19.3 Earth's Early History

THINK ABOUT IT How did life on Earth begin? What were the earliest forms of life? How did life and the biosphere interact? Origin-of-life research is a dynamic field. But even though some current hypotheses likely will change, our understanding of other aspects of the story is growing.

The Mysteries of Life's Origins

What do scientists hypothesize about early Earth and the origin of life?

Geological and astronomical evidence suggests that Earth formed as pieces of cosmic debris collided with one another. While the planet was young, it was struck by one or more huge objects, and the entire globe melted. For millions of years, violent volcanic activity shook Earth's crust. Comets and asteroids bombarded its surface. About 4.2 billion years ago, Earth cooled enough to allow solid rocks to form and water to condense and fall as rain. Earth's surface became stable enough for permanent oceans to form.

This infant planet was very different from Earth today. **Earth's early atmosphere contained little or no oxygen. It was principally composed of carbon dioxide, water vapor, and nitrogen, with lesser amounts of carbon monoxide, hydrogen sulfide, and hydrogen cyanide.** If you had been there, a few deep breaths would have killed you! Because of the gases in the atmosphere, the sky was probably pinkish-orange. And because the oceans contained lots of dissolved iron, they were probably brown. This was the Earth on which life began.

Key Questions

What do scientists hypothesize about early Earth and the origin of life?

What theory explains the origin of eukaryotic cells?

What is the evolutionary significance of sexual reproduction?

Vocabulary

endosymbiotic theory

Taking Notes

Flowchart Construct a flowchart that shows what scientists hypothesize are the major steps from the origin of Earth to the appearance of eukaryotic cells.

FIGURE 19–14 Early Earth Violent volcanic eruptions helped shape Earth's early history.

BIOLOGY.com Search Lesson 19.3 GO • Lesson Overview • Lesson Notes • Art Review

Getting Started

Objectives

19.3.1 Identify some of the hypotheses about early Earth and the origin of life.

19.3.2 Explain the endosymbiotic theory.

19.3.3 Explain the significance of sexual reproduction in evolution.

Student Resources

Study Workbooks A and B, 19.3 Worksheets

Spanish Study Workbook, 19.3 Worksheets

Lab Manual B, 19.3 Hands-On Activity Worksheet

BIOLOGY.com Lesson Overview • Lesson Notes
- Activity: Art Review
- Assessment: Self-Test, Lesson Assessment

For corresponding lesson in the **Foundation Edition**, see pages 462–469.

Build Background

Ask students if they have ever learned about something without actually seeing it happen. For example, what if they awoke in the morning to find tree branches broken and the power out? Ask how they could determine what might have happened. *(by looking at the evidence, e.g., fallen trees and weather reports)* Ask how scientists have figured out the process by which Earth may have formed. *(by looking at the evidence)* Direct students to keep a list of evidence described in this lesson that scientists used to learn about Earth's early history.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

I, II, III, IV, V

CONTENT

C.1.a, C.1.e, C.3.a, C.3.b, C.3.d, C.3.e, D.3, D.4, G.3

INQUIRY

A.1.c, A.2.a, A.2.b, A.2.e, A.2.f

UbD Teach for Understanding

ENDURING UNDERSTANDING The diversity of life is the result of ongoing evolutionary change. Species alive today have evolved from ancient common ancestors.

GUIDING QUESTION What happened during Earth's early history?

EVIDENCE OF UNDERSTANDING *After completing the lesson, give students the following assessment to show whether they understand the major events in Earth's early history.* Divide the class into four groups. Provide each group with a length of table paper, and have students create an illustrated wall chart that tracks the major events thought to have occurred around the time of the origin of life on Earth.

Teach

Use Visuals

Ask a volunteer to read aloud the numbered steps in **Figure 19–15.**

Then, use the following questions to enhance students' understanding of the Miller-Urey experiment.

Ask How did Miller and Urey model conditions that existed on early Earth in their experiment? *(They used water to simulate the oceans; water vapor, methane, ammonia, and hydrogen to simulate Earth's early atmosphere; and sparks of electricity to simulate lightning.)*

Ask What question did Miller and Urey's experiment seek to answer? *(Could organic molecules assemble under the conditions that existed on early Earth?)*

Ask What were the results of their experiment? *(Amino acids and other organic compounds could have assembled under the conditions that existed on early Earth.)*

DIFFERENTIATED INSTRUCTION

LPR Less Proficient Readers Emphasize that illustrations such as **Figure 19–15** usually go along with written text and help readers understand the text. Begin by having students read the text following the heading **The First Organic Molecules.** Then, go over each step in the illustration. After you read each internal caption aloud, have students find the corresponding description in the text. Once you have finished this process for all the steps, have students construct a **Flowchart** that summarizes the steps in the Miller-Urey experiment. (To help them, point out that their flowcharts will show five steps; the fifth step will be the collection of organic compounds.)

Study Wkbks A/B, Appendix S25, Flowchart. **Transparencies,** GO8.

BIOLOGY.com Have students find out more about early Earth by using **Art Review: Conditions on the Early Earth.**

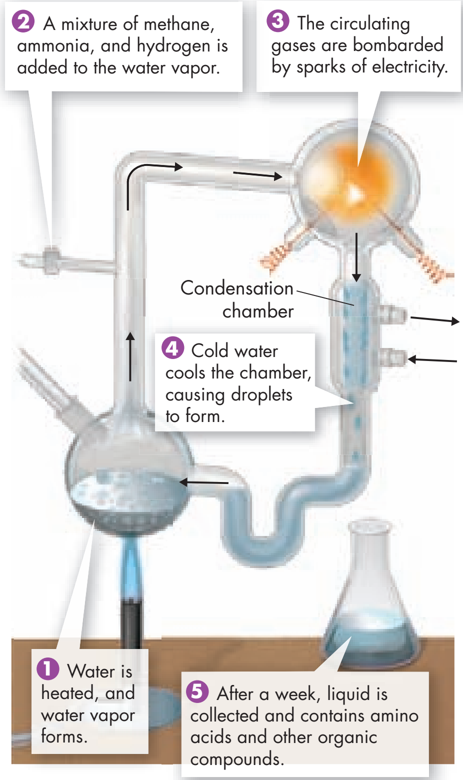


FIGURE 19–15 Miller-Urey Experiment Miller and Urey produced amino acids, which are needed to make proteins, by passing sparks through a mixture of hydrogen, methane, ammonia, and water vapor. Evidence now suggests that the composition of Earth's early atmosphere was different from their 1953 experiment. However, more recent experiments with different mixtures of gases have produced similar results.

The First Organic Molecules Could organic molecules assemble under conditions on early Earth? In 1953, chemists Stanley Miller and Harold Urey tried to answer that question. They filled a sterile flask with water, to simulate the oceans, and boiled it. To the water vapor, they added methane, ammonia, and hydrogen, to simulate what they thought had been the composition of Earth's early atmosphere. Then, as shown in **Figure 19–15,** they passed the gases through electrodes, to simulate lightning. Next, they passed the gases through a condensation chamber, where cold water cooled them, causing drops to form. The liquid circulated through the experimental apparatus for a week. The results were spectacular: They produced 21 amino acids—building blocks of proteins. **Miller and Urey's experiment suggested how mixtures of the organic compounds necessary for life could have arisen from simpler compounds on a primitive Earth.**

We now know that Miller and Urey's ideas on the composition of the early atmosphere were incorrect. But new experiments based on current ideas of the early atmosphere have also produced organic compounds. In fact, in 1995, one of Miller's more accurate mixtures produced cytosine and uracil, two bases found in RNA.

Formation of Microspheres A stew of organic molecules is a long way from a living cell, and the leap from nonlife to life is the greatest gap in scientific hypotheses of life's early history. Geological evidence suggests that during the Archean Eon, 200 to 300 million years after Earth cooled enough to carry liquid water, cells similar to bacteria were common. How might these cells have originated?

Large organic molecules form tiny bubbles called proteinoid microspheres under certain conditions. Microspheres are not cells, but they have some characteristics of living systems. Like cells, they have selectively permeable membranes through which water molecules can pass. Microspheres also have a simple means of storing and releasing energy. Several hypotheses suggest that structures similar to proteinoid microspheres acquired the characteristics of living cells as early as 3.8 billion years ago.

Evolution of RNA and DNA Another unanswered question is the origin of RNA and DNA. Remember that cells are controlled by information stored in DNA, which is transcribed into RNA and then translated into proteins. How could this complex biochemical machinery have evolved?

Biology In-Depth

POLYMERS ON EARLY EARTH

After small organic molecules appeared on prebiotic Earth, the second major chemical step before life could appear was most likely polymerization, or the formation of organic polymers from monomers. Polymers are usually synthesized by dehydration reactions. In living cells, specific enzymes catalyze these reactions. However, polymerization can also take place in laboratory situations without enzymes, as when dilute solutions of organic monomers are dripped onto hot sand, clay, or rock. The heat vaporizes the water and concentrates the monomers on the underlying substance. Some of the monomers spontaneously bond in chains, forming polymers. In a similar way, on early Earth, rain and waves could have splashed dilute solutions of organic monomers onto fresh lava or other hot surfaces and then rinsed the proteinoids and other polymers into the sea after they formed on the hot surfaces.

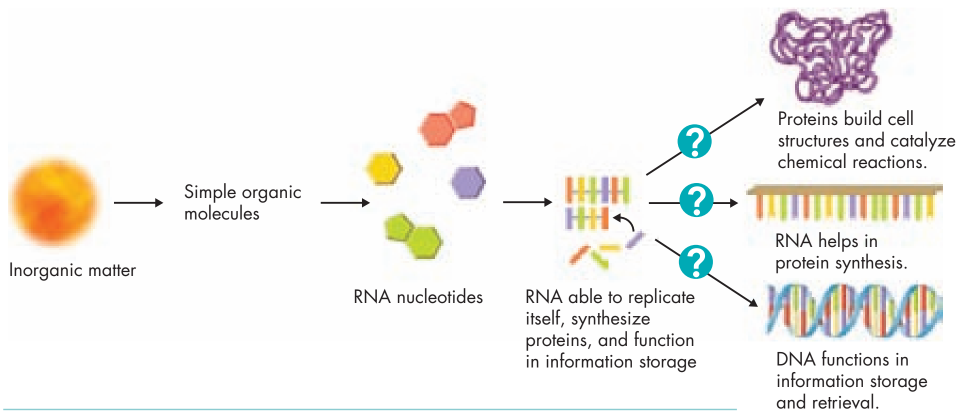


FIGURE 19–16 Origin of RNA and DNA The "RNA world" hypothesis about the origin of life suggests that RNA evolved before DNA. Scientists have not yet demonstrated the later stages of this process in a laboratory setting. **Interpret Visuals** ***How would RNA have stored genetic information?***

Scientists haven't solved this puzzle, but molecular biologists have generated intriguing hypotheses. A number of experiments that simulated conditions on early Earth suggest that small sequences of RNA could have formed from simpler molecules. Why is that interesting? It is interesting because we now know that, under the right conditions, some RNA sequences help DNA replicate. Other RNA sequences process messenger RNA after transcription. Still other RNA sequences catalyze chemical reactions, and some RNA molecules even grow and replicate on their own. **The "RNA world" hypothesis proposes that RNA existed by itself before DNA. From this simple RNA-based system, several steps could have led to DNA-directed protein synthesis.** This hypothesis, shown in **Figure 19–16,** is still being tested.

Production of Free Oxygen Microscopic fossils, or microfossils, of prokaryotes that resemble bacteria have been found in Archean rocks more than 3.5 billion years old. Those first life forms evolved in the absence of oxygen because at that time Earth's atmosphere contained very little of that highly reactive gas.

During the early Proterozoic Eon, photosynthetic bacteria became common. By 2.2 billion years ago, these organisms were churning out oxygen. At first, the oxygen combined with iron in the oceans, producing iron oxide, or rust. Iron oxide, which is not soluble in water, sank to the ocean floor, forming great bands of iron that are the source of most iron ore mined today. Without iron, the oceans changed color from brown to blue-green.

Next, oxygen gas began to accumulate in the atmosphere. The ozone layer began to form, and the skies turned their present shade of blue. Over several hundred million years, oxygen concentrations rose until they reached today's levels. In a sense, this increase in oxygen created the first global "pollution" crisis. To the first cells, which evolved in the absence of oxygen, this reactive gas was a deadly poison! The rise of oxygen in the atmosphere drove some early life forms to extinction. Some organisms, however, evolved new metabolic pathways that used oxygen for respiration. These organisms also evolved ways to protect themselves from oxygen's powerful reactive abilities.

FIGURE 19–17 Fossilized Bacteria Fossilized bacteria are the earliest evidence of life on Earth. These rod-shaped bacterial cells (red) are seen calcified on the shell of a single-celled protozoan.

Build Study Skills

Help students understand that oxygen has not always been available to organisms the way it is today. Have them read the passage headed **Production of Free Oxygen.** Then, as a class, create a **Timeline** on the board to help all students follow the sequence in the development of an oxygenated atmosphere.

Study Wkbks A/B, Appendix S15, Timeline.

DIFFERENTIATED INSTRUCTION

L1 Struggling Students Have students work in pairs to restate the timeline from above as a numbered list of events. Ask students to restate each entry on the timeline in their own words. Circulate among the pairs of students to answer questions or help students sequence the information.

L3 Advanced Students Challenge students to find out more about Earth's early atmosphere and how the atmosphere changed over time. Students can present the results of their research to the class. The following are some specific questions that students might research:

- What techniques have scientists used to estimate the amount of oxygen in the early atmosphere? Also, what inferences have scientists made, and on what observations have they based their inferences?
- What would have happened to lighter gases, such as hydrogen and helium, in the early atmosphere?
- Besides changing the amount of oxygen in the atmosphere, how else might early microbes have affected the atmosphere?
- What are oxidation-reduction reactions, and how were they significant in the early development of Earth's atmosphere?

UbD Check for Understanding

ONE-MINUTE RESPONSE

Write the following prompt on the board, and give students about one minute to write a response that summarizes their understanding.

- How would Earth be different today if photosynthesis had not evolved? *(Responses should indicate that Earth's atmosphere would not contain the amount of oxygen it does today and the oceans would still contain large amounts of iron. As a result, organisms would be very different than they are today.)*

ADJUST INSTRUCTION

If some students have difficulty answering the question, remind them that photosynthesis is the primary process through which oxygen is produced. So, the question could be rephrased as: How would Earth be different if its atmosphere contained no oxygen?

Answers

FIGURE 19–16 RNA would have stored genetic information in its nucleotide sequences.

LESSON 19.3

Teach continued

Lead a Discussion

Review eukaryotic and prokaryotic cells by calling on students at random to describe characteristics they recall about each type of cell. Show or draw examples of each type on the board, and label the parts as students mention individual organelles. Ask volunteers to describe the functions of the main organelles, particularly mitochondria and chloroplasts. Then, introduce the term *endosymbiotic theory*.

Ask What evidence do scientists use to support the endosymbiotic theory? *(similarity of the membranes around mitochondria and chloroplasts to the cell membranes of prokaryotes; similarity of the DNA in mitochondria and chloroplasts to bacterial DNA; similarity of ribosomes in mitochondria and chloroplasts to bacterial ribosomes; the fact that mitochondria and chloroplasts reproduce by binary fission, as do bacteria)*

DIFFERENTIATED INSTRUCTION

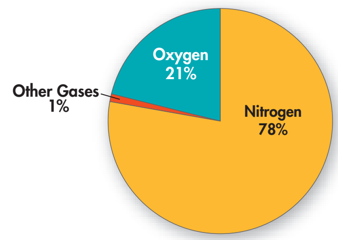
ELL **English Language Learners** Explain to ELL students that the prefix *endo-* means "inside, within." Remind students the *symbiotic* means "a close relationship between two organisms." So, *the endosymbiotic theory* has to do with two organisms, one within the other, that have a close relationship. Ask students to come up with and define three other words that use the prefix *endo-*.

LPR **Less Proficient Readers** As students read about the endosymbiotic theory, have them make a bulleted list of the evidence scientists use to support this theory. After they finish, have students compare lists. Ask each student to revise or add to his or her list, based on the comparison.

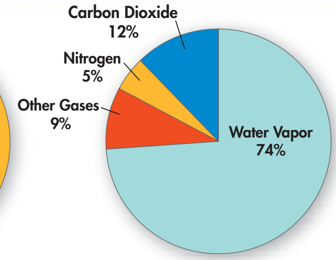
Analyzing Data

Comparing Atmospheres

Many scientists think that Earth's early atmosphere may have been similar to the gases released by a volcano today. The graphs show the composition of the atmosphere today and the composition of gases released by a volcano.



Composition of Earth's Atmosphere Today



Composition of Gases From Volcanoes

1. **Interpret Graphs** Which gas is most abundant in Earth's atmosphere today? What percentage of that gas may have been present in the early atmosphere?
2. **Interpret Graphs** Which gas was probably most abundant in the early atmosphere?
3. **Infer** Where did the water in today's oceans probably come from?

Origin of Eukaryotic Cells

What theory explains the origin of eukaryotic cells?

One of the most important events in the history of life was the evolution of eukaryotic cells from prokaryotic cells. Remember that eukaryotic cells have nuclei, but prokaryotic cells do not. Eukaryotic cells also have complex organelles. Virtually all eukaryotes have mitochondria, and both plants and algae also have chloroplasts. How did these complex cells evolve?

BUILD Vocabulary

PREFIXES The prefix *endo-* in **endosymbiotic theory** means "within" or "inner." The endosymbiotic theory involves a symbiotic relationship between eukaryotic cells and the prokaryotes within them.

Endosymbiotic Theory Researchers hypothesize that about 2 billion years ago, some ancient prokaryotes began evolving internal cell membranes. These prokaryotes were the ancestors of eukaryotic organisms. Then, according to **endosymbiotic** (en doh sim by AHT ik) **theory,** prokaryotic cells entered those ancestral eukaryotes. These intruders didn't infect their hosts, as parasites would have done, and the host cells didn't digest them, as they would have digested prey. Instead, the small prokaryotes began living inside the larger cells, as shown in **Figure 19–18.**

The endosymbiotic theory proposes that a symbiotic relationship evolved over time, between primitive eukaryotic cells and the prokaryotic cells within them. This idea was proposed more than a century ago. At that time, microscopists saw that the membranes of mitochondria and chloroplasts resembled the cell membranes of free-living prokaryotes. This observation led to two related hypotheses.

Analyzing Data

PURPOSE Students will interpret graphs that compare the composition of Earth's atmosphere today with the composition of gases from volcanoes.

PLANNING Explain that circle graphs can be used to compare the parts of a whole. Review the structure of a circle graph and how it can be divided. Remind students that a circle is 360°. Any pie-shaped part, or sector, of the circle graph is a percentage of 360°.

ANSWERS

1. nitrogen; 5 percent
2. water vapor
3. The water in today's oceans probably came from water vapor in the early atmosphere that condensed into liquid form.

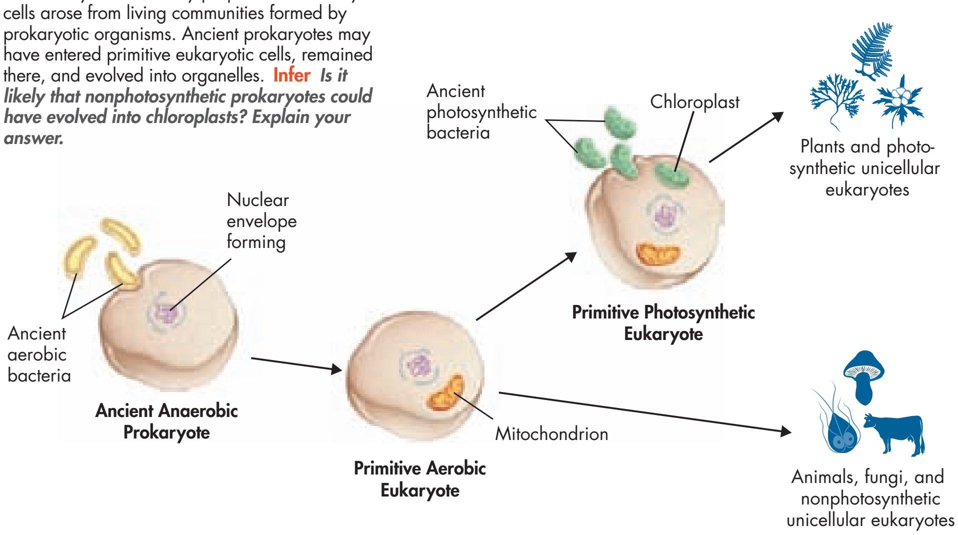
One hypothesis proposes that mitochondria evolved from endosymbiotic prokaryotes that were able to use oxygen to generate energy-rich ATP. Inside primitive eukaryotic cells, these energy-generating prokaryotes evolved into mitochondria that now power the cells of all multicellular organisms. Mitochondria enabled cells to metabolize oxygen. Without this ability, cells would have been killed by the free oxygen in the atmosphere.

Another hypothesis proposes that chloroplasts evolved from endosymbiotic prokaryotes that had the ability to photosynthesize. Over time, these photosynthetic prokaryotes evolved within eukaryotic cells into the chloroplasts of plants and algae.

Modern Evidence During the 1960s, Lynn Margulis of Boston University gathered evidence that supported the endosymbiotic theory. Margulis noted first that mitochondria and chloroplasts contain DNA similar to bacterial DNA. Second, she noted that mitochondria and chloroplasts have ribosomes whose size and structure closely resemble those of bacteria. Third, she found that mitochondria and chloroplasts, like bacteria, reproduce by binary fission when cells containing them divide by mitosis. Mitochondria and chloroplasts, then, share many features of free-living bacteria. These similarities provide strong evidence of a common ancestry between free-living bacteria and the organelles of living eukaryotic cells.

In Your Notebook *Describe two hypotheses relating to the endosymbiotic theory.*

FIGURE 19–18 The Endosymbiotic Theory The endosymbiotic theory proposes that eukaryotic cells arose from living communities formed by prokaryotic organisms. Ancient prokaryotes may have entered primitive eukaryotic cells, remained there, and evolved into organelles. **Infer** ***Is it likely that nonphotosynthetic prokaryotes could have evolved into chloroplasts? Explain your answer.***



LESSON 19.3

Use Visuals

Have the class spend 5 minutes in small groups to study and discuss **Figure 19–18.**

After studying the figure, have all groups come together to discuss the evidence offered by Lynn Margulis to support the endosymbiotic theory.

DIFFERENTIATED INSTRUCTION

L1 **Struggling Students** Help students understand the events described in **Figure 19–18** by having them work with a partner to read and paraphrase the caption and labels. Then, have the members of each pair work together to describe, in their own words, each event shown in the figure.

ELL Focus on ELL: Build Background

ALL SPEAKERS Ask students to explain what the following words mean: *events, complex, ancestral, digest, proposes, generate,* and *features.* If necessary, ask them to find the words in the passage and use context clues.

Then, assign students to small groups that include a mix of levels of speakers. Present each group with a written copy of the following discussion topics:

- How did ancient anaerobic prokaryotes benefit from a symbiotic relationship with bacteria?
- How did bacteria benefit from the relationship?

Allow groups about 10 minutes to discuss the topics. Then, have one member of each group share an oral response with the class.

UbD Check for Understanding

INDEX CARD SUMMARIES

Give students each an index card. Ask students to write one concept about the endosymbiotic theory that they understand on the front of the card. Then, have them identify something about the endosymbiotic theory they do not understand and write it on the back of the card in the form of a question.

ADJUST INSTRUCTION

Read students' cards to identify concepts that are well understood and those that are causing confusion. Choose several representative questions to discuss with the class.

Answers

FIGURE 19–18 No, chloroplasts have the ability to carry out photosynthesis.

IN YOUR NOTEBOOK Mitochondria evolved from endosymbiotic prokaryotes that could use oxygen to generate ATP. Chloroplasts evolved from endosymbiotic prokaryotes that could photosynthesize.

LESSON 19.3

Teach continued

Lead a Discussion

Ask How did the development of sexual reproduction impact the amount of genetic variation in populations? *(It increased genetic variation.)*

Ask How is the pace of evolution affected by an increase in genetic variation? *(It increases.)*

DIFFERENTIATED INSTRUCTION

LPR **Less Proficient Readers** Have students use a **Cause and Effect Diagram** to clarify the effect that the development of sexual reproduction had on the rate of evolution. Then, ask students to explain why sexual reproduction increases the rate of evolution. *(It increases genetic variation.)*

Study Wkbks A/B, Appendix S18, Cause and Effect Diagram. **Transparencies,** GO1.

Assess and Remediate

EVALUATE UNDERSTANDING

Have students work with a partner to ask and answer each of the Key Questions. Then, have students complete the 19.3 Assessment.

REMEDIATION SUGGESTION

L1 **Struggling Students** If students have trouble with **Question 2b,** suggest they review **Figure 19–18.**

BIOLOGY.com Students can check their understanding of lesson concepts with the **Self-Test** assessment. They can then take an online version of the **Lesson Assessment.**

Sexual Reproduction and Multicellularity

What is the evolutionary significance of sexual reproduction?

Sometime after eukaryotic cells arose, they began to reproduce sexually. **The development of sexual reproduction sped up evolutionary change because sexual reproduction increases genetic variation.**

Significance of Sexual Reproduction When prokaryotes reproduce asexually, they duplicate their genetic material and pass it on to daughter cells. This process is efficient, but it yields daughter cells whose genomes duplicate their parent's genome. Genetic variation is basically restricted to mutations in DNA.

In contrast, when eukaryotes reproduce sexually, offspring receive genetic material from two parents. Meiosis and fertilization shuffle and reshuffle genes, generating lots of genetic diversity. That's why the offspring of sexually reproducing organisms are never identical to either their parents or their siblings (except for identical twins). The more heritable variation, the more "raw material" natural selection has to work on. Genetic variation increases the likelihood of a population's adapting to new or changing environmental conditions.

Multicellularity Multicellular organisms evolved a few hundred million years after the evolution of sexual reproduction. Early multicellular organisms underwent a series of adaptive radiations, resulting in great diversity.

19.3 Assessment

Review Key Concepts

1. a. **Review** What was Earth's early atmosphere like?
   b. **Explain** What does Miller and Urey's experiment tell us about the organic compounds needed for life?
   c. **Predict** You just read that life arose from nonlife billions of years ago. Could life arise from nonlife today? Why or why not?
2. a. **Review** What does the endosymbiotic theory propose?
   b. **Explain** According to this theory, how did mitochondria evolve?
   c. **Apply Concepts** What evidence supports the theory?
3. a. **Review** Why is the development of sexual reproduction so important in the history of life?
   b. **Sequence** Put the following events in the order in which they occurred: *sexual reproduction, development of eukaryotic cells, free oxygen in the atmosphere,* and *development of photosynthesis.*

WRITE ABOUT SCIENCE

Explanation

4. Write a paragraph explaining the "RNA world" hypothesis. What parts of the hypothesis have yet to be proved? Is it possible that we will never know the origins of RNA and DNA? Explain your answer.

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Assessment Answers

1a. It was made up mainly of carbon dioxide, water vapor, and nitrogen, and had little or no oxygen.

1b. In the environmental conditions of early Earth, simple compounds could have given rise to mixtures of organic compounds.

1c. Sample answer: probably not, because the same conditions no longer exist on Earth, and oxygen in the atmosphere would destroy organic molecules

2a. A symbiotic relationship evolved between ancient eukaryotic cells and prokaryotic cells within them.

2b. Mitochondria evolved from endosymbiotic prokaryotes that were able to use oxygen to generate ATP.

2c. Mitochondria and chloroplasts share many features of free-living bacteria. They contain similar DNA and ribosomes. They also reproduce by binary fission.

3a. Sexual reproduction increases genetic variation, which gives natural selection more raw material to work on.

3b. development of photosynthesis, free oxygen in the atmosphere, development of eukaryotic cells, sexual reproduction

WRITE ABOUT SCIENCE

4. Sample answer: One RNA hypothesis suggests that RNA evolved before DNA. Under certain conditions, RNA molecules can help DNA replicate, catalyze chemical reactions, and replicate themselves. Therefore, it is likely that RNA existed before DNA. Scientists have not yet been able to show how RNA led to DNA-directed protein synthesis, and we may never know.