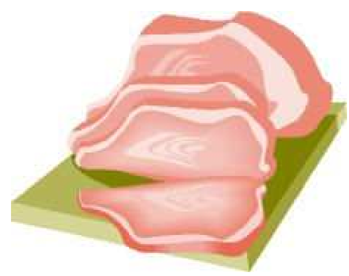
(Text from Modern Biology, Holt, Rinehart, and Winston)

Chapter Fourteen (Evolution)

SECTION ONE: BIOGENESIS

The principle of **biogenesis** states that all living things come from other living things. Even though this seems like common sense to people today, prior to the 17th century, it was widely thought that living things could arise from nonliving things in a process called **spontaneous generation**.

REDI'S EXPERIMENT



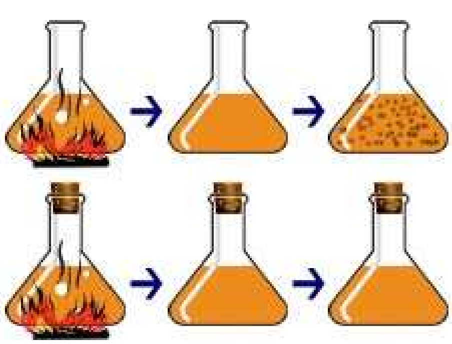
The Italian scientist Francesco Redi noticed and described the developmental forms of flies in the middle of the 17th century. He also observed that maggots appeared where adult flies had previously landed. These observations led him to question the commonly held belief that flies emerge from rotting meat.

He conducted an experiment to see whether meat kept away from adult flies would remain free of maggots. His experimental group consisted of netting-covered jars that contained meat. The control group consisted of uncovered jars of meat. After a few days, maggots were living in meat in the open jars, but the net-covered jars remained free of maggots, since adult flies could not land on the meat. His experiment showed that flies come only from eggs laid by other flies. When his hypothesis was confirmed, this was important proof against the hypothesis of spontaneous generation.

SPALLANZANI'S EXPERIMENT

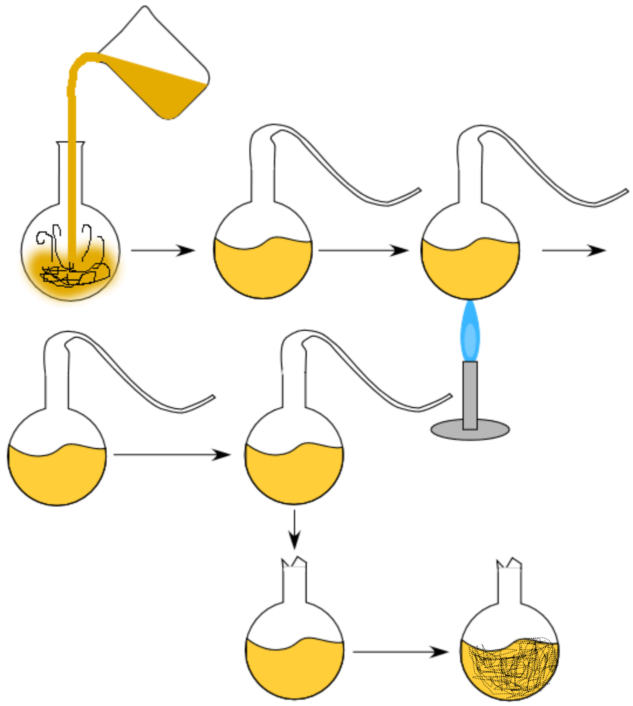
Scientists during the 1700s had just begun to observe the microscopic world using a microscope. They discovered that microorganisms are widespread, and concluded that the microorganisms arise spontaneously from a "vital force" in the air.

Lazzaro Spallanzani designed an experiment to test this hypothesis. He thought that microorganisms formed from other microorganisms, not from the air. He knew that microorganisms grew easily in food, such as broth. He reasoned that boiling broth in flask would kill all the microorganisms in the broth and flask.



For his experimental group, he boiled fresh broth until the flasks filled with steam, then sealing the flask. The control group flasks were left open. The broth in the sealed in the flask remained clear of microorganisms, while the broth in the open flasks became contaminated with microorganisms.

Spallanzani concluded that the boiled broth only became contaminated when microorganisms from the air entered the flask. His opponents disagreed, saying that Spallanzani destroyed the "vital force" in the flasks by heating them too long. Air lacking the "vital force," supposedly could not generate life.



PASTEUR'S EXPERIMENT

The Paris Academy of Science offered a prize to anyone who could clear up the issue of spontaneous generation in the mid-1800s. French scientist Louis Pasteur was the winner of the prize; his experiment disproved the hypothesis of spontaneous generation.

Pasteur made a curved-neck flask that allowed the air inside the flask to mix with air outside of the flask. The curve in the neck of the flask prevented microorganisms from entering the body of the flask. Broth boiled inside the experimental curve-necked flasks remained clear for up to a year. However, when Pasteur broke off the curved necks, the broth became cloudy with microorganisms within a day.

Pasteur's experiment prompted the principle of biogenesis to become a cornerstone of biology, as those who had previously believed in spontaneous generation of microorganisms gave up.

SECTION 1 REVIEW

1. What does the term *spontaneous generation* mean?
2. Explain how Redi's experiment disproved the hypothesis that flies formed in food by spontaneous generation.
3. What caused people to think the air contained a "vital force that produced living organisms?
4. Describe the argument that Spallanzani's experiment failed to disprove the occurrence of spontaneous generation. Explain how Pasteur's experiment addressed these concerns.

CRITICAL THINKING

5. Spallanzani and Pasteur both used a technique that is now widely used to preserve food. What was this technique?
6. What would have happened if Pasteur had tipped one of his flasks so that the broth in the flask had come into contact with the curve of the neck?
7. If spontaneous generation does not occur and the principle of biogenesis is true, what scientific question remains?

SECTION TWO: EARTH'S HISTORY

THE FORMATION OF EARTH

Evidence from computer models of the sun suggests that about 5 billion years ago, our solar system was a mass of gas and dust. Over time, most of this material was pulled together by gravity, forming the Sun.

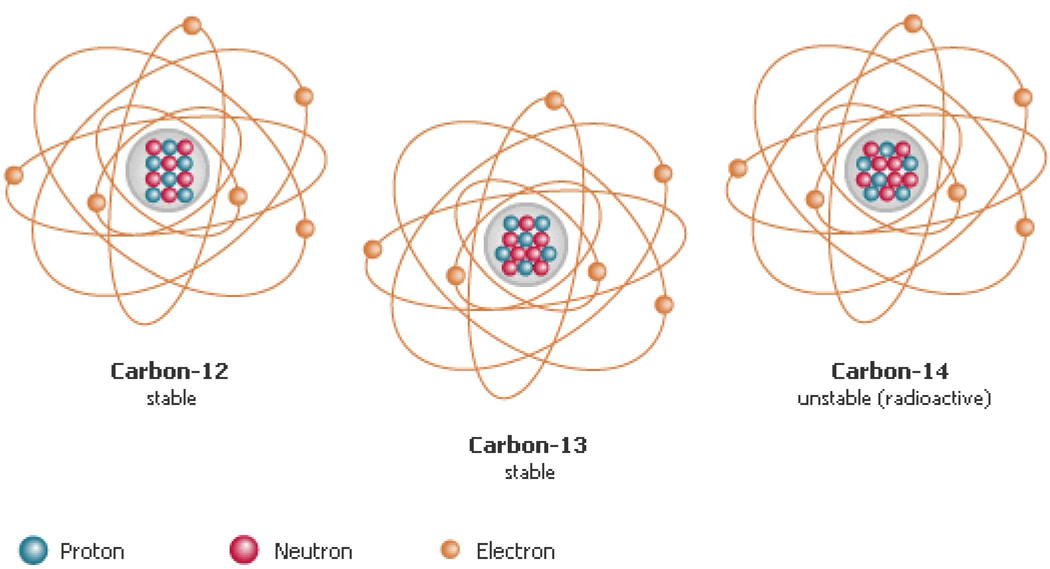
Earth's Age

The estimated age of Earth is about 700,000 times as long as the period of recorded history: more than 400 billion years old. By exploring Earth's surface and examining its layers, scientists have been able to establish a picture of Earth's geologic history. Early estimates of Earth's age were made from studying layers of sedimentary rocks in the crust. The age of Earth could not be estimated accurately until the middle of the twentieth century, when modern methods of dating the age of materials were developed.

Radiometric Dating

One of the methods of establishing the age of a material is **radiometric dating.** The atomic number of an element is the number of protons in the nucleus. All atoms of an element have the same atomic number, but their number of neutrons can vary. Atoms of the same element with differing numbers of neutrons are called **isotopes.**

The **mass number** of an isotope is the total number of protons and neutrons in the nucleus. The mass number of the most common carbon isotope is 12. Isotopes are designated by their chemical name followed by their mass number.



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Some isotopes have unstable nuclei, which undergo **radioactive decay**; their nuclei release particles and/or radiant energy until the nuclei become stable. Such isotopes are called **radioactive isotopes**. Rates of decay of radioactive isotopes have been determined for many isotopes. The length of time it takes for one half of any size sample of an isotope to decay to a stable form is called the **half-life** of the isotope.

The quantity of a particular radioactive isotope in a material can be measured to determine the material's age. For example, organic material can be dated by comparing the amount of carbon-14 to the amount of carbon-12 in it. After 5,730 years, half of the carbon-14 in a sample will have decayed.

By using a dating method based on the decay of uranium and thorium isotopes in rock crystals, scientists have estimated the Earth's age. Since collisions between the Earth's surface and large pieces of space debris probably caused the surface of the Earth to melt, the age of the oldest unmelted surface should be the time when these collisions stopped. The oldest known rocks and crystals are about 4 billion years old; scientists estimate that organic molecules began to accumulate during that time period.

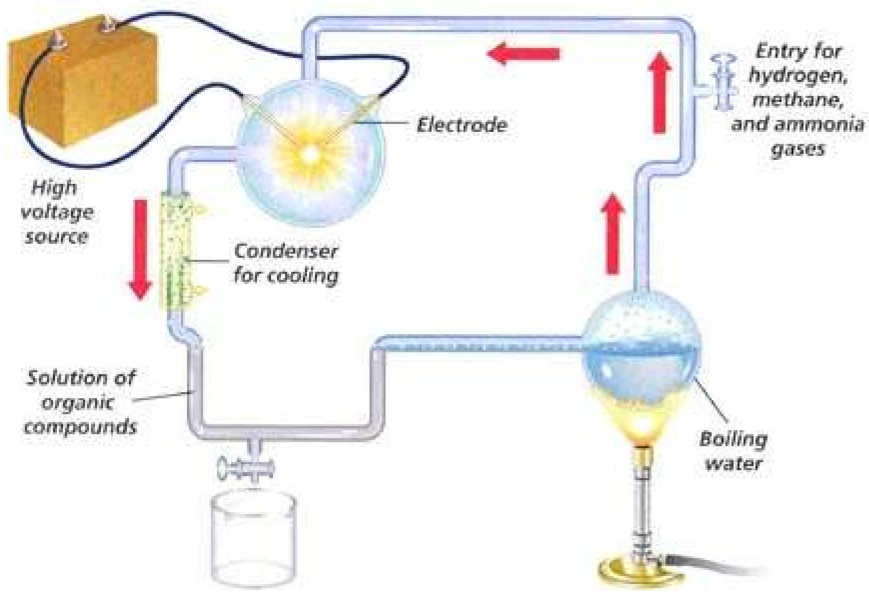
FIRST ORGANIC COMPOUNDS

All of the elements found in organic compounds are thought to have existed on Earth and in the rest of the solar system when the Earth formed. The mystery is: how and where were these elements assembled into organic compounds? Alexander Oparin and John Haldane proposed a hypothesis in the 1920s to explain the formation of organic compounds. They thought that the early atmosphere contained ammonia, hydrogen gas, water vapor, and compounds made of hydrogen and carbon, such as methane. According to Oparin, these gases might have formed simple organic compounds at high temperatures. When Earth cooled and water vapor condensed to form lakes and seas, the organic compounds would have collected in the water. Over time, these compounds could have entered complex chemical reactions fueled by ultraviolet radiation and lightning. He reasoned that such reactions would have resulted in macromolecules.

Synthesis of Organic Compounds

While Oparin and Haldane carefully developed their hypotheses, they did not perform experiments to test them. In 1953, graduate student Stanley Miller and professor Harold Urey, set up an experiment using Oparin's hypotheses as a starting point. Their apparatus included a chamber containing the gases Oparin assumed were present in the Earth's atmosphere. As the gases circulated in the chamber, electric sparks, substituting for lightning, supplied energy to drive chemical reactions. Their experiment, and other variations that have followed, produced a variety of organic compounds, including amino acids.

Figure 14.12 Miller and Urey's experiments showed that under the proposed conditions on early Earth, small organic molecules, such as amino acids, could form.



Scientists have been able to combine a variety of chemicals and energy sources to produce several assortments of organic compounds, including ATP and nucleotides. Furthermore, scientists have proposed new hypotheses about early Earth's atmosphere. One hypothesis holds that the atmosphere was composed largely of carbon dioxide, nitrogen, and water vapor. Laboratory simulations show that both carbon dioxide and oxygen gas interfere with the production of organic compounds. Therefore, the production of organic compounds may only have been possible in areas protected from the atmosphere.

Organic Compounds from Beyond Earth

Some scientists hypothesize that organic compounds could have been carried to Earth by debris from space. In 1970, organic compounds were found in a newly fallen meteorite, which is evidence that organic compounds could have accumulated on the surface of early Earth from meteorites.

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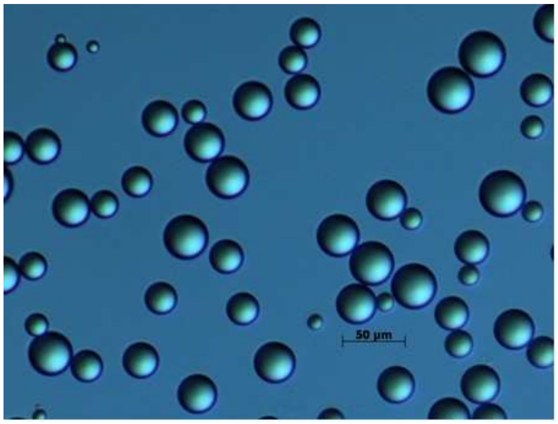
FROM MOLECULES TO CELL-LIKE STRUCTURES



Several scientists have done research on the physical structures that could have been the predecessors of the first cells. Cell-like structures that form spontaneously from solutions of simple organic compounds are **microspheres** (shown at left) and **coacervates**. Microspheres are spherical in shape and are composed of many protein molecules organized as a membrane. Coacervates are collections of droplets composed of molecules of different types.

It has been assumed for many years that all cell structures and the chemical reactions of life required enzymes made by genetic information in the cell. However, coacervates and microspheres are able to form spontaneously under certain conditions. Both can take up certain substances from their surroundings and grow. These properties show that the gap between nonliving chemical compounds and cellular life may not be as wide as previously thought.

However, microspheres and coacervates do not have all of the properties of life, such as hereditary characteristics.

SECTION 2 REVIEW

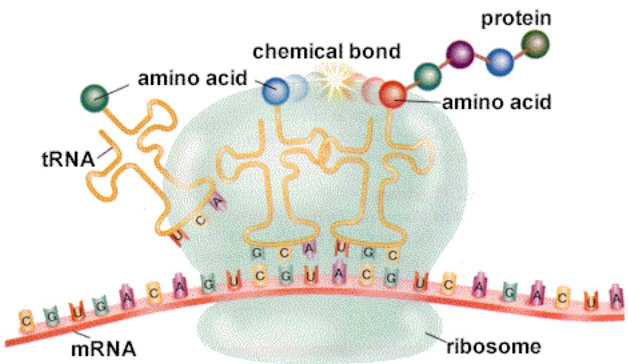
1. Outline the major steps in the formation of Earth, as reconstructed by modern scientists.
2. If 1.0 g of a radioactive isotope had a half-life of 1 billion years, how much of it would be left after each of the following intervals of time: 1 billion years, 2 billion years, 3 billion years, and 4 billion years?
3. What are two possible sources of simple organic compounds on early Earth?
4. What properties to microspheres and coacervates share with cells?

CRITICAL THINKING

5. Which parts of Oparin's hypothesis were tested by the Miller-Urey experiment? Which parts were not tested?
6. Some radioactive isotopes used in medicine have half-lives of a few years. Would these isotopes be useful in dating rocks? Why or why not?
7. Form your own hypothesis about a stage in the formation or development of early life on Earth. Describe how scientists might tests this hypothesis.

SECTION THREE: THE FIRST LIFE-FORMS

THE ORIGIN OF HEREDITY



The clues to a more complete understanding of RNA function may be found in its structure. RNA molecules take on a greater variety of shapes that DNA molecules do. The different shapes are dictated by hydrogen bonds between particular nucleotides in an RNA molecule. Some RNA molecules might even behave like proteins to catalyze chemical reactions.

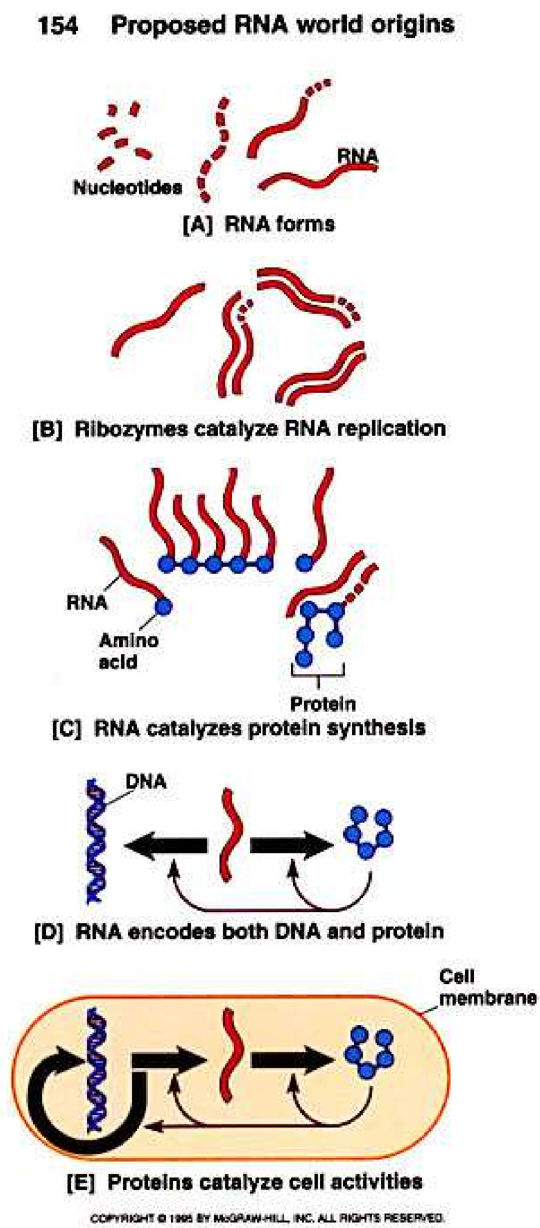
THE ROLES OF RNA

Research Thomas Cech found that a type of RNA in some unicellular eukaryotes is able to act as a chemical catalyst, similar to the way an enzyme acts. He used the term **ribozymes** for an RNA molecule that can act as a catalyst and promote a specific chemical reaction.

Later studies showed that ribozymes could act as catalysts for their own replication. Self-replicating systems of RNA molecules have been created in the laboratory, which support the hypothesis that life could have started with self-replicating molecules of RNA.

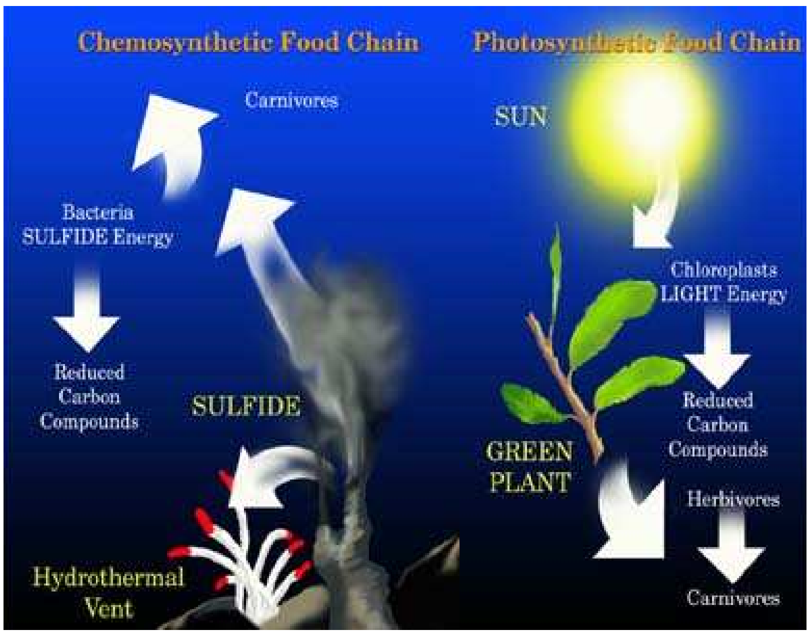
Furthermore, other roles for RNA have been discovered. RNA has an important role in DNA replication, protein synthesis, and other basic biochemistry. The model of the beginning of life on earth that is based on RNA is called the *RNA world*.

Self-replicating RNA might also have been the first case of competition, as different types of RNA may have competed with each other for a limited number of available nucleotides. There are several hypotheses about how RNA or other simple replicating systems could have evolved into modern cellular life.



THE FIRST CELLS

Scientists can makes some inferences about the first cells based on some information: 1) little or no oxygen gas was present on early Earth, 2) The oldest fossils are thought to be cells with the size and shape of some living prokaryotes, and 3) The first cells might have developed in an environment filled with organic molecules for food. Thus, the first cells were probably anaerobic, heterotrophic prokaryotes.

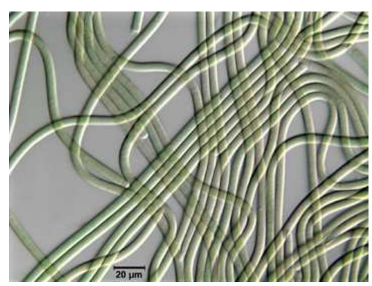


Chemosynthesis

The **Archaea** are a related group of unicellular organisms that may be similar to early prokaryotic life. Many species are autotrophs that obtain energy through **chemosynthesis**, the process in which carbon dioxide serves as a carbon source for the assembly of organic molecules. Energy is obtained from the oxidation of inorganic substances such as sulfur.

Photosynthesis and Aerobic Respiration

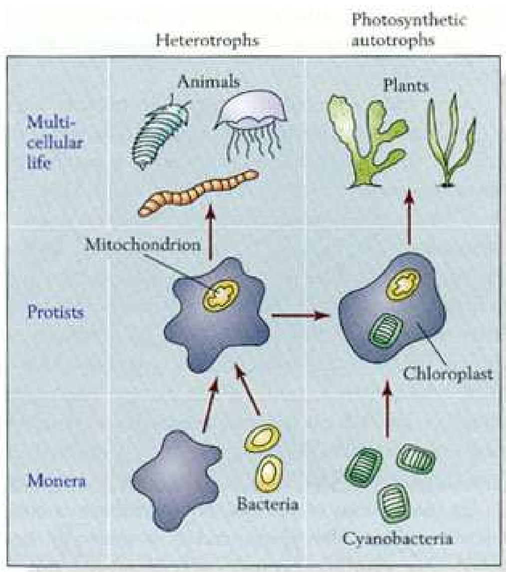
Some forms of life had become photosynthetic by 3 billion years ago. Scientists infer this from a variety of geologic evidence. Most of the oldest known fossils of cells are similar to modern **cyanobacteria**, a group of photosynthetic, unicellular prokaryotes. *Lynbgya*, a genus of modern cyanobacteria, is shown at right.



Oxygen, a byproduct of photosynthesis, was damaging to many early unicellular organisms. Oxygen could destroy many coenzymes essential to cell function. Within some organisms, oxygen bonded to other compounds, preventing the oxygen from doing damage. This bonding was one of the first steps in aerobic respiration. An early function of aerobic respiration may have been to prevent the destruction of essential organic compounds by oxygen.

Once oxygen gas levels reached the upper part of the atmosphere, it was bombarded with sunlight. As oxygen split apart and oxygen atoms sometimes merged with others, **ozone** was created. The ozone layer protected against ultraviolet radiation, which is harmful to DNA.

THE FIRST EUKARYOTES



Lynn Margulis proposed that early prokaryotic cells may have developed a mutually beneficial relationship. The theory of **endosymbiosis** suggests that a type of small aerobic prokaryote was engulfed into a larger anaerobic prokaryote. The eukaryotes provided a beneficial environment while the prokaryotes provided a method of energy synthesis.

Scientists think endosymbiotic aerobic prokaryotes evolved into mitochondria, which perform aerobic respiration in modern cells. In a later case of endosymbiosis, photosynthetic bacteria may have evolved into chloroplasts.

Evidence such as the fact that mitochondria and chloroplasts contain their own DNA supports the theory of endosymbiosis. Mitochondria and chloroplasts also replicate independently from the replication cycle of the cell that contains them. The DNA of mitochondria and chloroplasts is also circular – a characteristic of prokaryotic cells.

SECTION 3 REVIEW

1. How does RNA differ from DNA?
2. Describe three major scientific inferences about the first living cells on Earth.
3. What traits make archaebacteria likely relatives of Earth's earliest organisms?
4. Explain the difference between chemosynthesis and photosynthesis.
5. Explain the theory of endosymbiosis.

CRITICAL THINKING

6. What evidence supports the hypothesis that mitochondria were once free-living prokaryotic cells?
7. How did anaerobic cells influence the development of aerobic cells?
8. Some forms of air pollution reduce the thickness of Earth's ozone layer. How might this change affect modern life?

CHAPTER HIGHLIGHTS

Section 1: Biogenesis

- Before the 1600s, it was generally thought that organisms could arise from nonliving material by spontaneous generation.

- Redi showed in 1668 that rotting meat kept away from flies would not produce new flies. Maggots appeared only on meat that had been exposed to flies.
- Spallanzani showed in the 1700s that microorganisms would not grow in broth when its container was heated then sealed. He inferred that microorganisms do not arise spontaneously but, rather, are carried in the air.
- Pasteur in the 1800s used a variation of Spallanzani's design to prove that microorganisms are carried in the air and do not arise by spontaneous generation.

Section 2: Earth's History

- Scientists think that Earth formed by he gravitational accumulation of dust and debris moving through space.
- Isotopes are atoms with varying numbers of neutrons. The ages of rocks and other materials can be determined by measuring the amount of radioactive decay that has occurred in radioactive isotopes found in samples of those materials. An isotope's half-life is the time that one-half of a sample of the isotope takes to decay.
- The first simple organic compounds on early Earth may have formed under conditions of high energy and in an atmosphere very different from that of today's Earth.
- Meteorites may have brought organic compounds to Earth.
- Further chemical reactions may have converted simple organic compounds into the macromolecules important to life. Lightning, ultraviolet radiation, or heat from within the Earth could have provided the energy for these reactions. These conditions have been experimentally modeled.
- Cell-like structures, including microspheres and coacervates, form spontaneously in certain kinds of solutions. These structures could have been a step in the formation of modern cells but lack hereditary material.
- Scientists continue to investigate many hypotheses about the origins of organic molecules and cells in Earth's history.

Section 3: The First Life-Forms

- In addition to serving as a template for protein assembly, some RNA molecules can at as enzymes. Like proteins, RNA molecules can assume different shapes. These shapes depend on areas of attraction between the RNA nucleotides. For these reasons, the first molecule that held hereditary information may have been RNA rather than DNA.
- The first cells that formed on Earth were probably heterotrophic prokaryotes.
- The first autotrophic cells probably used chemosynthesis to make food. Chemosynthesis produces energy through the oxidation of inorganic substances.
- Most modern autotrophic cells use photosynthesis to make food. An important byproduct of photosynthesis is oxygen.
- Once oxygen began to accumulate on Earth, cells would need to bind oxygen to other compounds in order to prevent damage to cell enzymes. This binding function may have been a first step toward aerobic respiration in cells.
- Eukaryotic cells may have evolved form large prokaryotic cells that engulfed smaller prokaryotic cells. The engulfed prokaryotic cells may have become the ancestors of organelles such as mitochondria and chloroplasts.