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TABLE 14-1 ***Some Isotopes Used in Radioactive Dating***

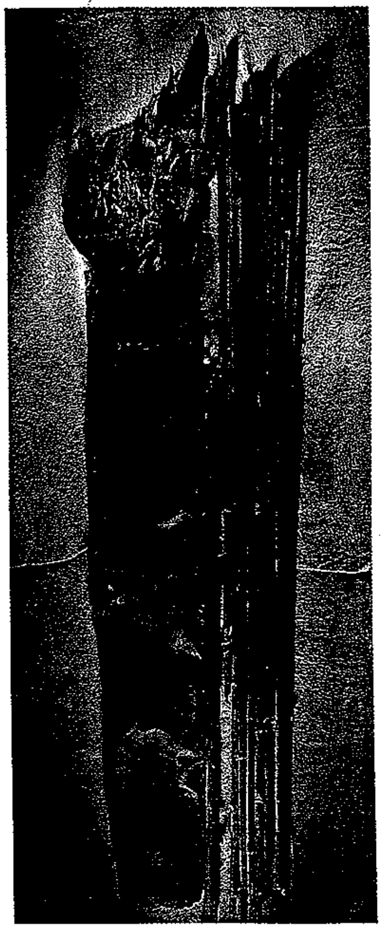
Isotope	Half-life
Carbon-14	5,730 y
Thorium-230	75,000 y
Potassium-40	1,300,000,000 y
Uranium-238	4,500,000,000 y

~~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 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, like the leather quiver and wooden bow and arrows shown in Figure 14-5. Isotopes with longer half-lives are used to date older fossils and rocks. Some of the isotopes commonly used in radioactive dating procedures appear in Table 14-1.~~

~~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. Scientists have found zircon crystals that are 4.2 billion years old. We can infer that organic molecules could have survived and begun to accumulate sometime after this.~~

FIGURE 14-5

This deerskin quiver, with a wooden bow and arrows, is about 3,000 years old. Carbon-14 dating methods can be used for organic materials less than 60,000 years old.



THE 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 the organic compounds found in life? One of the most popular hypotheses proposed to solve this puzzle was developed by the Soviet scientist Alexander I. Oparin in 1923. Oparin (1894–1980) suggested that the atmosphere of the primitive Earth was very different from that of today. Oparin thought the early atmosphere contained ammonia, NH_3; hydrogen gas, H_2; water vapor, H_2O; and compounds made of hydrogen and carbon, such as methane, CH_4. At temperatures well above the boiling point of water, these gases might have formed simple organic compounds, such as amino acids. According to Oparin, 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.

The Experimental 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 continued to explore the origin of simple organic compounds. Their experiments have produced a variety of compounds, including various amino acids, ATP, and the nucleotides in DNA. Such results suggest many ways that vital organic compounds might have formed on the young Earth.

In recent years, new hypotheses regarding early Earth's atmosphere have been proposed by investigators who study planet formation. In contrast to Oparin's hypotheses, it has been suggested that the atmosphere of early Earth was composed largely of carbon dioxide, CO_2; nitrogen, N_2; and water vapor, H_2O. Laboratory simulations of these atmospheric conditions have shown that both carbon dioxide and oxygen gas interfere with the production of organic compounds. Therefore, it is thought that conditions in areas protected from the atmosphere, such as those that exist in undersea hot springs, might have favored the production of organic compounds.

Organic Compounds from Beyond Earth

Recently, a broad mixture of organic compounds was found in a newly fallen meteorite that was recovered before it was contaminated with organic compounds from Earth. These compounds, which had not been destroyed by heat as the meteoroid entered Earth's atmosphere, must have formed in space. Some scientists hypothesize that after the period of Earth's formation, some organic compounds may have accumulated on the surface of Earth in this way, carried by space debris rather than originating here.

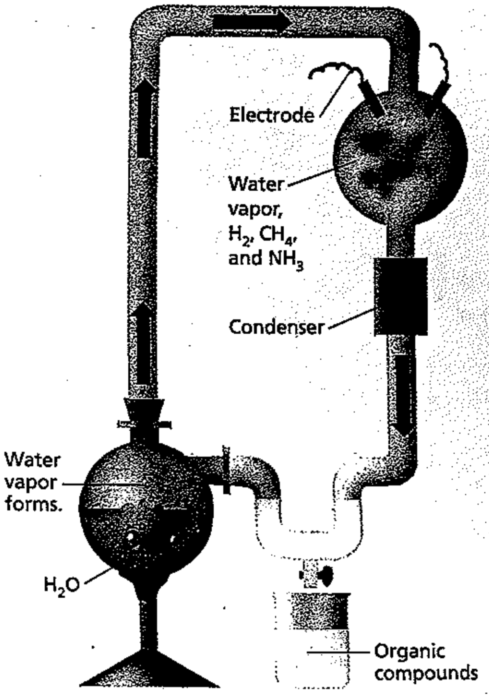


FIGURE 14-6

Miller and Urey's apparatus was a model for the atmospheric and temperature conditions of early Earth.

Quick Lab

Inferring Probability

Materials 3 × 5 in. cards (12) labeled with organic compounds

Procedure

1. Deal three cards, and try to make one of the following combinations: $NH_2{-}CH_2{-}COOH$, $CH_3{-}COOH$, or $CH_3{-}CH_2{-}COOH$. Each of these combinations represents an organic molecule.
2. Record your results. Replace the dealt cards in the set and shuffle the cards. Repeat the procedure 19 times.
3. Count the number of molecules you were able to form. Then calculate the probability of forming a molecule with each deal.

Analysis How can you compare a simple game of chance to the synthesis of organic compounds?

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4-2 REVIEW

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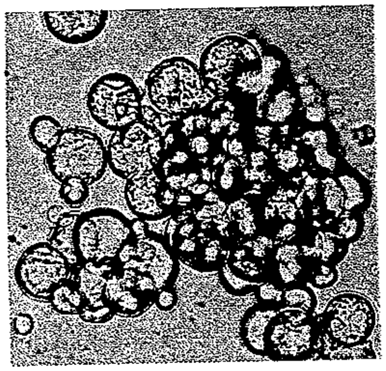

FIGURE 14-7

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.

FROM MOLECULES TO CELL-LIKE STRUCTURES

Sidney Fox (1912–) and others have done extensive research on the physical structures that may have given rise to the first cells. These cell-like structures, like 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 linked 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 lifelike 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.

When considering the evolution of cells from simpler structures, it is important to remember that microspheres and coacervates could not have responded to natural selection. Recall from Chapter 1 that natural selection is an important driving force of evolution—which is descent with modification, or change over generations. The laboratory-produced cell-like structures do not have hereditary characteristics. Thus, although these cell-like structures have some of the properties of life, they are not alive because they do not have heredity.

SECTION 14-2 REVIEW

1. **The oldest rocks on Earth date from about 4.2 billion years ago. What does this suggest about the interval between 4.6 billion years ago, when the Earth started to form, and 4.2 billion years ago?**
2. **If 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 the early Earth?**
4. **What was Oparin's hypothesis, and how was it tested?**
5. **What properties do microspheres and coacervates share with cells?**
6. **CRITICAL THINKING Some radioactive isotopes that are used in medicine as tracers in the bloodstream have very short half-lives, often only a few years or less, rather than thousands of years. Would these isotopes also be useful in dating fossils? Why or why not?**

THE FIRST LIFE-FORMS

A remote and desolate corner of Australia was nicknamed the North Pole by disappointed gold prospectors in the 1800s. But this region has been a "gold mine" after all for twentieth-century scientists. It was there that the oldest known cellular fossils—3.5-billion-year-old traces of early unicellular organisms—were found.

SECTION

14-3

OBJECTIVES

▲

Explain the importance of the chemistry of RNA in relation to the origin of life.

●

List three inferred characteristics that describe the first forms of cellular life on Earth.

■

Name two types of autotrophy and explain the difference between them.

◆

Explain how photosynthesis and aerobic respiration are thought to be related.

▲

Define *endosymbiosis,* and explain why it is important in the history of eukaryotes.

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 shape. Unlike DNA, RNA molecules can take on a great variety of shapes, for example, the t 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.

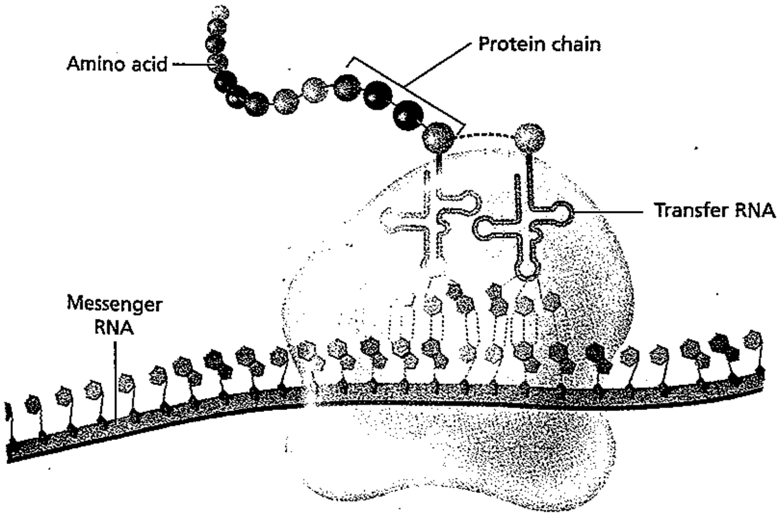

FIGURE 14-8

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.

Eco Connection

Archaebacteria

Some species of archaebacteria, such as *Methanosarcina barkeri* pictured in Figure 14-9, are referred to as methanogens. Within these bacteria, hydrogen gas reacts with carbon dioxide to produce methane, a simple carbon compound. Methanogens are poisoned by oxygen, but they can live in watery environments where other bacteria have consumed all free oxygen, such as in swamps and even the intestines of animals.

Methanogens may prove useful to humans in two significant ways: they are currently used in the cleanup of organic waste, such as sewage, and they may eventually be harnessed for large-scale production of methane for use as a fuel source.

Other species of archaebacteria are being used in the cleanup of petroleum spills into soil, such as occur when underground gasoline tanks develop leaks. This technique, called bioremediation, often relies on bacteria already present in the soil. These bacteria are activated by application of nutrient-rich solutions formulated to their taste. As the bacteria multiply, they metabolize petroleum, releasing harmless byproducts.

Word Roots and Origins

archaebacteria

from the Greek *arche,* meaning "the beginning," and *bactron,* meaning "a staff"

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 an enzyme. Cech used the term **ribozyme** (RIE-boh-ziem) for an RNA molecule that can act as an enzyme and promote a specific chemical reaction. Hypothetically, a ribozyme could act as an enzyme *and* have the ability to replicate itself.

Recent studies based on Cech's discovery have indicated that life may have started with self-replicating molecules of RNA. RNA molecules would have heredity and would be able to respond to natural selection and thus evolve. How could a single molecule respond to natural selection? Replication—or reproduction of the RNA molecule—might involve competing with other similar, but not identical, RNA molecules for a fixed number of available nucleotides. An RNA molecule that is more successful in getting nucleotides from its environment has an advantage over other RNA molecules. This advantage would then be passed on to the "offspring" of the RNA molecules, the new RNA molecules created by replication.

Since Cech's discovery, other ribozymal activities have been discovered, and it is clear that RNA plays a vital role in DNA replication, protein synthesis, RNA processing, and other basic biochemistry. Perhaps most or all of the chemistry and genetics of early cells were based on RNA.

As exciting as these discoveries have been, there are several questions left unanswered. For one thing, investigators still have not made or found a ribozyme capable of producing other ribozymes. Moreover, it is unclear how such RNA molecules could have evolved into cellular life. Perhaps self-replicating molecules of RNA started to evolve inside cell-like structures similar to microspheres or coacervates. If these RNA molecules were able to alter the phenotype of the cell-like structure that carried them, cellular life could have begun. The self-replicating RNA would have provided the hereditary information that the cell-like structures lack.

THE FIRST PROKARYOTES

What clues do we have about the nature of the first cellular life? When the first organisms arose, there was little or no oxygen gas in existence. Thus, the first cells must have been anaerobic. The small size of the oldest of the microfossils indicates that these early cells were prokaryotes. These cells probably were heterotrophs taking in organic molecules from their environment.

We can reason that a growing population of heterotrophs that depended on spontaneously formed organic molecules for food