

- Protists are a diverse group of mostly unicellular eukaryotes. They obtain nutrition in a variety of ways and live in a variety of moist habitats. Some are simple in structure, and others are among the most complex cells known. Eukaryotic cells evolved via primary and secondary endosymbiosis: First prokaryotic cells took up residence inside larger cells, becoming mitochondria and chloroplasts. Later, certain eukaryotes themselves became endosymbiotic, giving rise to diverse eukaryotic lineages.
- Protists classification is a work in progress. Protists are grouped on the basis of specialized organelles, feeding structures, or method of locomotion. One group can include photosynthetic "algae," animal-like "protozoa," and others that resemble fungi. Many protists are parasitic and pathogenic. Some have complex life cycles. Three major lineages led to multicellular organisms—one to brown algae; one to red algae, green algae, and land plants; and a third to fungi and animals.

Review the Concepts

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

Exercise 1 (Modules 16.1–16.2)

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

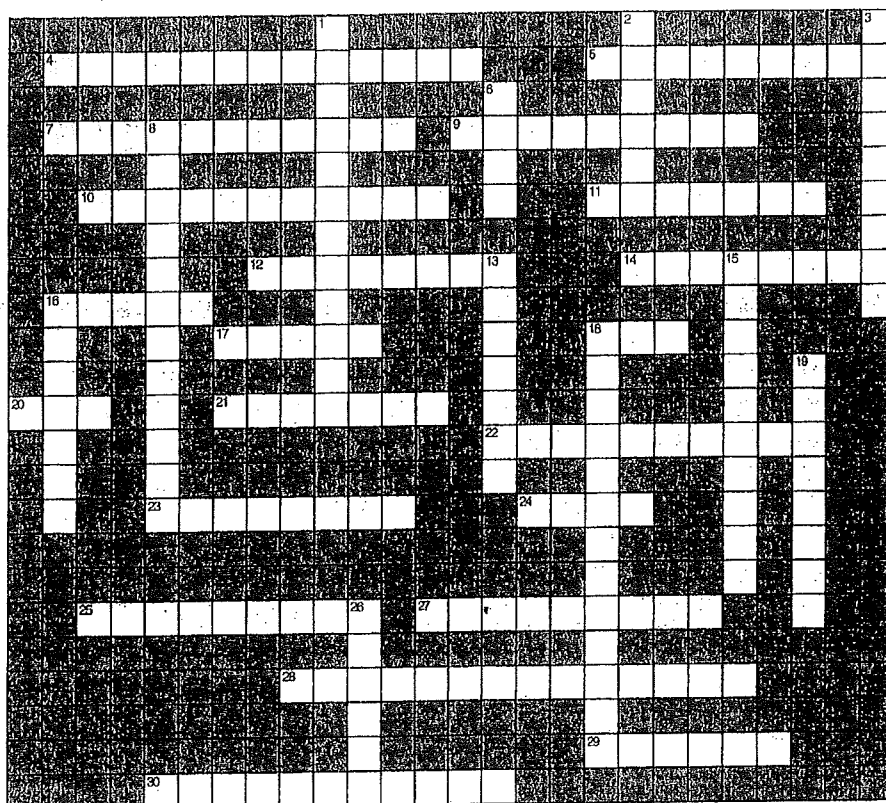
- _____ 1. Genes rarely contain introns
- _____ 2. Some rRNAs match eukaryote rRNAs
- _____ 3. Cell walls contain peptidoglycan
- _____ 4. Uninhibited by streptomycin
- _____ 5. rRNAs different from eukaryotic rRNAs
- _____ 6. Some genes contain introns
- _____ 7. Several kinds of complex RNA polymerase
- _____ 8. Cell walls lack peptidoglycan
- _____ 9. One kind of simple RNA polymerase
- _____ 10. Inhibited by streptomycin
- _____ 11. More like eukaryotes

Exercise 2 (Modules 16.2-16.8)

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

Across

4. ____ are blue-green photosynthetic bacteria.
5. Prokaryotes ____ quickly in a favorable environment.
7. Archaea called ____ inhabit your digestive tract.
9. Prokaryotic ____ are smaller than those of eukaryotes, and differ in RNA and protein content.
10. Certain ____ block prokaryotic ribosomes, but not those of eukaryotes.
11. Archaea produce and consume vast amounts of ____, a greenhouse gas.
12. The ____ diverged from archaea early in the history of life.
14. Gram- ____ bacteria often cause disease.
16. A ____ of cyanobacteria may indicate polluted water.
17. Spherical prokaryotes are called ____.
18. ____ pili link prokaryotes during conjugation.
20. Certain proteobacteria ____ nitrogen.
21. Many archaea live in extreme environments such as hot ____.
22. Many bacteria produce dormant, resistant cells called ____.
23. Photoautotrophs can get energy from ____.



24. We can identify bacteria by using a ____ stain.
25. You might find an extreme ____ in very salty water.
27. A prokaryote may be able to swim using a propeller-like prokaryotic ____.
28. A ____ gets carbon from carbon dioxide and energy from inorganic chemicals.
29. Vibrios, spirilla, and spirochetes are curved or ____-shaped.
30. Archaea and bacteria are both ____.

Down

1. Cocci that occur in chains are called ____.
2. Comparison of ____ sequences supports a three-domain view of life.
3. Some prokaryotes have folded ____ that perform metabolic functions.
6. Hairlike appendages called ____ enable bacteria to stick to surfaces and each other.
8. ____ obtain carbon atoms from organic compounds.
13. The major kinds of prokaryotes are bacteria and ____.
15. ____ make their own organic compounds from inorganic sources.
16. Rod-shaped prokaryotes are called ____.
18. Cyanobacteria formed layered ____ in the ancient seas.
19. Gram- ____ bacteria include actinomycetes and mycoplasmas.
26. Chemoheterotrophs obtain ____ and carbon from organic compounds.

Exercise 3 (Module 16.5)

Prokaryotes (and other organisms, by the way) 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 |
| _____ | 5. A plant |
| _____ | 6. An animal |

Exercise 4 (Modules 16.6–16.7)

Match each of the following descriptions with a particular group of prokaryotes (M-T), and then state whether each are bacteria (B) or archaea (A).

Group B or A

- | | | | |
|-------|-------|--|---------------------------|
| _____ | _____ | 1. Live in salt lakes and brine ponds | M. Methanogens |
| _____ | _____ | 2. Only prokaryotes with plantlike photosynthesis | N. Gram-positive bacteria |
| _____ | _____ | 3. <i>Salmonella</i> , <i>E. coli</i> , and cholera | O. Proteobacteria |
| _____ | _____ | 4. Cause blindness and a common sexually transmitted disease | P. Extreme thermophiles |
| _____ | _____ | 5. <i>Rhizobium</i> and other nitrogen-fixers | Q. Cyanobacteria |
| _____ | _____ | 6. Create "marsh gas" | R. Spirochetes |
| _____ | _____ | 7. <i>Streptococcus</i> , <i>Staphylococcus</i> , and anthrax | S. Extreme halophiles |
| _____ | _____ | 8. Generated ancient stromatolites and oxygenated the atmosphere | T. Chlamydia |
| _____ | _____ | 9. Twisted prokaryotes that cause syphilis and Lyme disease | |
| _____ | _____ | 10. Actinomycetes, soil-dwelling recyclers | |
| _____ | _____ | 11. Residents of hot springs and deep-sea vents | |
| _____ | _____ | 12. Enable cattle and deer to digest cellulose | |

Exercise 5 (Modules 16.8–16.10)

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

"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."

"What? Well, I'm not going to live much longer if I don't get rid of this cold."

"You're not gonna die from a cold. Seriously, 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."

Matt sniffled. "Yeah, yeah, yeah. Well, maybe they don't cause colds, but they do make people sick."

"Yes, there are many ³ _____, or disease-causing, bacteria," Alex replied. "But bacteria and archaea are important and helpful in many ways—"

"So how do they make you sick?"

"Most bacteria cause illness by producing ⁴ _____. *Staphylococcus aureus*, for example, is a common skin bacterium, but it secretes substances called ⁵ _____ that can cause food poisoning or toxic shock in the body. A strain of *E. coli* bacteria from cattle produces an exotoxin that can cause bloody ⁶ _____.

"Is that the one people get from bad ⁷ _____ and spinach? Is that like botulism or *Salmonella*?"

Both can poison you. The toxin produced by *Clostridium botulinum*, called ⁸ _____, is an exotoxin, and it is the most potent poison on Earth. *Salmonella* causes food poisoning, too, but its toxin is actually part of its cell wall. It's called an ⁹ _____. Another kind of *Salmonella* causes ¹⁰ _____ fever, and—"

"Achoo!" Matt sneezed again, and gasped "Maybe it's typhoid fever. Or chlamydia!"

Alex groaned. "I don't think so—besides, chlamydia is ¹¹ _____ transmitted. If that's what you've got, I think it is going to affect a rather different part of your body! Trust me, it's a cold."

"I tell you, this doesn't feel like a regular cold. It could be pneumonia. Or maybe I inhaled anthrax! Let's see. Have I been exposed to a white powder?"

"What a hypochondriac! How long have you been sick? A week? If it were anthrax, you'd probably be dead by now. By the way, the powder form of anthrax isn't a toxin. It consists of anthrax ¹² _____, dried dormant cells that are easily dispersed in air. The dried fine powder is the ¹³ _____ form of anthrax used by terrorists. Once they are inhaled and germinate, anthrax starts growing in your body and making its exotoxin."

Matt looked defeated. "Guess it's not anthrax. Could it be pneumonia?"

Alex brightened. "Ahh, now we're getting somewhere. 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 ¹⁴ _____ and ¹⁵ _____ 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 ¹⁶ _____. So if it is pneumonia, and not a cold, you might be able to do something. And then you might stop whining!"

Matt sneezed yet again. "I need to get to the emergency room. I think all bacteria should be wiped off the face of the earth."

Alex interrupted, "Have you been listening? We couldn't live without them. Many prokaryotes are involved in the cycling and recycling of various ¹⁷ _____ between living things and the nonliving environment. They decompose ¹⁸ _____ matter, like ¹⁹ _____ and ²⁰ _____, and return chemicals to the environment. For example, prokaryotes are important in a chemical cycle that makes ²¹ _____ available to plants—"

"O.K.—I get it. If it weren't for prokaryotes, in no time we'd be up to our necks in . . ."

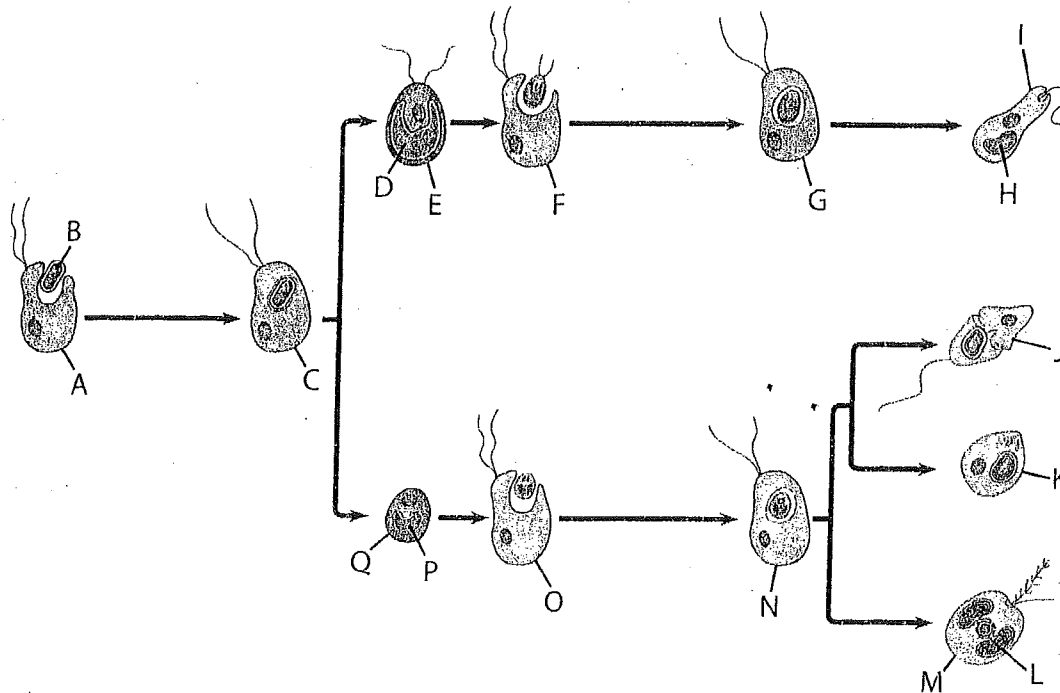
"Sewage. Right. That's why prokaryotes are important in sewage-
²² _____ plants. ²³ _____ prokaryotes work on solid matter, called ²⁴ _____, and ²⁵ _____ bacteria in a layer called a ²⁶ _____ break down liquid wastes. Some bacteria can even break down oil spills, and some are used to extract metals, like ²⁷ _____ and ²⁸ _____, 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 ²⁹ _____."

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 pneumonia. Maybe it's Lemon disease!"

Alex sighed. "You mean Lyme disease? Been bitten by a ³⁰ _____ lately?"

Exercise 6 (Modules 16.11-16.12)

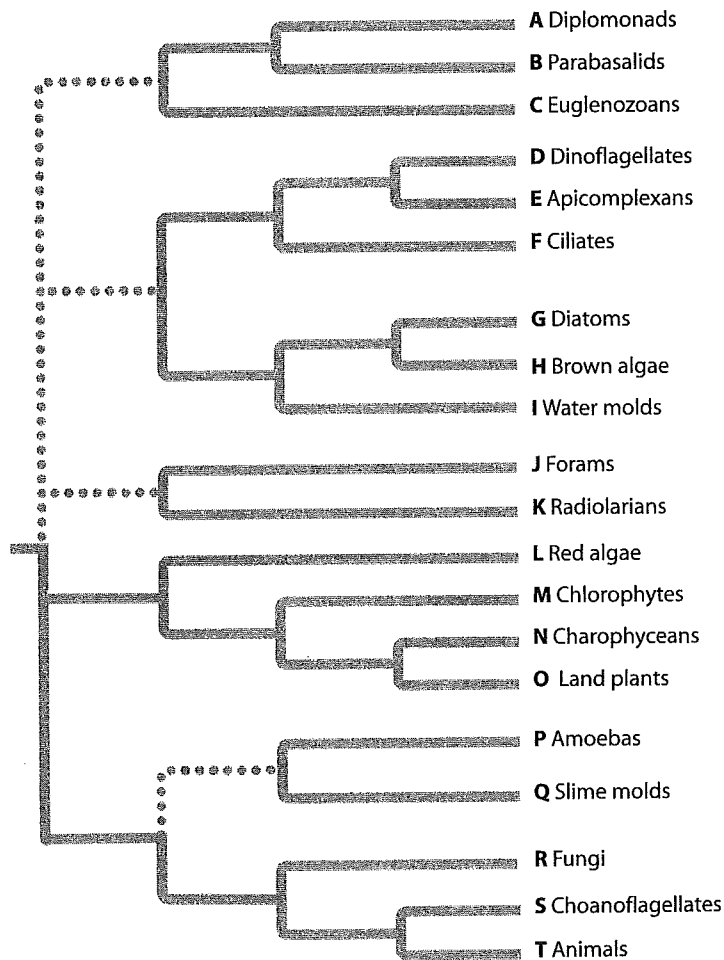
Complex eukaryotic cells evolved when prokaryotic cells took up residence inside other, larger prokaryotic cells. Mitochondria probably got their start this way. The diagram in Module 16.12 takes up the story a bit later, when a cyanobacterium established residence in a heterotrophic eukaryote, eventually becoming a chloroplast. This is called primary endosymbiosis. Still later certain photosynthetic *eukaryotes* became endosymbiotic in heterotrophic eukaryotes, eventually becoming different kinds of chloroplasts in these host cells. This is called secondary endosymbiosis. Make sense? See if you understand the process by identifying each of the following on the diagram. (Some questions have more than one answer.)



- _____ 1. Heterotrophic eukaryotes
- _____ 2. Photosynthetic prokaryote
- _____ 3. Chloroplasts derived from prokaryote
- _____ 4. Green alga
- _____ 5. Red alga
- _____ 6. Chloroplast derived from red alga
- _____ 7. Chloroplast derived from green alga
- _____ 8. New cell produced by primary endosymbiosis
- _____ 9. New cells produced by secondary endosymbiosis
- _____ 10. Diverse forms of existing photosynthetic eukaryotes
(be careful - don't leave any out!)

Exercise 7 (Modules 16.13–16.20)

This phylogenetic tree tentatively outlines the evolution of various groups of eukaryotes. Most are informally called protists. Protists are a diverse collection of eukaryotes, simple to complex, with varying lifestyles. Read the modules about protists, and match as many statements as you can with the correct branch(es) of the phylogenetic tree. Then look up the ones you don't know. (Names are often clues—ciliates, green algae, etc.) Some answers are used more than once, and some questions have multiple answers.



- _____ 1. Three groups of organisms that are *not* protists
- _____ 2. This group gets its name from the green flagellate *Euglena*.
- _____ 3. These three groups of organisms make up the stramenopiles, named for their "hairy" flagella.
- _____ 4. Some reside within coral animals and are important reef food producers.
- _____ 5. Two groups of green algae
- _____ 6. The names of these two groups suggest that they are fungi, but they are not.
- _____ 7. Probably the most ancient surviving lineage of eukaryotes
- _____ 8. Fungus-like protists that decompose dead plants and animals in the water
- _____ 9. Mostly free-living protists that move by means of cilia
- _____ 10. Kelps
- _____ 11. These two groups move via lobe-shaped extensions called pseudopodia.

- _____ 12. Algae characteristic of warm coastal tropical waters
- _____ 13. You may see *Paramecium*, a representative of this group, in lab.
- _____ 14. Two groups that feed with threadlike pseudopodia
- _____ 15. Closest relatives of plants
- _____ 16. These three groups are called alveolates, named for sacs under their membranes.
- _____ 17. Algae with complex, glassy, silica cell walls
- _____ 18. Seaweeds are in these three groups
- _____ 19. A flagellate in this group causes sleeping sickness.
- _____ 20. Fossils of their calcium carbonate shells help identify rock strata
- _____ 21. Population explosions of these organisms, called "red tides," can poison fish and people.
- _____ 22. Protists that exist part-time as individual cells and part-time as large "blobs"
- _____ 23. *Giardia*, an intestinal parasite, is in this group.
- _____ 24. Animal parasites that cause diseases such as malaria
- _____ 25. Some are serious plant parasites, such as the organism that causes potato blight.

Exercise 8 (Module 16.21)

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

- | | |
|---|--|
| <ol style="list-style-type: none"> 1. Cell specialization involved separation of somatic cells and _____. 2. The links between unicellular and multicellular life were _____. 3. Organisms moved onto land when green algae gave rise to _____. 4. At least three lineages may have given rise to _____. 5. Multicellularity probably evolved several times among _____. 6. In all _____, all life functions happen in one cell. 7. In _____, different cells do different jobs. 8. The oldest known multicellular organisms include algae and _____, such as corals and worms. | <ol style="list-style-type: none"> A. Seaweeds B. Animals C. Protists D. Unicellular organisms E. Plants F. Colonies G. Multicellular organisms H. Gametes |
|---|--|

Test Your Knowledge

Multiple Choice

- There are many similarities between prokaryotes called ____ and eukaryotic organisms.
 - archaea
 - bacteria
 - protozoa
 - cyanobacteria
 - dinoflagellates
- E. coli* bacteria, which live in human intestines, are shaped like tiny, straight sausages. They are
 - bacilli.
 - vibrios.
 - spirochetes.
 - cocci.
 - spirilla.
- Which of the following is a difference between bacteria and archaea?
 - Archaea are unicellular and bacteria are colonial.
 - The genes of bacteria have introns, while archaea lack introns.
 - They have different chemicals in their cell membranes and cell walls.
 - Bacteria are autotrophic and archaea are heterotrophic.
 - They look very different under a microscope.
- Most prokaryotes
 - obtain energy from sunlight and carbon from organic compounds.
 - obtain both energy and carbon from inorganic compounds.
 - obtain energy from inorganic compounds and carbon from CO_2 .
 - obtain energy from sunlight and carbon from CO_2 .
 - obtain both energy and carbon from organic compounds.
- Which of the following is true of cyanobacteria?
 - They are pathogenic.
 - They are chemoheterotrophs.
 - They are archaea.
 - They are protists.
 - They are photoautotrophs.
- Archea called ____ live in salty environments, such as salt lakes.
 - methanogens
 - actinomycetes
 - extreme halophiles
 - apicomplexans
 - extreme thermophiles
- All organisms called "algae" are
 - unicellular.
 - green.
 - autotrophic.
 - prokaryotic.
 - multicellular.
- Different groups of seaweeds can generally be distinguished on the basis of
 - color.
 - size.
 - whether they are multicellular or unicellular.
 - whether or not they have true leaves, stems, and roots.
 - whether they are autotrophic or heterotrophic.
- Which of the following groups of bacteria is not paired with the correct description?
 - gram-positive bacteria—*Staphylococcus* and *Streptococcus*
 - chlamydias—soil nutrient recyclers
 - proteobacteria—several kinds fix nitrogen
 - spirochetes—cause syphilis and Lyme disease
 - cyanobacteria—carry out plantlike photosynthesis
- You would *not* expect which of the following to cause disease?
 - apicomplexan
 - gram-negative bacterium
 - euglenozoan
 - diatom
 - sprochete
- Which of the following is *incorrectly* paired with its mode of nutrition?
 - Streptococcus*—chemoheterotroph
 - red alga—photoautotroph
 - animal—chemoheterotroph
 - cyanobacterium—chemoheterotroph
 - plant—photoautotroph

Essay

- Name four diseases caused by bacteria. How do bacteria cause disease?
- In what ways are prokaryotes useful and even vital to our well-being?
- Primitive cyanobacteria radically changed Earth for all life that followed. Their effect on the environment is described as a "revolution." What did these prokaryotes do?

4. Explain the endosymbiosis model for the origin of eukaryotes and protist diversity.
5. How did multicellular eukaryotes—plants, animals, and fungi—probably arise?

Apply the Concepts

Multiple Choice

1. 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.
2. 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.
3. Certain dinoflagellates enter the cells of coral animals and carry out photosynthesis, producing food for themselves and the coral. This is a lot like
 - a. formation of a biofilm.
 - b. primary endosymbiosis
 - c. secondary endosymbiosis
 - d. how ancient stromatolites were formed
 - e. endospore formation
4. 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
5. If you collected a sample of plankton—floating organisms—from near the ocean surface, you would be unlikely to find which of the following?
 - a. diatoms
 - b. cyanobacteria
 - c. radiolarians
 - d. forams
 - e. methanogens
6. Normally, a certain intestinal bacterium is relatively harmless, but if the body's defenses attack it and cells are broken open, it becomes deadly. It sounds like this bacterium
 - a. produces an endotoxin
 - b. is a methanogen
 - c. produces an exotoxin
 - d. is a spirochete
 - e. has peptidoglycan in its cell wall
7. Which of the following is *not* the product of endosymbiosis?
 - a. rabbit
 - b. green alga
 - c. euglenozoan
 - d. spirochete
 - e. pine tree
8. 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 plant 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.
9. 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."
10. 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.