Molten rock breaks through Earth’s crust in the form of a volcano. Conditions in a volcano are similar to those thought to have been present on early Earth.

SECTION 1  Biogenesis

SECTION 2  Earth’s History

SECTION 3  The First Life-Forms
Biogenesis

The principle of biogenesis (BIE-oh-JEN-uh-sis), which states that all living things come from other living things, seems very reasonable to us today. Before the seventeenth century, however, it was widely thought that living things could also arise from nonliving things in a process called spontaneous generation. This seemed to explain why maggots appeared on rotting meat and why fish appeared in ponds that had been dry the previous season—people thought mud might have given rise to the fish. In attempting to learn more about the process of spontaneous generation, scientists performed controlled experiments. As you read about these experiments, refer to the figures that show the experimental design.

Redi’s Experiment

Flies have often been viewed as pesky creatures. Most people are too busy trying to get rid of flies to even think about studying them. In the middle of the 17th century, however, the Italian scientist Francesco Redi (1626–1697) noticed and described the different developmental forms of flies. Redi observed that tiny wormlike maggots turned into sturdy oval cases, from which flies eventually emerge. He also observed that maggots seemed to appear where adult flies had previously landed.

These observations led Redi to question the commonly held belief that flies were generated spontaneously from rotting meat. Figure 14-1 shows an experiment that Redi conducted in 1668 to test his hypothesis that meat kept away from adult flies would remain free of maggots.

Figure 14-1
In Redi’s experiment, maggots were found only in the control jars because that was the only place where adult flies could reach the meat to lay eggs.
Redi’s experimental group consisted of netting-covered jars that contained meat. The control group consisted of uncovered jars that also contained meat. The netting allowed air to enter and prevented flies from landing on the meat. After a few days, maggots were living in the meat in the open jars, but the net-covered jars remained free of maggots. Redi’s experiment showed convincingly that flies come only from eggs laid by other flies. Redi’s hypothesis was confirmed, and a major blow was struck against the hypothesis of spontaneous generation.

**SPALLANZANI’S EXPERIMENT**

At about the same time that Redi carried out his experiment, other scientists began using a new tool—the microscope. Their observations with the microscope revealed that the world is teeming with tiny creatures. They discovered that microorganisms are simple in structure and amazingly numerous and widespread. Many investigators at the time thus concluded that microorganisms arise spontaneously from a “vital force” in the air.

In the 1700s, another Italian scientist, Lazzaro Spallanzani (1729–1799), designed an experiment to test the hypothesis of spontaneous generation of microorganisms, as shown in Figure 14-2. Spallanzani hypothesized that microorganisms formed not from air but from other microorganisms. He knew that microorganisms grew easily in food, such as broth made from boiled meat. Spallanzani reasoned that boiling broth in a flask would kill all the microorganisms in the broth, on the inside of the glass, and in the air in the flask. For his experimental group, Spallanzani boiled clear, fresh broth until the flasks filled with steam. While the broth was hot, he sealed the flasks by melting their glass necks. The control-group flasks of broth were left open. The broth in the sealed flasks remained clear and free of microorganisms, while the broth in the open flasks became cloudy because it was contaminated with microorganisms.

Spallanzani concluded that the boiled broth became contaminated only when microorganisms from the air entered the flask. Spallanzani’s opponents, however, objected to his method and disagreed with his conclusions. They claimed that Spallanzani had heated the experimental flasks too long, destroying the “vital force” in the air inside them. Air lacking this “vital force,” they claimed, could not generate life. Thus, those who believed in spontaneous generation of microorganisms kept the idea alive for another century.
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 criticisms.

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**CRITICAL THINKING**

5. **Making Comparisons** Spallanzani and Pasteur both used a technique that is now widely used to preserve food. What was this technique?

6. **Analyzing Methods** 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. **Analyzing Ideas** If spontaneous generation does not occur and the principle of biogenesis is true, what scientific question remains?
If spontaneous generation does not happen on Earth today, then the question remains: How did cell-based life arise in the first place? The key to answering this question lies in scientific hypotheses that conditions on early Earth were very different from present conditions. Scientists continue to form and test these hypotheses by modeling conditions and processes that could have given rise to the first cellular life on Earth.

THE FORMATION OF EARTH

Evidence from computer models of the sun suggests that about 5 billion years ago, our solar system was a swirling mass of gas and dust, as shown in Figure 14-4. Over time, most of this material was pulled together by gravity and formed the sun. The remaining gas, dust, and debris circled the young sun. Scientists think that the planets formed through repeated collisions of this space debris. During a 400 million–year period, Earth grew larger as gravity pulled in more debris. The collisions between Earth and space debris also released a great deal of thermal energy. Some collisions would have released enough energy to melt large portions of Earth’s surface.

Earth’s Age

The estimated age of Earth, more than 4 billion years, is about 700,000 times as long as the period of recorded history. It is about 50 million times as long as an average human life span. How can we determine what happened so long ago? Scientists have explored Earth’s surface and examined its many layers to establish a fairly complete picture of its geologic history. Early estimates of Earth’s age were made from studying layers of sedimentary rock in Earth’s crust. The age of Earth could not be estimated accurately, however, until the middle of the twentieth century, when modern methods of establishing the age of materials were developed.

Radiometric Dating

Methods of establishing the age of materials include the techniques known as radiometric dating. Recall that 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 that differ in the number of neutrons they contain are called isotopes (IE-suH-TOHPs). Most elements have several 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. If you recall that the atomic number of carbon is 6, you can calculate that this carbon isotope has six protons and six neutrons. Isotopes are designated by their chemical name followed by their mass number; for example, carbon exists as both carbon-12 and carbon-14.

Some isotopes have unstable nuclei, which undergo **radioactive decay**; that is, their nuclei release particles or radiant energy, or both, 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. Depending on the isotope, half-lives vary from a fraction of a second to billions of years.

The quantity of a particular radioactive isotope in a material can be measured to determine the material’s age. This amount is compared with that of some other substance whose quantity in the material remains constant over time. For example, organic materials can be dated by comparing the amount of carbon-14, a radioactive isotope, with the amount of carbon-12, a stable isotope. Living things take carbon into their bodies constantly. Most of the carbon is in the form of carbon-12. A very small proportion of it, however, is in the form of carbon-14, which undergoes decay. This ratio of carbon-14 to carbon-12 is a known quantity for living organisms.
When an organism dies, its uptake of carbon stops, and decay of the existing carbon-14 continues. Thus, over time, the amount of carbon-14 declines with respect to the original amount of the stable carbon-12. After 5,730 years, half of the carbon-14 in a sample will have decayed. After another 5,730 years, half of the remaining carbon-14 in the sample likewise will have decayed. Use of carbon-14 dating is limited to organic remains less than about 60,000 years old, such as the leather quiver and wooden bow and arrows shown in Figure 14-5. Isotopes with longer half-lives are used to date older rocks.

Radioactive isotopes occur naturally in all matter. Some of the isotopes commonly used in radiometric dating procedures appear in Table 14-1. Radiometric dating is accurate within certain limits. The techniques depend on making careful measurements and obtaining samples that are uncontaminated with more recent material. Scientists compare several types of independent measurements to determine a range of plausible dates.

Scientists have estimated Earth’s age by using a dating method that is based on the decay of uranium and thorium isotopes in rock crystals. Collisions between Earth and large pieces of space debris probably caused the surface of Earth to melt many times as the planet was formed. Therefore, the age of the oldest unmelted surface rock should tell us when these collisions stopped and the cooling of Earth’s surface began. The oldest known rocks and crystals are about 4 billion years old. So, scientists infer that organic molecules began to accumulate about 4 billion years ago.

**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. But how and where were these elements assembled into organic compounds? An important hypothesis to solve this puzzle was proposed in the 1920s by two scientists: Soviet Alexander I. Oparin (1894–1980) and American John B. S. Haldane (1892–1964). They thought that the early atmosphere contained ammonia, \( \text{NH}_3 \); hydrogen gas, \( \text{H}_2 \); water vapor, \( \text{H}_2\text{O} \); and compounds made of hydrogen and carbon, such as methane, \( \text{CH}_4 \).
According to Oparin, at high temperatures, these gases might have formed simple organic compounds, such as amino acids. When Earth cooled and water vapor condensed to form lakes and seas, these simple organic compounds would have collected in the water. Over time, these compounds could have entered complex chemical reactions, fueled by energy from lightning and ultraviolet radiation. These reactions, Oparin reasoned, ultimately would have resulted in the macromolecules essential to life, such as proteins.

**Synthesis of Organic Compounds**

Oparin carefully developed his hypotheses, but he did not perform experiments to test them. So, in 1953, an American graduate student, Stanley L. Miller (1930–), and his professor, Harold C. Urey (1893–1981), set up an experiment using Oparin’s hypotheses as a starting point. Their apparatus, illustrated in Figure 14-6, included a chamber containing the gases Oparin assumed were present in the young Earth’s atmosphere. As the gases circulated in the chamber, electric sparks, substituting for lightning, supplied energy to drive chemical reactions. The Miller-Urey experiment, and other variations that have followed, produced a variety of organic compounds, including amino acids.

Since the 1950s, scientists have used similar experiments to test and revise hypotheses about the origin of simple organic compounds. In such experiments, scientists have combined a variety of chemicals and energy sources to produce an assortment of organic compounds, including amino acids, ATP, and nucleotides. Scientists are convinced that basic organic compounds could have formed on early Earth in many ways.

Furthermore, scientists who study planet formation have proposed new hypotheses about early Earth’s atmosphere. For example, one hypothesis holds that the atmosphere of early Earth was composed largely of carbon dioxide, \( \text{CO}_2 \); nitrogen, \( \text{N}_2 \); and water vapor, \( \text{H}_2\text{O} \). Laboratory simulations of these atmospheric conditions have shown that both carbon dioxide and oxygen gas interfere with the production of organic compounds. Therefore, the production of organic compounds might only have been possible in areas protected from the atmosphere, such as those that exist in undersea hot springs.

**Organic Compounds from Beyond Earth**

Some scientists hypothesize that organic compounds could have been carried to Earth by debris from space. In 1970, a broad mixture of organic compounds was found in a newly fallen meteorite. Because the meteorite was recovered before it was contaminated with organic compounds from Earth, these compounds must have formed in space. So, organic compounds from space could have accumulated on the surface of early Earth.
CHAPTER 14

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 do microspheres and coacervates share with cells?

CRITICAL THINKING

5. Evaluating Conclusions Which parts of Oparin’s hypothesis were tested by the Miller-Urey experiment? Which parts were not tested?

6. Making Inferences Some radioactive isotopes that are used in medicine have half-lives of a few years. Would these isotopes also be useful in dating rocks? Why or why not?

7. Designing an Experiment Form your own hypothesis about a stage in the formation or development of early life on Earth. Describe how scientists might test this hypothesis.

SECTION 2 REVIEW

FROM MOLECULES TO CELL-LIKE STRUCTURES

Sidney Fox (1912–1998) and others have done extensive research on the physical structures that may have given rise to the first cells. These cell-like structures, such as the ones shown in Figure 14-7, form spontaneously in the laboratory from solutions of simple organic chemicals. The structures include microspheres, which are spherical in shape and are composed of many protein molecules that are organized as a membrane, and coacervates (coh-AS-uhr-VAYTS), which are collections of droplets that are composed of molecules of different types, including lipids, amino acids and sugars.

For many years, it had been assumed that all cell structures and the chemical reactions of life required enzymes that were specified by the genetic information of the cell. Both coacervates and microspheres, however, can form spontaneously under certain conditions. For example, the polymers that form microspheres can arise when solutions of simple organic chemicals are dripped onto the surface of hot clay. The heat vaporizes the water, encouraging polymerization. Coacervates and microspheres have a number of cell-like properties, including the ability to take up certain substances from their surroundings. Coacervates can grow, and microspheres can bud to form smaller microspheres. These properties of coacervates and microspheres show that some important aspects of cellular life can arise without direction from genes. Thus, these studies suggest that the gap between the nonliving chemical compounds and cellular life may not be quite as wide as previously thought.

However, microspheres and coacervates do not have all of the properties of life. These cell-like structures do not have hereditary characteristics. Thus, these structures cannot respond to natural selection. Scientists are still investigating hypotheses about how living cells may have formed from simpler ingredients.

FIGURE 14-7

Membrane-bound structures, such as these, have been formed in the laboratory under conditions that may have existed on early Earth. Structures such as these may have enclosed replicating molecules of RNA and may have been the forerunners of the first cells.
The First Life-Forms

Scientists continue to investigate many competing hypotheses about possible transitions from simple organic molecules to cellular life. A critical part of each such hypothesis is to explain how molecules could be organized into self-replicating systems, in other words, to explain the origin of heredity.

The Origin of Heredity

Chapter 10 provides a detailed explanation of how hereditary information affects the phenotype of cells. Recall that the hereditary information contained in a DNA molecule is first transcribed into an RNA message, and then the RNA message is translated into a protein, as shown in Figure 14-8. Thus, DNA serves as the template for RNA, which in turn serves as the template for specific proteins.

In recent years, scientists have taken a closer look at the DNA-RNA-protein sequence. Why is RNA necessary for this process? Why doesn't DNA, which is a template itself, carry out protein synthesis directly? 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 than DNA molecules do. An example is the unique shape of transfer RNA, shown in Figure 14-8. These shapes are dictated by hydrogen bonds between particular nucleotides in an RNA molecule, much as the shapes of proteins depend on hydrogen bonds between particular amino acids. These questions and observations led to the speculation that some RNA molecules might actually behave like proteins and catalyze chemical reactions.

Figure 14-8

Messenger RNA is transcribed from a DNA template. Transfer RNA translates the three-base codons in the mRNA, assembling a protein from the specified amino acids.
CHAPTER 14

THE ROLES OF RNA

In the early 1980s, researcher Thomas Cech (1947–) found that a type of RNA found in some unicellular eukaryotes is able to act as a chemical catalyst, similar to the way an enzyme acts. Cech used the term ribozyme (RIE-buh-ZIEM) for an RNA molecule that can act as a catalyst and promote a specific chemical reaction.

Later studies based on Cech’s discovery indicated that ribozymes could act as catalysts for their own replication. In fact, self-replicating systems of RNA molecules have been created in the laboratory. These findings support the hypothesis that life could have started with self-replicating molecules of RNA.

Furthermore, other roles for RNA have been discovered. RNA plays a vital role in DNA replication, protein synthesis, and other basic biochemistry. Perhaps most or all of the chemistry and genetics of early cells were based on RNA. This model of the beginnings of life on Earth is sometimes called the RNA world.

Self-replicating RNA molecules might have been not only the first case of heredity but also the first case of competition. For an RNA molecule, self-replication might involve competing with other RNA molecules for a limited number of available nucleotides. A particular RNA molecule with a slightly different structure than other RNA molecules might be more successful in getting nucleotides from its environment and thus more likely to be replicated. Thus, over time, the more-efficient RNA molecules would “survive,” and the “world” of RNA would slowly change.

There are several competing hypotheses about how RNA or other simple replicating systems could have evolved into modern cellular life. Some hypotheses propose that certain kinds of minerals formed a template on which organic molecules could line up and form polymers. Another hypothesis is that self-replicating RNA started to evolve inside cell-like structures such as microspheres or coacervates. The self-replicating RNA could have provided the hereditary information that the cell-like structures lack. If the RNA molecules were able to direct the assembly of the structures that carried them, a cell-like system would be formed.

THE FIRST CELLS

Although lacking direct evidence of the first cells, scientists can make some inferences. First, many scientists think that little or no oxygen gas existed on early Earth. Second, the oldest fossils that are thought to be cells are the size and shape of some living prokaryotes. Finally, the first cells might have developed in an environment filled with organic molecules for food. Thus, the first cells were probably anaerobic, heterotrophic prokaryotes.
We can reason that a growing population of heterotrophs that depended on spontaneously formed organic molecules for food eventually would have removed most of these molecules from the environment. At this point, autotrophs would have begun to have an advantage. The first autotrophs, however, probably did not depend on photosynthesis the way that most autotrophs do today.

**Chemosynthesis**

If we look for living organisms that may be similar to these early organisms, we find the archaea (ahr-KEE-uh). The archaea are a related group of unicellular organisms, many of which thrive under extremely harsh environmental conditions. Methanosarcina barkeri, the archaea shown in Figure 14-9, lives in anaerobic environments. Many species of archaea are autotrophs that obtain energy by chemosynthesis (KEE-moh-SIN-thuh-sis) instead of photosynthesis. In the process of chemosynthesis, CO$_2$ serves as a carbon source for the assembly of organic molecules. Energy is obtained from the oxidation of various 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, such as the chemical traces of photosynthetic activity. Also, most of the oldest known fossils of cells are similar to modern cyanobacteria (SIH-uh-no-bak-TIR-ee-uh)—a group of photosynthetic, unicellular prokaryotes. Lynbgya, a genus of modern cyanobacteria, is shown in Figure 14-10a. Lynbgya cells often grow in colonies and form layered structures called stromatolites, shown in Figure 14-10b. Fossils of stromatolites as old as 3.5 billion years are known.

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

Many scientists think that it took a billion years or more for oxygen gas levels to reach today’s levels. The oxygen gas, O$_2$, eventually reached the upper part of the atmosphere, where it was bombarded with sunlight. Some wavelengths of sunlight can split O$_2$ to form highly reactive single oxygen atoms, O. These O atoms react with O$_2$ and form ozone, O$_3$. Ozone is poisonous to both plant and animal life, but in the upper atmosphere, a layer of ozone absorbs much of the ultraviolet radiation from the sun. Ultraviolet radiation damages DNA, and without the protection of the ozone layer, life could not have come to exist on land.
THE FIRST EUKARYOTES

Recall that eukaryotic cells differ from prokaryotic cells in several ways. Eukaryotic cells are larger, their DNA is organized into chromosomes in a cell nucleus, and they contain membrane-bound organelles. How did eukaryotic cells evolve? Researcher Lynn Margulis (1938–) proposed that early prokaryotic cells may have developed a mutually beneficial relationship. A large body of evidence suggests that between about 2.0 billion and 1.5 billion years ago, a type of small aerobic prokaryote was engulfed by and began to live and reproduce inside of a larger, anaerobic prokaryote. This theory is called endosymbiosis (EN-duh-SIM-bee-oh-sis) and is modeled in Figure 14-11. The eukaryotes provided a beneficial environment, and the prokaryotes provided a method of energy synthesis.

Scientists infer that endosymbiotic aerobic prokaryotes evolved into modern mitochondria, which perform aerobic respiration in eukaryotic cells. In a later case of endosymbiosis, photosynthetic cyanobacteria may have evolved into chloroplasts, which perform photosynthesis in modern eukaryotic plant and algae cells. There is compelling evidence to support these hypotheses for the origin of these organelles. Both chloroplasts and mitochondria replicate independently from the replication cycle of the cell that contains them. Moreover, chloroplasts and mitochondria contain some of their own genetic material, which differs from that of the rest of the cell. Finally, the DNA of these organelles is found in a circular arrangement that is characteristic of prokaryotic cells.

Word Roots and Origins

**endosymbiosis**

from the Greek *endon*, meaning “within,” *syn* meaning “together,” and *biosis*, meaning “way of 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 and 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.

Vocabulary

<table>
<thead>
<tr>
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<tr>
<td>biogenesis</td>
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<td>spontaneous generation</td>
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SECTION 2  Earth’s History

- Scientists think that Earth formed by the 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.

Vocabulary

<table>
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<td>radiometric dating</td>
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<td>microsphere</td>
<td>286</td>
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<td>coacervate</td>
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SECTION 3  The First Life-Forms

- In addition to serving as a template for protein assembly, some RNA molecules can act 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 from large prokaryotic cells that engulfed smaller prokaryotic cells. The engulfed prokaryotic cells may have become the ancestors of organelles such as mitochondria and chloroplasts.

Vocabulary

<table>
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<td>endosymbiosis</td>
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**Using Vocabulary**

1. For each of the following pairs of terms, explain how the meanings of the terms differ.
   a. biogenesis and spontaneous generation
   b. ribozyme and enzyme
   c. photosynthesis and chemosynthesis
   d. archaeobacteria and cyanobacteria

2. Explain the relationships between radioactive decay, isotopes, and half-life.

3. _____ and ____ are examples of nonliving, cell-like structures that can form in certain solutions.

4. **Word Roots and Origins** The word biogenesis is derived from the Greek word gignesthai, which means “origin.” The prefix bio means “to be born.” Using this information, explain how the meaning of biogenesis relates to this chapter.

**Understanding Key Concepts**

5. **Predict** what would have happened if Redi had used jars covered with netting that had very large openings in his experiment.

6. **Evaluate** Spallanzani’s experiment, and explain why his results did not conclusively disprove the theory of spontaneous generation.

7. **Describe** Pasteur’s experiment, and explain how it disproved spontaneous generation.

8. **Relate** the role of gravity to the early formation of Earth.

9. **Calculate** the age of a sample containing thorium-230 (whose half-life is 75,000 years) after three-fourths of the sample has decayed.

10. **Identify** the natural phenomenon that the electric spark in the Miller-Urey experiment was intended to model.

11. **Compare** the hypothesis tested in the Miller-Urey experiment with subsequent hypotheses about the conditions under which life may have first formed on Earth.

12. **Compare** microspheres and coacervates with modern, living cells.

13. **Explain** why many scientists who investigate the origin of life have focused on RNA chemistry.

14. **Describe** a hypothesis about the role of RNA in the original development of cells on early Earth.

15. **Identify** which modern organisms are thought to be most like the first forms of life on Earth.

16. **Infer** which environmental factors would probably favor the evolution of autotrophs.

17. **List** and describe two types of autotrophs. State how each makes its own food.

18. **Describe** the conditions under which the ability to bind oxygen gas is an advantage to a cell.

19. **Explain** how the formation of the ozone layer permitted organisms to colonize land.

20. **Explain** the theory of endosymbiosis.

21. **CONCEPT MAPPING** Use the following terms to create a concept map illustrating the theory of endosymbiosis: anaerobic prokaryotes, eukaryotes, cyanobacteria, aerobic prokaryotes, endosymbiosis, mitochondria, and chloroplasts.

**Critical Thinking**

22. **Comparing Concepts** How does the principle of biogenesis pose a scientific question regarding the origin of life on Earth?

23. **Evaluating Conclusions** People once believed fish could form from the mud in a pond that sometimes dried up. How could you demonstrate that this conclusion is false?

24. **Evaluating Methods** Why did the Miller-Urey experiment not include oxygen gas, $O_2$, in the mixture of gases simulating Earth’s first atmosphere?

25. **Interpreting Graphics** The apparatus shown below is an example of the Miller-Urey experiment modeling conditions on early Earth. Explain the function of each part of the apparatus.
DIRECTIONS: Choose the letter that best answers the question.

1. In the 17th and 18th centuries, which of the following was the hypothesis of spontaneous generation used to explain?
   A. how new life started
   B. how eukaryotes evolved
   C. how simple organic compounds formed
   D. how coacervates and microspheres formed

2. Coacervates are similar to cells but lack which of the following?
   F. genetic information
   G. interior fluid
   H. complex organic molecules
   J. the chemical properties of cells

3. The planets of our solar system gained mass for a half-billion years after their formation as a result of which of the following?
   A. flames from the sun
   B. collisions with space debris
   C. tidal forces generated by moons
   D. the synthesis of organic molecules

INTERPRETING GRAPHICS: Use the graph below to answer the question that follows.

4. If the half-life of carbon-14 is 5,730 years, how many years would it take for \( \frac{1}{16} \) of the original amount of carbon-14 in a sample to decay?
   F. 5,014 years
   G. 11,460 years
   H. 17,190 years
   J. 22,920 years

DIRECTIONS: Complete the following analogy.

5. chloroplasts : cyanobacteria :: mitochondria :
   A. archaea
   B. aerobic prokaryotes
   C. anaerobic eukaryotes
   D. chemosynthetic bacteria

INTERPRETING GRAPHICS: Use the table below to answer the questions that follow.

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<thead>
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<th>Estimated Abundance of Some Elements on Earth and in Meteorites</th>
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<tbody>
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<td><strong>Element</strong></td>
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<tr>
<td>Iron</td>
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<tr>
<td>Oxygen</td>
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<tr>
<td>Magnesium</td>
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<tr>
<td>Silicon</td>
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<td>Sulfur</td>
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6. According to the table, which element is found on Earth in a greater abundance than the element’s abundance in meteorites?
   F. iron
   G. sulphur
   H. oxygen
   J. magnesium

7. If this table is typical of the relative abundance of all elements on Earth, in meteorites, and on other planets, which of the following statements would be supported?
   A. Earth and meteorites have similar origins.
   B. Earth and meteorites have different origins.
   C. All meteorites formed from parts of Earth.
   D. All elements on Earth come from meteorites.

SHORT RESPONSE

Describe the prevailing scientific model of the original formation of Earth.

EXTENDED RESPONSE

Little direct evidence has been found of any life that existed in the first few billion years of Earth’s history.

Part A  Describe the major steps that may have led to the development of eukaryotic organisms.

Part B  Describe evidence that supports hypotheses about some of these steps.

Test TIP  For short-response and essay questions, be sure to answer the prompt as fully as possible. Include major steps, important facts, descriptive examples, and supporting details in your response.
Making Microspheres

OBJECTIVES

- Make microspheres from amino acids by simulating the conditions found on early Earth.
- Compare the structure of microspheres with the structure of living cells.

PROCESS SKILLS

- observing
- comparing and contrasting
- modeling
- relating

MATERIALS

- safety goggles
- lab apron
- heat-protective gloves
- 500 mL beaker
- hot plate
- 125 mL Erlenmeyer flasks, 2
- ring stand with clamp
- balance
- amino acid mixture (supplied by your teacher)
- glass stirring rod
- tongs
- clock or timer
- 1% sodium chloride (NaCl) solution
- 50 mL graduated cylinder
- dropper
- microscope slide
- coverslip
- compound light microscope
- 1% sodium hydroxide (NaOH) solution

Background

1. Microspheres are very small, spherical vessels that are bounded by a membranelike layer of amino acids. Microspheres can be created in the laboratory under controlled conditions.
2. How do microspheres differ from living cells?
3. How do microspheres resemble living cells?
4. What role might have been played by microspheres or similar structures before life began on Earth?

Procedure

1. Put on safety goggles, a lab apron, and heat-protective gloves before beginning this investigation.
2. CAUTION Do not plug in or unplug the hot plate with wet hands. Use care to avoid burns when working with the hot plate. Do not touch the hot plate. Use tongs to move heated objects. Turn off the hot plate when not in use. Fill a 500 mL beaker half full with water, and heat it on a hot plate. You will use the beaker as a hot-water bath. Leave space on the hot plate for a 125 mL Erlenmeyer flask, to be added later.
3. While waiting for the water to boil, clamp a 125 mL Erlenmeyer flask to a ring stand. Add 6 g of the amino acid mixture to the flask.
4. When the water in the beaker begins to boil, move the ring stand carefully so that the flask of amino acids sits in the hot-water bath.
5. When the amino acids have heated for 20 minutes, measure 10 mL of NaCl solution in a graduated cylinder, and pour the solution into a second Erlenmeyer flask. Place the second flask on the hot plate beside the hot-water bath.
6. When the NaCl solution begins to boil, use tongs to remove the flask containing the NaCl solution from the hot plate. Then, while holding the flask with tongs, slowly add the NaCl solution to the hot amino acids while stirring.

7. Let this NaCl–amino acid solution boil for 30 seconds.

8. Remove the solution from the water bath, and allow it to cool for 10 minutes.

9. **CAUTION** Slides break easily. Use caution when handling them. Use a dropper to place a drop of the solution on a microscope slide, and cover the drop with a coverslip.

10. Place the slide on the microscope stage. Examine the slide under low power for tiny spherical structures. Then, examine the structures under high power. These tiny sphere-shaped objects are microspheres.

11. **CAUTION** If you get the sodium hydroxide (NaOH) solution on your skin or clothing, wash it off at the sink while calling to your teacher. If you get the sodium hydroxide solution in your eyes, immediately flush your eyes at the eyewash station while calling to your teacher. Place a drop of 1% NaOH solution at the edge of the coverslip to raise the pH as you observe the microspheres. What happens?

12. In your lab report, make a table similar to the one shown below. Based on your observations of microspheres and cells, complete your table. Consider the appearance of microspheres and cells, their method of reproduction, their interaction with their environment, and any other characteristics that you observe.

13. Clean up your lab materials, and wash your hands before leaving the lab.

**Analysis and Conclusions**

1. Suggest how the microspheres in step 10 were formed.

2. What did you observe when the pH was raised in step 11?

3. What does this suggest about the relationship of pH to microsphere formation?

4. Compare and contrast microspheres with living cells.

5. What characteristics would microspheres have to exhibit in order to be considered living?

6. How might the conditions you created in the lab be similar to those that are thought to have existed when life first evolved on Earth?

7. Predict what would happen to microspheres if they were placed in hypotonic and hypertonic solutions.

**Further Inquiry**

1. What do you think would happen if you added too much or too little heat? What happens to proteins at high temperatures? How can you test for the right amount of heat to use?

2. Do you think your microsphere experiment would have worked if you had substituted other amino acids? How can you test your hypothesis?

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<tr>
<th>Cell-like characteristics</th>
<th>Characteristics that are not cell-like</th>
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