CHAPTER 16

The Origin of Life





Tests performed by the Viking spacecraft on Martian soil indicated that there is no life on Mars today. Astronauts who walked on the moon confirmed what scientists already knew: There is no life on our lunar neighbor.

We shall not cease from exploration.
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.
T.S. Eliot, *Four Quartets*

In this work by T.S. Eliot, the author suggests that to truly understand ourselves and the world about us, we must return to our roots and discover where we came from and how we came to be. Although the author is not speaking about biology, his words have meaning to scientists, as well as students of literature.

This chapter deals with the origin of life on planet Earth. Here you will discover that there are many current hypotheses regarding the formation of life. But you will also learn that, as in much of science, there are many unanswered questions as well.

CHAPTER OUTLINE

16–1 Spontaneous Generation
- Spontaneous Generation: True or False?
- Pasteur and Spontaneous Generation

16–2 The First Signs of Life
- Starting from Scratch: The Molecules of Life
- The Formation of Complex Molecules
- From Proto-life to Cells
- The First True Cells
- The Evolution of Photosynthesis
- Life from Nonlife

16–3 The Road to Modern Organisms
- The Evolution of Aerobic Metabolism
- The Evolution of Eukaryotic Cells
- The Evolution of Sexual Reproduction
- The Evolution of Multicellular Life

16–1 Spontaneous Generation

Section Objectives

- Define spontaneous generation.
- Describe the experiments of Redi, Spallanzani, and Pasteur.

Scientists have always wondered how life on Earth began. For many centuries, they believed that life simply "arose" from nonliving matter. They believed, in fact, that life arose from nonlife all the time. Mice, for example, arose from piles of grain. Bees were "produced" in the carcasses of cattle. Those who disputed this idea were ridiculed. The English naturalist Ross expressed a common feeling when he wrote, "To question that beetles and wasps were generated in cow dung is to question reason, sense, and experience." **The hypothesis that life arises regularly from nonlife is called spontaneous generation.**

Spontaneous Generation: True or False?

Lazzaro Spallanzani was born in Italy in 1729—three years before the birth of George Washington. As he grew up, he developed an interest in the natural world and began to consider one of the burning questions that people argued about in his school: **spontaneous generation.** Those who believed in spontaneous generation often supported their argument with the example of rotting meat. As meat spoiled, it was said to give rise to maggots, which eventually changed into flies. The rotting of

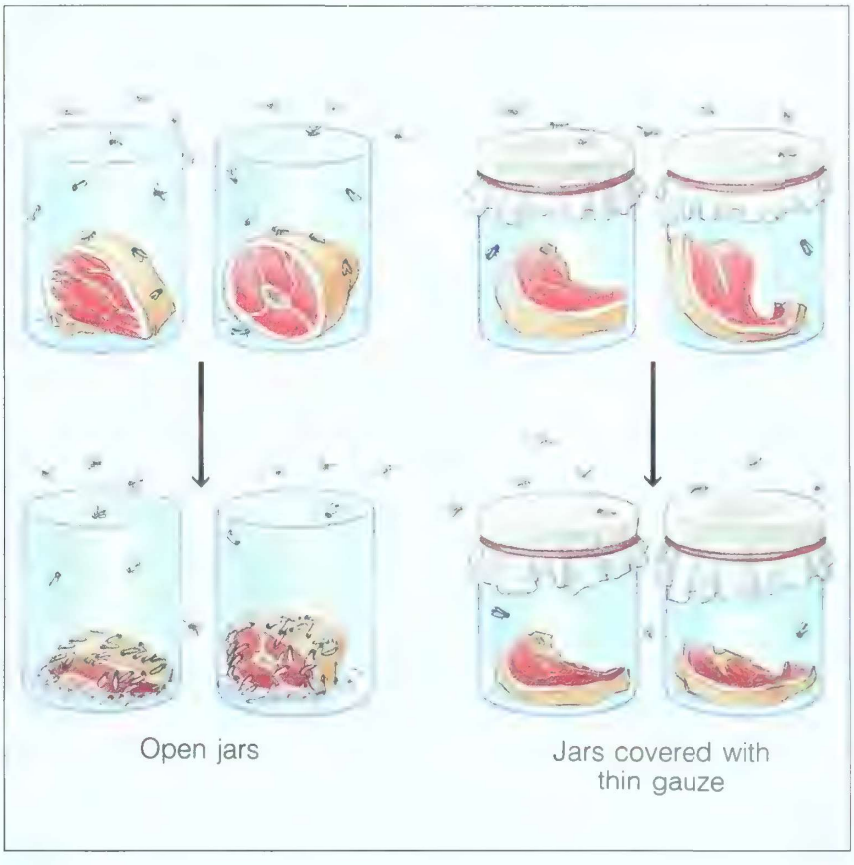


Figure 16–1 *Redi's experiments helped disprove spontaneous generation. No maggots were found on the meat in jars that were covered with netting or were tightly sealed. Maggots appeared only when adult flies were able to enter the jars and deposit their eggs.*

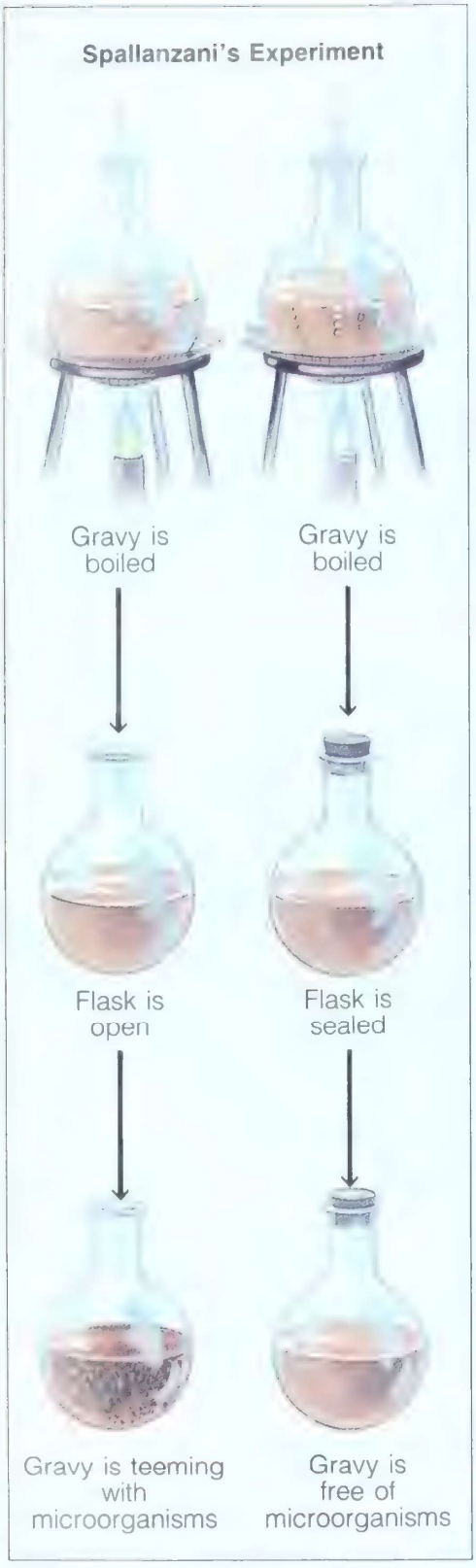


Figure 16–2 *Spallanzani's experiment showed that microorganisms do not grow in nutrient broth that has been boiled and placed in sealed flasks.*

meat in the warm Italian climate was a common experience before refrigeration. Everyone seemed to agree that the maggots were produced from the meat.

Spallanzani was already skeptical of the idea that life could arise from nonlife when he came upon a small book written by another Italian scientist, Francesco Redi. In his book, Redi hypothesized that the maggots actually arose not from the meat itself but from eggs. He believed that flies laid their eggs, which were too small to be seen with the unaided eye, directly on the meat. The eggs then developed into maggots, which later became adult flies. Redi described the simple experiment he had performed to test his spontaneous generation hypothesis. See Figure 16–1 on page 339.

Redi placed pieces of meat in several jars. Half of the jars he left open to the air so that flies could land on the meat. The other jars were covered with a thin gauze. Although these jars were open to the air, the gauze prevented flies from landing on the meat. After a few days, the meat in all the jars had spoiled. But maggots were found only on the meat in the uncovered jars. Redi concluded that the maggots did not arise spontaneously; rather, the maggots developed from the eggs laid by the flies.

Redi's conclusions were attacked by another eighteenth-century scientist, the Englishman John Needham. Needham claimed that spontaneous generation could occur under the right conditions and cited his own experiment as proof. He sealed some gravy in a bottle. Then he heated the bottle, killing (he claimed) all living things in the gravy. After several days, he examined the contents of the bottle under a microscope and found it swarming with microscopic organisms. "These little animals," he argued, "can only have come from the juice of the gravy."

The work of both Redi and Needham was well known to Spallanzani, and it is to his role in spontaneous generation that we will now return. Spallanzani believed that Needham was wrong and that all the organisms had not been completely killed when the gravy was heated. He could have written Needham with his objections. Instead, he chose to perform an experiment to prove his hypothesis. See Figure 16–2.

Spallanzani prepared some gravy identical to that used by Needham. He placed half of the gravy into one jar and half into another jar. He then boiled the gravy in both jars thoroughly. Spallanzani sealed one of the jars tightly and left the other jar open to the air.

After a few days, Spallanzani noticed that the gravy in the open jar was teeming with microscopic organisms. The gravy in the sealed jar contained no living things. Spallanzani concluded that the microorganisms did not develop from the gravy—from nonlife—but entered the jar from the air. If this was not the case, he argued, then both jars should contain microorganisms.

Pasteur and Spontaneous Generation

Despite the work of Redi and Spallanzani, many people still believed in spontaneous generation. They argued that air was necessary for spontaneous generation and because Spallanzani had kept air out of the sealed jar, spontaneous generation could not have occurred in that part of his experiment. It was not until 1864, and the elegant experiment of French scientist Louis Pasteur, that the hypothesis of spontaneous generation was finally disproved.

Pasteur placed nutrient broth, a substance similar to Needham's gravy, in a flask that had a long, curved neck. Although the end of the neck was open to the air, the curve in the neck served to trap dust and other airborne particles. Pasteur boiled the flask thoroughly to kill any microorganisms it might contain. But he did not seal the open end of the flask. Pasteur waited an entire year. In all that time, no microorganisms could be found in the flask. See Figure 16–4.

Pasteur took his experiment even further. He broke off the neck of the flask, allowing air, dust, and other particles to enter the broth. In just one day the flask was clouded from the growth of microorganisms. Pasteur had clearly shown that the microorganisms had entered the flask along with dust particles from the air. Pasteur, like Redi and Spallanzani before him, had shown that life comes only from life.

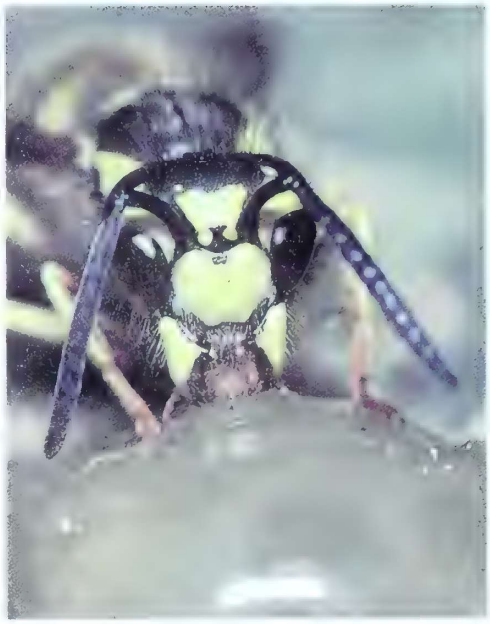


Figure 16–3 *According to the spontaneous generation hypothesis, living things, such as a wasp, could arise from inorganic matter.*

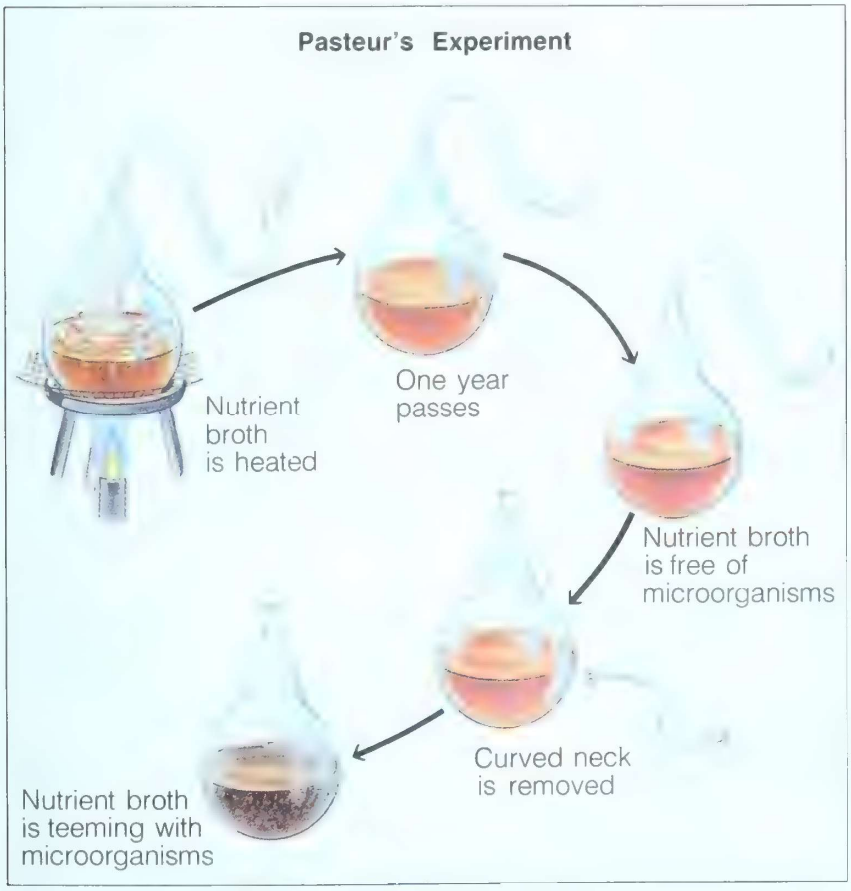


Figure 16–4 *Louis Pasteur put an end to the spontaneous generation hypothesis. He showed that microorganisms did not arise in a boiled nutrient broth, even if the broth was exposed to the air, as long as dust particles and other airborne matter were not allowed to enter the broth.*

16-1 SECTION REVIEW

1. Define spontaneous generation.
2. What evidence did Spallanzani give to refute Needham's experiment?
3. In Redi's first experiment he used only open jars and sealed jars. What arguments might scientists have come up with that caused Redi to redo his experiment with open jars and jars covered with gauze?
4. How did Pasteur's use of a flask with a long, curved neck finally disprove spontaneous generation?

Section Objectives

- Describe conditions on ancient Earth.
- Define microfossil.
- Discuss various hypotheses on the evolution of cells.

16-2 The First Signs of Life

If life can come only from life, how did life on Earth first arise? For that matter, does life exist (or has it ever existed) on Mars? Or Venus? By studying the beginnings of life, we examine our own origins.

Our planet was born approximately 4.6 billion years ago as a great cloud of gas and dust condensed into a sphere. As gravity pulled this matter tightly together, heat from great pressure and radioactivity melted first the planet's interior and then most of its mass. As far as we can tell, Earth cooled enough to allow the first solid rocks to form on its surface about 4 billion years ago. For millions of years afterward, violent planet-wide volcanic activity shook the crust. At the same time, an intense meteor shower bombarded Earth with missiles from space.



Figure 16-5 *You can see from this illustration depicting primitive Earth that most living things would not easily survive, even if the atmosphere were similar to the atmosphere you breathe today.*

What was Earth like 4 billion years ago? Had you been able to visit, you wouldn't have recognized the place. In fact, you wouldn't have been able to survive, even for an instant! For the first atmosphere that covered our planet was lost to space before the Earth cooled. And there was no liquid water at all.

Where did our atmosphere come from? We know from studying volcanoes that eruptions pour out carbon dioxide, nitrogen, and other gases. We also know that meteorites carry water (in the form of ice) and many carbon-containing compounds. So it is reasonable to propose that between 4 billion and 3.8 billion years ago, a combination of volcanic activity and a constant stream of meteorites released the gases that created Earth's early atmosphere.

What was that early atmosphere like? **The Earth's first atmosphere most likely contained water vapor (H_2O), carbon monoxide (CO) and carbon dioxide (CO_2), nitrogen (N_2), hydrogen sulfide (H_2S), and hydrogen cyanide (HCN).** Notice that this atmosphere contained no free oxygen gas and thus could not support life as we know it. Geological evidence supports this hypothesis because rocks from this time contain almost no rust or other compounds that require free oxygen to form.

Where did the oceans of ancient Earth come from? Oceans could not exist at first because Earth's surface was extremely hot. Any rain that fell upon it would immediately boil away. But, about 3.8 billion years ago, Earth's surface cooled enough for water to remain a liquid on the ground. Thunderstorms drenched the planet for many thousands of years, and oceans began to fill. We know this because the earliest sedimentary rocks, which are laid down in water, have been dated to this time period.

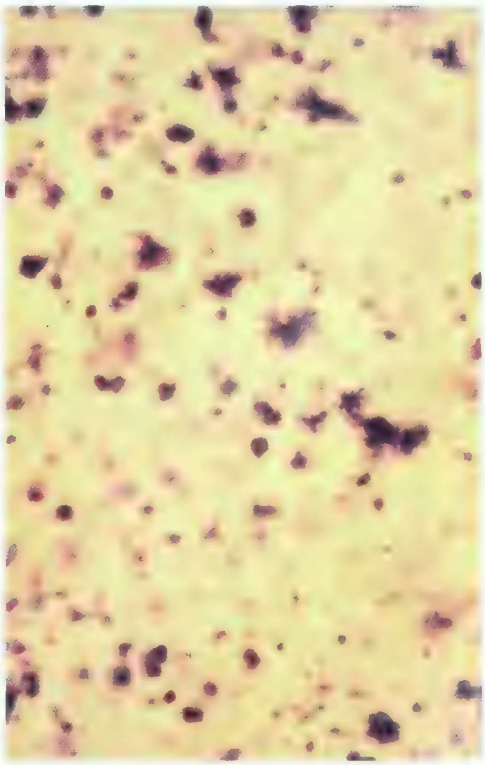
No one can say with certainty exactly when life first formed on ancient Earth. But paleontologists working near Lake Superior have found microscopic fossils, called **microfossils**, that have been dated as far back as 3.5 billion years. **Microfossils provide outlines of ancient cells that have been preserved in enough detail to identify them as prokaryotes, similar to bacteria alive today**. See Figure 16–7.

Somehow these earliest life forms appeared within half a billion years after the formation of Earth's first rocks. How might that have happened?



Figure 16–6 *Scientists collect ice samples from Earth's polar regions. Dust trapped in the ice helps scientists study changes in Earth's early atmosphere.*

Figure 16–7 *You can see 2-billion-year old microfossil bacteria in this thin slice of rock.*



Starting from Scratch: The Molecules of Life

Experiments first performed in 1953 by American scientists Stanley Miller and Harold Urey provide a fascinating glimpse of events leading to the appearance of Earth's first life forms. Miller recreated what he thought might have been Earth's earliest atmosphere by mixing methane, ammonia, water, and hydrogen in a flask. He then exposed the contents of the flask to



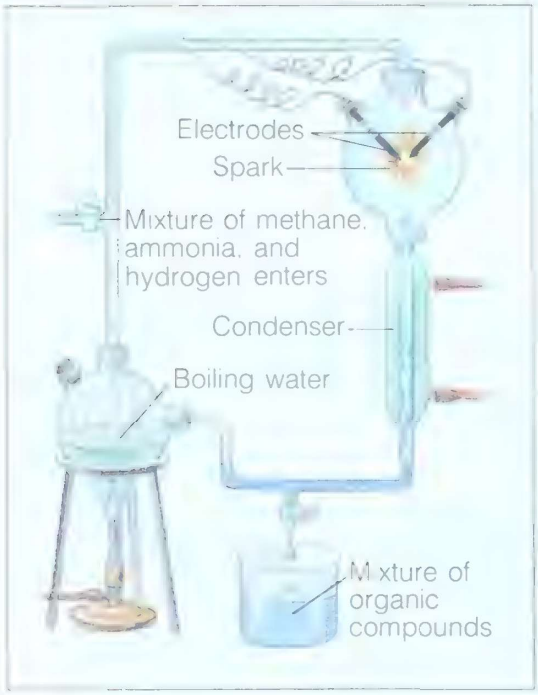


Figure 16–8 *An experiment performed by Stanley Miller (top) and Harold Urey first demonstrated how organic matter may have formed in Earth's primitive atmosphere. By recreating the early atmosphere (ammonia, water, hydrogen, and methane) and passing an electric spark (lightning) through the mixture, Miller and Urey proved that organic matter such as amino acids could have formed spontaneously (bottom).*

electric sparks to simulate sunlight and lightning on primitive Earth. See Figure 16–8.

In just a few days, an organic "soup" of complex molecules formed. Analyzing this soup, Miller found urea, acetic acid, lactic acid, and several amino acids. Other researchers have since repeated Miller's experiments using slightly different mixtures of gases that reflect more current views of the early atmosphere. All these experiments produced important organic molecules, including ATP and the nitrogenous base adenine, in the absence of oxygen. Thus, over the course of millions of years, at least some of the basic building blocks of life could have been produced in great quantities on early Earth.

In another exciting development, astronomers have discovered that the synthesis of life's building blocks is not limited to Earth alone. Meteors, comets, and even the dust scattered across the universe are filled with organic molecules, ice, and other elements essential to life. No one knows how these compounds are produced in the bitter cold of outer space. But more than 75 molecules, ranging from hydrogen gas (H_2) to a variety of amino acids, have been found in space.

A large meteorite that crashed to Earth in Australia in 1969 even contained lipids and all five nitrogenous bases that form the structures of DNA and RNA. Thus, meteors that bombarded the young Earth could have showered the planet with a rain of organic molecules that mixed with those already forming.

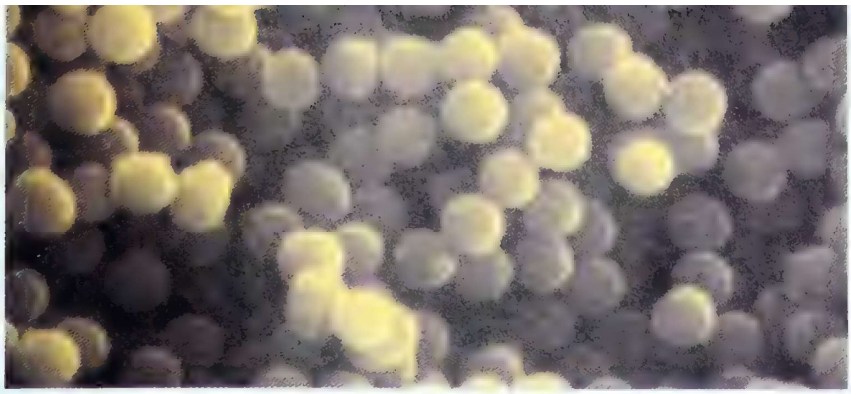
The Formation of Complex Molecules

A collection of organic molecules such as amino acids is certainly not life. What, then, happened next? Experiments by Russian scientist Alexander Oparin and American scientist Sidney Fox have shown that the organic soup that formed in the oceans of Earth would not necessarily have remained as simple chemical mixtures. In the absence of oxygen, for example, amino acids tend to link together spontaneously to form short chains. And as you will remember, chains of amino acids are called polypeptides (proteins). Other compounds can link together to form simple carbohydrates, alcohols, and lipids.

Even more fascinating is the fact that collections of molecules such as these tend to gather into tiny round droplets. Some of these droplets grow all by themselves, and others even reproduce. See Figure 16–9. Still others can break down glucose. At this stage, we would still not say that these droplets are alive. But we might call them "proto-life" because they have begun to perform tasks necessary for life.

From Proto-life to Cells

The next step in our story is the most difficult to understand completely. From the jumbled mixture of molecules in the organic soup that formed in Earth's oceans, the highly organized structures of RNA and DNA must somehow have



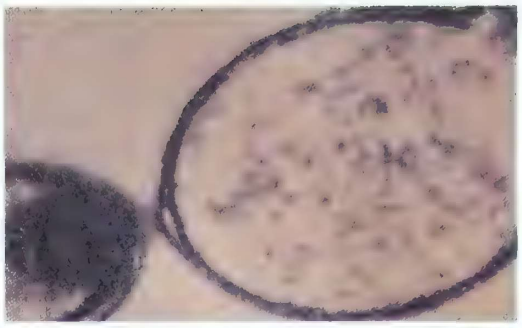


Figure 16–9 *These droplets (left), magnified 3000 times, were created in the laboratory of Sidney Fox. Although the droplets are not alive, they can perform some basic life functions, including breaking down glucose. Some droplets can actually reproduce by dividing into two separate droplets (right).*

evolved. Scientists do not know how these vital information-carriers formed, but there are several interesting hypotheses.

Some biologists believe that the first true cells arose in a shallow pool containing an organic soup. Experiments show that when such a soup is dried, lipids spontaneously form spheres, or droplets, around small DNA molecules. Given enough time, a form of DNA capable of replicating itself could have arisen within such proto-cells.

An alternative hypothesis is offered by G. Cairns-Smith and J. Bernal. They noted that various attractive forces can concentrate amino acids and nucleic acids (DNA and RNA) onto the regular, repeating structures that make up clay crystals. Held together in such a manner, these organic molecules might have combined to form lengths of both DNA and proteins.

Building on this second hypothesis, several scientists propose that the first cells formed near a volcanic vent far beneath the ocean, not in a shallow pool. In such places, molten rock heats water to very high temperatures. When this water gushes out of the vent into the ocean, it is filled with energy-rich sulfur compounds. See Figure 16–10. Thus these vents offer a set of conditions favorable for the chemical reactions leading to life: an assortment of necessary chemicals, strong currents to mix those compounds together, a source of naturally formed chemical energy, and deposits of clay.

Researchers who duplicate these conditions in the laboratory observe the spontaneous synthesis of both amino acids and stretches of RNA. As you will see in the next chapter, the oldest living prokaryotes—a group of bacteria that survive by obtaining energy from sulfur compounds—still live near these hot vents today. This is one piece of evidence supporting this interesting, but as yet unproven, hypothesis.

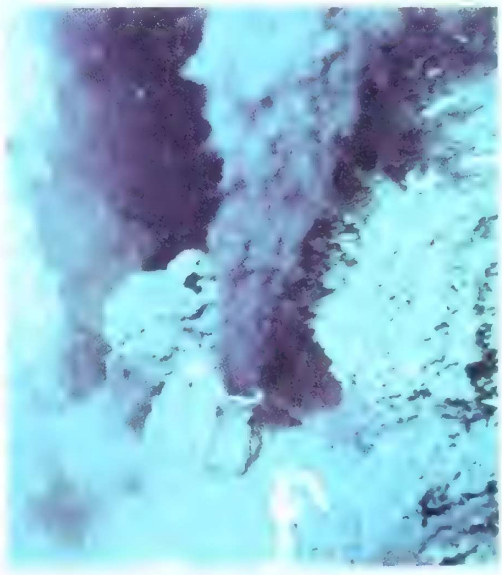


Figure 16–10 *One hypothesis about the origin of life suggests that living things evolved around hot sea vents, which spew out high-energy sulfur compounds. Today, bacteria that can use the sulfur compounds as a source of energy live in areas near deep-sea vents.*

The First True Cells

Although the origin of the first true cells is uncertain, we can identify several of their characteristics with certainty. They were prokaryotes that resembled types of bacteria alive today. They were heterotrophs that obtained their food and energy from the organic molecules in the soup that surrounded them. And they must have been **anaerobes**. Anaerobes are organisms that can live without oxygen. Why can we be certain these first cells were anaerobes?



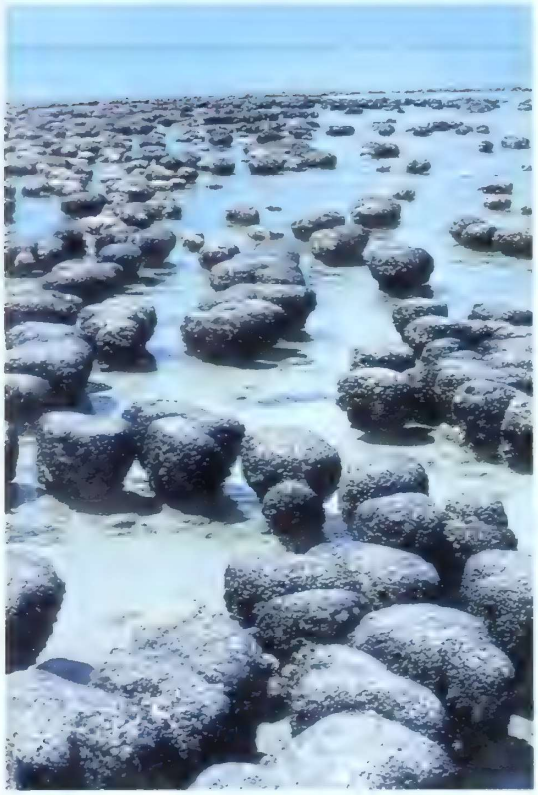


Figure 16–11 *The first autotrophs grew in layered mats called stromatolites. Fossils of such stromatolites can be found in rock layers throughout the world (top). However, Shark Bay, Australia, is one of the few places on Earth where living stromatolites still exist (bottom).*

The Evolution of Photosynthesis

The first heterotrophic cells could have survived without difficulty for a long time because there were plenty of organic molecules for them to "eat." But as time went on, the complex molecules in the organic soup would have begun to run out. In order for life to continue, some organisms would have had to develop a way to make complex molecules from simpler ones. In addition, the intense pressure of natural selection would have favored organisms that could harness an outside source of energy for their own purposes. The stage was set for the appearance of the first autotrophs.

At some point an ancient form of photosynthesis evolved. Photosynthesis in early cells, however, was very different from the photosynthesis that occurs in modern plants, which you read about in Chapter 6. The first true cells probably used hydrogen sulfide (H_2S) the way modern photosynthetic organisms use water (H_20).

These first autotrophs were enormously successful, spread rapidly, and were commonplace on Earth about 3.4 billion years ago. They grew in layered, matlike formations called stromatolites (the prefix *stroma-* means layer). Today, living stromatolites can be found only in special habitats such as Shark Bay, Australia. See Figure 16–11. However, fossils of stromatolites have been found in many parts of the world.

Life from Nonlife

In Section 16–1 you read about some experiments that disproved the hypothesis of spontaneous generation. "Hey, what's going on?" you might exclaim. If we just said that life did arise from nonlife billions of years ago, why couldn't it happen again? The answer is simple: Today's Earth is a very different planet from the one that existed billions of years ago. On primitive Earth, there were no bacteria to break down organic compounds. Nor was there any oxygen to react with the organic compounds. As a result, organic compounds could accumulate over millions of years, forming that original organic soup. Today, however, such compounds cannot remain intact in the natural world for a long enough period of time to give life another start.

16–2 SECTION REVIEW

1. List five gases in Earth's first atmosphere.
2. What is a microfossil?
3. Name two sources for Earth's first organic molecules.
4. Why did photosynthesis (or something like it) have to evolve if life was to continue past its earliest stages?

16–3 The Road to Modern Organisms

Section Objectives

- Relate oxygen production in photosynthesis to the evolution of aerobic metabolism.
- Describe the importance of membrane-bound organelles and sexual reproduction to the evolution of life on Earth.

Once life evolved on Earth, things would never be the same. For over millions of years, life has changed the Earth in ways that have affected our planet dramatically. The first great change occurred roughly 2.2 billion years ago when a more modern form of photosynthesis evolved. By substituting H_2O for H_2S in their metabolic pathways, photosynthetic organisms released a deadly new gas into the atmosphere. That gas was oxygen—a waste product of photosynthesis!

Because you rely on oxygen to survive, you might be surprised to learn that it can be deadly. However, oxygen is a very reactive gas that destroys organic compounds. So imagine the catastrophe that struck Earth's earliest life forms. Over a period of 500 million years, a waste product (oxygen) produced by some organisms transformed Earth from a totally anaerobic planet into a planet whose atmosphere is nearly 1/5 oxygen.

Because oxygen was deadly to anaerobes, such organisms were forever banished from the planet's surface. Today, organisms that cannot tolerate oxygen survive only deep in mud or in other places where the atmosphere does not reach. The very first case of living organisms producing a kind of pollution that made the entire Earth uninhabitable for many forms of life had occurred. Let us hope that we as a species do not make decisions that have similar results!

One effect of oxygen in the atmosphere, however, was beneficial to those organisms that survived. The first atmosphere had allowed ultraviolet radiation from the sun to strike the Earth's surface. Ultraviolet radiation is damaging, even toxic, to many life forms. But as oxygen gas (O_2) from photosynthesis reached the upper atmosphere, some of it was broken apart by ultraviolet radiation into individual oxygen atoms (O). These atoms quickly recombined with oxygen molecules to form the gas ozone (O_3). In time, an ozone layer formed in the Earth's atmosphere. This ozone layer absorbs much of the ultraviolet radiation from the sun, shielding living things from the dangerous rays. In Unit 10 of this textbook, you will read how the burning of fossil fuels and the release of certain compounds into our atmosphere is slowly but surely destroying the ozone layer so very important to life on our planet.

The Evolution of Aerobic Metabolism

The addition of oxygen to the atmosphere began a new chapter in the history of life on Earth. That chapter started with the evolution of organisms that not only survive in oxygen but utilize it in their metabolic pathways. Metabolism is the sum total of all the chemical reactions that occur in a living thing. These new aerobic pathways allowed organisms to obtain 18 times more energy from every sugar molecule than

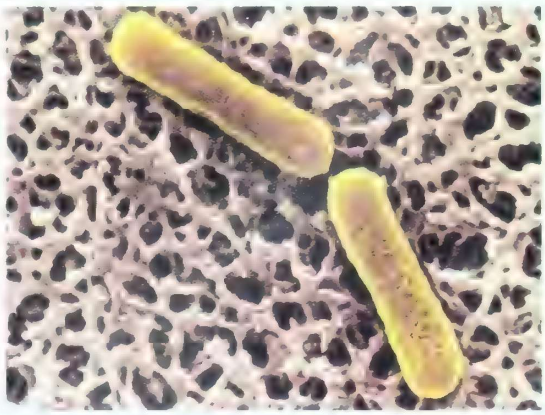


Figure 16–12 *Once Earth's atmosphere contained oxygen, anaerobic bacteria such as these were banished to places where the atmosphere could not reach.*

anaerobic pathways did. As you may recall from Chapter 6, these new aerobic pathways are part of the process of obtaining energy called cellular respiration.

The Evolution of Eukaryotic Cells

Between 1.4 and 1.6 billion years ago, the first eukaryotic cells evolved, fully adapted to an aerobic world. Eukaryotes have a nucleus that contains DNA. The outer membrane of the nucleus is called the nuclear envelope. Eukaryotic cells also carry other membrane-bound organelles such as mitochondria and chloroplasts.

The Evolution of Sexual Reproduction

Among the most important steps in the evolution of eukaryotic life was the emergence of sexual reproduction. The advent of sexual reproduction catapulted the process of evolution forward at far greater speeds than ever before. But why did sexual reproduction speed up the evolutionary process? Isn't it just another form of reproduction?

Most prokaryotes reproduce asexually. Often they simply duplicate their genetic material and divide into two new cells. (This process, called binary fission, will be discussed in detail in the next chapter.) Although this is an efficient and effective form of reproduction, it yields daughter cells that are exact duplicates of the original parent cell. As such, this type of reproduction restricts genetic variation to mistakes or mutations in DNA. As you read in Chapter 14, genetic variation is crucial to the process of adaptive radiation and the evolution of new species.

Sexual reproduction, on the other hand, shuffles and reshuffles genes in each generation, much like a person shuffling a deck of cards. The offspring of sexually reproducing organisms, therefore, never resemble their parents (or each other) exactly. This increase in genetic variation greatly increases the chances of evolutionary change in a species due to natural selection.

The evolution of sexual reproduction, along with the development of the membrane-bound organelles mitochondria and chloroplasts, were of enormous importance to the history and development of life on Earth. If not for these developments, multicellular organisms may not have evolved.

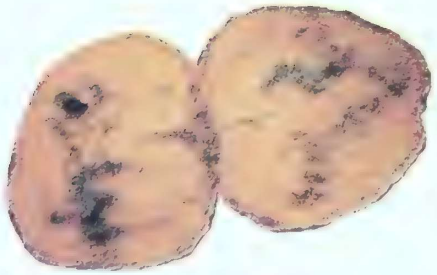




Figure 16–13 *In asexual reproduction, such as the division of a bacterium into two new bacteria, each new cell is an exact copy of the original cell (top). In sexual reproduction, however, offspring contain genes from each parent, and genetic variation is increased. How boring it would be if we all contained the exact same genes and looked exactly alike (bottom).*

The Evolution of Multicellular Life

A few hundred million years after the evolution of sexual reproduction, evolving life forms crossed another great threshold: the development of multicellular organisms from single-celled organisms. In the blink of an evolutionary eye, these first multicellular organisms experienced a great adaptive radiation. Earth's parade of life was well on its way.

SCIENCE, TECHNOLOGY, AND SOCIETY **BREAKTHROUGH**

The Symbiotic Theory of Eukaryotic Origins

For many years biologists have wondered how eukaryotic cells evolved from prokaryotic cells. Eukaryotic cells contain membrane-bound organelles and a nucleus surrounded by a nuclear envelope, or membrane.

Of particular interest to scientists are the organelles called mitochondria and chloroplasts. Why? Although these organelles usually act like ordinary parts of a cell, they contain their own DNA. That DNA is different from the DNA found within the nucleus of the cell. These organelles also reproduce on their own when the cell divides.



Some years ago biologists noted that mitochondria and chloroplasts strongly resemble living prokaryotes. Mitochondria resemble certain aerobic bacteria, whereas chloroplasts resemble certain photosynthetic bacteria. One American scientist, Lynn Margulis, has championed an intriguing hypothesis about the evolution of eukaryotic cells.

Margulis feels that eukaryotic cells evolved when ancient aerobic prokaryotes similar to modern chloroplasts and mitochondria took up residence within other prokaryotic cells. Over time, a long-lasting symbiosis developed. Symbiosis refers to any relationship in which two organisms live closely together. This ancient symbiosis was particularly helpful to both organisms. The organisms, which evolved into mitochondria and chloroplasts, now lived within the nutrient-rich cytoplasm of their host cell. The host cell containing mitochondria-type prokaryotes could now produce energy faster and more efficiently because it could utilize oxygen in its metabolic pathways. If the host cell contained chloroplast-type prokaryotes, it could now use the energy from the sun to produce food. In time, of course, mitochondria and chloroplasts came to function more and more as part of the cell structure in eukaryotes.

It was not easy, at first, for scientists to accept the idea that eukaryotic cells developed as communities. But both structural and chemical evidence strongly supports the theory proposed by Margulis. The symbiotic theory of eukaryotic origins is now accepted by most biologists. However, there are still many unanswered questions in the search for eukaryotic origins. We still do not know, for example, how the earliest eukaryotes developed the nuclear envelope that surrounds their DNA.

16-3 SECTION REVIEW

1. What compound replaced H_2S in the photosynthetic process?
2. What is the importance of the Earth's ozone layer?
3. How did the development of sexual reproduction speed up the evolutionary process?

LABORATORY INVESTIGATION

INVESTIGATING SPONTANEOUS GENERATION

PROBLEM

Does spontaneous generation occur on Earth today?

MATERIALS *(per group)*

600-mL beaker	hot plate
3 125-mL flasks	safety goggles
#5 rubber stopper	beaker tongs
#5 one-hole rubber stopper with S-tube	heat-resistant gloves
	dried grass
	Bunsen burner

PROCEDURE

1. Place two handfuls of dried grass in the 600-mL beaker. Pour water into the beaker until the water level is about 1 cm below the top of the beaker.
2. Put on the safety goggles. Carefully place the beaker on the hot plate. Set the hot plate to its highest level. **CAUTION:** *Do not touch the top of the hot plate.*
3. Allow the water to boil for about 30 minutes. **CAUTION:** *If the water level drops below the midpoint of the beaker, have your teacher replenish the water with some more boiling water.*
4. After the water has boiled for 30 minutes, turn off the hot plate. Light the Bunsen burner. Pass the front of the tongs through the flame of the burner several times. Turn off the burner. Now use the tongs to remove all of the grass from the water in the beaker. Discard the grass.
5. At this point, ask your teacher for three sterile flasks, a rubber stopper without a hole, and a rubber stopper with an S-tube in the hole.
6. Put on the heat-resistant gloves. Pick up the hot beaker and pour 100 mL of the hot grass solution into each flask. Do not allow any grass to fall into the flasks.
7. As quickly as possible, place the rubber stoppers into two of the flasks. Do not stopper the third flask. Set the flasks aside and observe each flask twice a week for three weeks.
8. On a separate sheet of paper, prepare a data table similar to the one shown. Record your observations in the data table. If you observe thin threadlike structures, you are probably seeing the growth of mold. If the solution in the flask becomes clouded, you are probably seeing evidence of bacterial growth.

OBSERVATIONS

1. Describe what you saw in each flask after three weeks.
2. How long did it take before you saw living things in any of the flasks?

ANALYSIS AND CONCLUSIONS

1. What purpose did the grass serve in this investigation?
2. Why was it necessary to boil the water containing the grass before adding the grass/water solution to the flasks?
3. Why was it necessary to use sterile flasks and stoppers?
4. If living things appeared in any of the flasks, where did the living things come from?
5. Do the results of this investigation provide evidence for or against spontaneous generation?

		Appearance of Liquid in Each Flask		
Week	Observation	Stopper	No Stopper	Stopper with S-tube
1	1			
	2			

STUDENT STUDY GUIDE

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

16–1 Spontaneous Generation

- The hypothesis that life arises from nonlife is called spontaneous generation.
- Louis Pasteur, a French scientist, put an end to the spontaneous generation controversy when he showed that a nutrient broth that had been thoroughly heated did not have any signs of microorganisms even when left open to the air. Pasteur had allowed air but not dust or other particles to reach the broth. When he did allow dust and other particles to enter the broth, microorganisms soon appeared. Pasteur had proved that the microorganisms in the broth did not develop spontaneously.

16–2 The First Signs of Life

- The atmosphere on ancient Earth was very different from our modern atmosphere. It contained water vapor, carbon monoxide, carbon dioxide, nitrogen, hydrogen sulfide, and hydrogen cyanide. The atmosphere did not contain free oxygen gas.
- Microfossils indicate that the first life forms were prokaryotes, similar to modern bacteria.
- Many organic compounds, including amino acids and ATP, could have formed when ultraviolet rays and lightning reacted with the gases in the early atmosphere. Laboratory experiments have recreated the formation of these compounds on early Earth. The organic compounds formed an organic "soup" containing the basic building blocks of life.
- The first true cells were prokaryotic heterotrophic anaerobes.
- In time, some cells developed the ability to harness energy from the sun in a primitive form of photosynthesis.

16–3 The Road to Modern Organisms

- Once organisms that used water and produced oxygen as a waste product during photosynthesis developed, the atmosphere slowly accumulated oxygen gas.
- Once oxygen was plentiful, aerobic metabolism utilizing cellular respiration evolved. Aerobic metabolism provided more energy than earlier forms of anaerobic metabolism.
- Around 1.4 billion years ago, eukaryotic cells containing membrane-bound organelles evolved.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

16–1 Spontaneous Generation

spontaneous generation

16–2 The First Signs of Life

microfossil
anaerobe

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. The hypothesis that mice can arise from spoiled grain is called
   a. evolution.
   b. microfossil.
   c. spontaneous generation.
   d. metabolism.
2. One scientist who believed in spontaneous generation was
   a. Redi.
   b. Needham.
   c. Pasteur.
   d. Spallanzani.
3. Earth's early atmosphere did not contain free
   a. nitrogen.
   b. oxygen.
   c. carbon dioxide.
   d. hydrogen cyanide.
4. Microfossils indicate that the first living cells were not
   a. prokaryotes.
   b. heterotrophic.
   c. eukaryotes.
   d. anaerobes.
5. Modern photosynthetic organisms have replaced H_2S with
   a. HCN.
   b. CO_2.
   c. H_2O.
   d. O_2.
6. In the atmosphere, oxygen forms a layer of O_3, or ozone, that protects organisms from
   a. sunlight.
   b. infrared radiation.
   c. ultraviolet radiation.
   d. hydrogen cyanide.
7. Cells with membrane-bound organelles are called
   a. prokaryotes.
   b. mitochondria.
   c. chloroplasts.
   d. eukaryotes.
8. Sexual reproduction can speed up evolution because it provides more
   a. chromosomes.
   b. genetic variation.
   c. identical cells.
   d. organelles.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. The hypothesis that nonlife arises from life is called spontaneous generation.
2. Redi showed that the flies that developed on raw meat did not arise spontaneously.
3. Earth formed around 4.6 billion years ago.
4. In the presence of oxygen, amino acids spontaneously link to form short chains.
5. The first true cells were prokaryotes.
6. The first heterotrophs were similar to modern-day stromatolites.
7. The ozone layer protects living things from ultraviolet radiation from the sun.
8. Genetic variation increases when organisms reproduce asexually.

Word Relationships

A. *In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to the three terms and then identify the term that does not belong.*

1. early atmosphere, hydrogen sulfide, oxygen, nitrogen
2. organelle, amino acid, lipid, carbohydrate
3. RNA, DNA, amino acid, nucleic acid
4. aerobic, first true cells, heterotrophic, anaerobic
5. eukaryote, asexual, prokaryote, single-celled

B. *Replace the underlined definition with the correct vocabulary word.*

6. Pasteur helped disprove the life arises from nonlife hypothesis.
7. Microscopic fossils provide outlines of ancient cells in rocks.
8. The first true cells were organisms that can live without oxygen.

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Explain why scientists believe the first true cells were anaerobic heterotrophic prokaryotes.
2. Discuss the experiments of Redi, Needham, Spallanzani, and Pasteur as they relate to spontaneous generation.
3. Which is more likely to result in increased variety among organisms, sexual reproduction or asexual reproduction? Why?
4. In one early experiment, Pasteur used flasks that had curved necks. He tipped some of the flasks so that the nutrient broth ran into the flasks. Pasteur later observed microorganisms in these flasks. Explain this observation.
5. Discuss how scientists believe the Earth's early atmosphere and oceans formed.
6. Describe the symbiosis theory of eukaryotic development.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Sequencing events** Draw a time line that begins with the formation of the Earth and ends with the development of multicellular life. Make sure every significant event discussed in the chapter is included.
2. **Applying facts** Describe the ways in which the evolution of photosynthesis changed not only living things but the environment of Earth as well.
3. **Making predictions** Predict how modern life on Earth would have evolved if organisms did not begin using H_2O instead of H_2S in photosynthesis.
4. **Relating cause and effect** When people believed in spontaneous generation, a scientist developed this recipe for producing mice: Place a few wheat grains and a dirty shirt in an open pot; wait 3 weeks. Suggest a reason why this recipe may have worked. How could you prove that the mice were not due to spontaneous generation?
5. **Drawing conclusions** Although scientists have recreated some of the events that led to the formation of complex organic compounds, they do not believe that similar events could occur in the natural world today. Explain why not.
6. **Making inferences** Suppose autotrophic organisms had not evolved. What would life on Earth be like today?
7. **Using the writing process** You are asked to develop a television program for young children that explains the origin of life on Earth. Write a script for this show. You might like to videotape your presentation.
8. **Using the writing process** Did you ever wonder what it would have been like to be the first cell on Earth? Pretend you are that first cell. Keep a written diary of your first week on Earth.