacteria have introns, while archaea lack introns.
   c. They have different chemicals in their cell membranes and cell walls.
   d. Bacteria are autotrophic and archaea are heterotrophic.
   e. They look very different under a microscope.
7. Most prokaryotes
   a. obtain energy from sunlight and carbon from organic compounds.
   b. obtain both energy and carbon from inorganic compounds.
   c. obtain energy from inorganic compounds and carbon from CO_2.
   d. obtain energy from sunlight and carbon from CO_2.
   e. obtain both energy and carbon from organic compounds.

8. Which of the following is true of cyanobacteria?
   a. They are pathogenic.
   b. They are chemoheterotrophs.
   c. They are archaea.
   d. They are protists.
   e. They are photoautotrophs.
9. Archea called _____ live in salty environments, such as salt lakes.
   a. methanogens
   b. actinomycetes
   c. extreme halophiles
   d. apicomplexans
   e. extreme thermophiles
10. Koch's postulates
    a. outline the probable process by which life originated.
    b. are used to demonstrate that a microorganism causes a disease.
    c. enable researchers to determine whether an organism is prokaryotic.
    d. suggest how eukaryotes evolved from prokaryotes.
    e. are public health standards used to prevent the spread of disease.
11. Different groups of seaweeds can generally be distinguished on the basis of
    a. color.
    b. size.
    c. whether they are multicellular or unicellular.
    d. whether or not they have true leaves, stems, and roots.
    e. whether they are autotrophic or heterotrophic.
12. Which of the following are protozoans?
    a. diatoms, flagellates, amoebas, and ciliates
    b. apicomplexans, flagellates, amoebas, and ciliates
    c. amoebas, actinomycetes, ciliates, and flagellates
    d. flagellates, ciliates, cyanobacteria, and apicomplexans
    e. ciliates, diatoms, amoebas, and apicomplexans
13. In general, how do algae and protozoans differ?
    a. Protozoans can move, and algae cannot.
    b. Algae are free-living, and protozoans are parasitic.
    c. Protozoans are autotrophic, and algae are heterotrophic.
    d. Algae are photosynthetic, and protozoans are heterotrophic.
    e. Algae are prokaryotes, and protozoans are eukaryotes.
14. In the life cycle of a seaweed such as *Ulva*, a haploid spore develops into a(n)
    a. sporophyte.
    b. sperm.
    c. egg.
    d. gametophyte.
    e. zygote.
15. Until about 500 million years ago, all living things were
    a. asexual.
    b. autotrophic.
    c. aquatic.
    d. prokaryotic.
    e. unicellular.

Essay

1. If life could develop from nonliving chemicals 3 to 4 billion years ago, why can't the same thing happen at present?
2. Describe Stanley Miller's experiment that simulated conditions on the ancient Earth. How was the experiment carried out? What was its purpose? Its result?
3. Describe how molecules in the ancient seas may have cooperated to form the first "cells." What kinds of molecules may have been involved? How did they cooperate?
4. Name four diseases caused by bacteria. How do bacteria cause disease?
5. In what ways are prokaryotes useful and even vital to our well-being?
6. Primitive prokaryotes radically changed the Earth for all life that followed. Their effect on the environment is described as a "revolution." What did these prokaryotes do?
7. Explain the endosymbiosis model for the origin of eukaryotes.
8. How did multicellular eukaryotes—plants, animals, and fungi—probably arise?

Applying Your Knowledge

Multiple Choice

1. Which of the following discoveries would force scientists to revise their present theories regarding the origin of life on Earth?
   a. The 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.

2. The following are some major events in the early history of life.
   P. first heterotrophic prokaryotes
   Q. first genes
   R. first eukaryotes
   S. first autotrophic prokaryotes
   T. first animals
   Which answer below places these events in the correct order?
   a. PQSRT
   b. QSPTR
   c. QPSRT
   d. QSPRT
   e. SPQRT

3. Bacteria that live around deep-sea hot-water vents obtain energy by oxidizing inorganic hydrogen sulfide belched out by the vents. They use this energy to build organic molecules from carbon obtained from the carbon dioxide in the seawater. These bacteria might be described as
   a. photoheterotrophs.
   b. chemoautotrophs.
   c. photoautotrophs.
   d. chemoheterotrophs.
   e. none of the above.

4. The bacterium *Bacillus thuringensis* can withstand heating, dryness, and toxic chemicals that would kill most other bacteria. This indicates that it is probably able to form
   a. pseudopodia.
   b. endotoxins.
   c. endospores.
   d. pili.
   e. peptidoglycans.

5. In an experiment, a microbiologist put equal numbers of each of the following organisms into a flask of sterile broth consisting mostly of sugar and a few amino acids. She then placed the flask in the dark. Which of the organisms would be best able to survive and reproduce in this environment?
   a. chemoheterotrophic bacteria
   b. cyanobacteria
   c. diatoms
   d. extreme halophiles
   e. green algae

6. Which of the following is *not* evidence for the role of endosymbiosis in the origin of eukaryotes?
   a. Chloroplasts have their own DNA.
   b. The inner membrane of a chloroplast is similar to prokaryotic membranes.
   c. Mitochondria and chloroplasts are surrounded by two membranes.
   d. Mitochondria reproduce by binary fission.
   e. The DNA in the eukaryotic nucleus codes for some enzymes in mitochondria.

7. As she peered through the microscope, Paige said, "I know that this thing is supposed to be either a ciliate, a flagellate, or an amoeba, but I can't figure out which." Michelle replied, "That's easy . . . "
   a. "Watch how it moves."
   b. "How big is it?"
   c. "All you have to do is see whether it has a nucleus or not."
   d. "Watch and see what it eats."
   e. "Look at its chloroplasts."

8. Which of the following was probably *not* a direct evolutionary ancestor of a maple tree?
   a. a heterotrophic prokaryote
   b. a green alga
   c. an amoeba
   d. a colonial protist
   e. *All* of the above probably *were* ancestors of a maple tree.

9. Some biologists regard seaweeds as protists, even though most other protists are microscopic unicellular organisms. Other biologists think that at least some seaweeds should be considered plants, not protists. Which of the following would support the latter position?
   a. Certain seaweeds have been found to be heterotrophic.
   b. Certain seaweeds contain several kinds of specialized cells.

c. Certain seaweeds undergo sexual and asexual reproduction.
d. Certain seaweeds are found to be prokaryotic.
e. Certain seaweeds have very complex cells.

10. Protozoans called choanoflagellates live in small clusters. They look very much like choanocytes, special feeding cells found in sponges, which are simple animals. Why might biologists find choanoflagellates of great evolutionary interest?
a. They show how the very first organisms might have lived.
b. They might show how the first heterotrophs lived.
c. They might offer clues about the origin of multicellular organisms.
d. They suggest what the first eukaryotes might have been like.
e. They might offer clues about the first organisms to live in the sea.

Essay

1. No single simulation of conditions on the early Earth has produced all the fundamental building blocks of life. Under certain conditions, certain amino acids form. With different amounts of atmospheric chemicals, other amino acids are produced. Still other experiments generate nucleic acid bases, or sugars, or ATP. Do you think the fact that no one experiment has produced all these molecules is a problem for theories about the origin of life? Explain.

2. Scientists have found traces of amino acids on meteorites from space that have landed on the Earth. How would you suppose they interpret this finding? What might be a source of error? Why do you suppose they think amino acids from space are significant?

3. 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.

4. The diphtheria bacterium *Corynebacterium diphtheriae* grows into a mass at the back of the throat and can kill its victim by suffocation. But diphtheria victims also suffer from nervous tremors, paralysis, and heart failure. How might a bacterium that grows in the throat cause symptoms in other parts of the body?

5. Some bacteria can reproduce as often as every 20 minutes. If a hundred of these bacteria were placed in a large flask of culture medium, how many would there be after 6 hours?

Extending Your Knowledge

1. Diseases such as the Black Plague, typhus, malaria, and African sleeping sickness have shaped history, politics, and geography. Can you think of other diseases that have helped to shape the modern world? There are many excellent books on this subject. If you are interested in this, you might want to explore the library.

2. When the average person hears the word "bacteria," do the beneficial effects of prokaryotes in ecology and human life come to mind, or does the person tend to think of harmful disease-causing organisms? You might want to conduct an informal poll.

3. The recent anthrax scare has renewed fear of biological warfare and bioterrorism. What do you think is the best way to protect people from biological weapons?