1 Origin of Life

The evolution of life on earth has involved the following sequence of events. The first living things to appear were the simplest creatures, one-celled organisms. From these came more complex, multicellular organisms. Becoming more complex meant more than just an increase in cell number. With more cells came cellular specialization, where certain cells within the multicellular organism carried out specific tasks. Millions, even billions of years of organismal changes led to the living things we now call plants and animals.

Since this basic sequence of events is in accord with that agreed upon by most geologists, paleontologists, biologists, and even theologians, one might conclude that Moses, Aristotle, and Darwin were all keen observers and naturalists who were able to logically assess the most probable creation story.

Scientists generally concur that the time from the formation of our solar system until now has been on the order of some 4.5 billion years. Those who believe the world as we know it was created in six days are often called **creationists.** Their method of inquiry is based on the belief that the Bible is to be accepted as a completely accurate accounting of all about which it speaks. **Scientists,** on the other hand, utilize what they call the **scientific method,** which allows them to test hypotheses and theories and to develop concepts and ideas. However, there are many good scientists who also happen to be creationists. Even though the two are often compared and contrasted, the fact is that creationism is not a science, and therefore it is not dealt with in most biology books.

Spontaneous Generation

An early hypothesis concerning the origin of living organisms from nonliving material is known as **spontaneous generation.** This concept had many adherents for over a thousand years. Aristotle believed insects and frogs were generated from moist soil. Other elaborations on this basic theme prevailed for centuries. It wasn't until 1668 that Francesco Redi, an Italian, challenged the concept of spontaneous generation when he tested the widespread belief that maggots were generated from rotting meat. He placed dead animals in a series of jars, some of which were covered with a fine muslin that kept flies out while allowing air in. Other jars containing dead animals were left open. Maggots appeared only on the meat in the jars that were left open. In these, flies had been able to lay their eggs, which then hatched into fly larvae, or maggots. The flies were unable to land on the meat in the covered jars, and no maggots appeared there. From this he concluded that maggots would arise only where flies could lay their eggs.

During the nineteenth century, following other experiments, the theory of spontaneous generation of microorganisms was laid to rest by experiments conducted in France by Louis Pasteur and in England by John Tyndall. They demonstrated that bacteria are present in the air, and if the air surrounding a heat-sterilized nutrient broth is bacteria-free, then the broth remains bacteria-free. Until this time, people still believed microorganisms arose spontaneously.

One last vestige of mysticism in the debate concerning spontaneous generation had to be invalidated before theories regarding the origin of life could move ahead; this was known as the **vitalist doctrine.** Adherents of this idea maintained that life processes were not determined solely by the laws of the physical universe, but also partly by some **vital force,** or **vital principle.** By the late 1870s, most scientists agreed that all organisms arose from the reproduction of preexisting organisms, and the concept of spontaneous generation had become history.

Conditions for the Origin of Life

Life is thought to have developed here on earth through a sequence of chemical reactions over time. The most widely held hypothesis begins with the formation of the sun and the planets, which coalesced from a cloud of matter that resulted from a supernova, an old star that had exploded. Given the same explosion and the same amount of time, the same sequence of events would probably happen again, though the results might not be quite the same.

In what became our solar system, the largest mass to coalesce became our sun, and one of the smaller masses became our earth. On earth, the heavier materials sank to the core of the planet while the lighter substances are now more concentrated at the surface. Among these are hydrogen, oxygen, and carbon—important components for all life that eventually evolved.

The primordial atmosphere on earth was considerably different from that which currently exists. The present atmospheric gases are composed primarily of molecular nitrogen (N_2, 78 percent) and molecular oxygen (O_2, 21 percent), with a small amount of carbon dioxide (CO_2, 0.033 percent) and many other gases, such as helium and neon, found in only trace amounts.

The composition of today's atmosphere differs markedly from that found here when life was just beginning to evolve. At that time, the atmosphere contained far more hydrogen, and unlike now, there was very little oxygen. In such an atmosphere, the nitrogen probably combined with hydrogen, forming ammonia (NH_3); the oxygen was probably found combined with hydrogen in the form of water vapor (H_2O), and the carbon occurred primarily as methane (CH_4). The moderately high temperatures of the earth's crust continually evaporated any water that rained into the form of water vapor. As the earth cooled, rain water washed dissolved minerals into low areas creating lakes, seas, and oceans. In addition, volcanic activity erupting in the oceans and on land brought other minerals to the earth's surface, many of which eventually accumulated in the oceans, such as the various types of salts. It should also be mentioned that long before there was any life on earth, the seas contained large amounts of the simple organic compound methane.

Most of the compounds necessary for the development of the initial stages of life are thought to have existed in these early seas. Other studies have indicated that suitable environments for the first steps leading to living material could have existed elsewhere as well. But these environments are still poorly understood, and their potential connection with the origin of life is unclear.

Experimental Search for Life's Beginnings

In the 1920s, S. I. Oparin, a Soviet scientist, investigated how life could have evolved from the inorganic compounds that occurred on earth billions of years ago. His work is credited with leading to important later advances, most prominent of which were Stanley Miller's experiments during the 1950s. Miller duplicated the chemical conditions of the early oceans and atmosphere and provided an energy source, in the form of electric sparks, to generate chemical reactions. He found that when warm water and gases containing the compounds presumed to be found in the early oceans and in the earth's primordial atmosphere were subjected to sparks for about a week, organic compounds were formed.

Subsequent experiments, such as those performed by Melvin Calvin and Sydney Fox, have shown that many of the important so-called building blocks of life, or the amino acids that make up proteins, form quite readily under circumstances similar to those first established experimentally by Stanley Miller.

The thin film of water found on the microscopic particles that make clay has been shown to possess the proper conditions for important chemical reactions. Clays serve as a support and as a catalyst for the diversity of organic molecules involved in what we define as living processes. Ever since J. Desmond Bernal presented (during the late 1940s) his ideas concerning the importance of clays to the origin of life, additional prebiotic scenarios involving clay have been proposed. Clays store energy, transform it, and release it in the form of chemical energy that can operate chemical reactions. Clays also have the capacity to act as buffers and even as templates. A. G. Cairns-Smith analyzed the microscopic crystals of various metals that grew in association with clays and found that they had continually repeating growth patterns. He suggested that this could have been related to the original templates on which certain molecules reproduced themselves. Cairns-Smith and A. Weiss both suggest clays might have been the first templates for self-replicating systems.

Some researchers believe that through the mutation and selection of such simple molecular systems, the clay acting as template may eventually have been replaced by other molecules. And in time, instead of merely encoding information for a rote transcription of a molecule, some templates may have been able to encode stored information that would transcribe specific molecules under certain circumstances.

Other scenarios have been suggested to explain how the molecules that make more molecules could have become enclosed in cell-like containments. Sydney Fox and coworkers first observed that molecular boundaries between protein-nucleic acid systems can arise spontaneously. They heated amino acids under dry conditions and ascertained that long polypeptide chains were produced. These polypeptides were then placed in hot-water solutions, and upon cooling them, the researchers found that the polypeptides coalesced into small spheres. Within these spherical membranes, or **microspheres,** certain substances were trapped. Also, lipids from the surrounding solution became incorporated into the membranes, creating a protein-lipid membrane.

Oparin said "the path followed by nature from the original systems of protobionts to the most primitive bacteria . . . was not in the least shorter or simpler than the path from the amoeba to man." His point was that although the explanations intended to show how organic molecules could have been manufactured in primitive seas or on clays seem quite simple, and although one can see how such molecules could have been enclosed inside lipid-protein membranes, taking these experimental situations and actually creating living cells is a tremendous leap that may have taken, at the very least, hundreds of millions of years, perhaps considerably longer.

Panspermia

Although most modern theorists do not accept the idea that living organisms are generated spontaneously, at least not under present conditions, most do believe that life could have and probably did arise spontaneously from non-living matter under conditions that prevailed long ago, as described above. However, other hypotheses have also been suggested for the origin of life on earth.

In 1821 the Frenchman Sales-Guyon de Montlivault described how seeds from the moon accounted for the earliest life to occur on earth. During the 1860s, a German, H. E. Richter, proposed the possibility that germs carried from one part of the universe aboard meteorites eventually settled on earth. However, it was subsequently found that meteoric transport could be discounted as a reasonable possibility for the transport of living matter because interstellar space is quite cold (–220°C) and would kill most forms of microbial life known to exist. And even if something had survived on a meteor, reentry through the earth's atmosphere would probably burn any survivors to a crisp.

To counter these arguments, in 1905 a Swedish chemist, Svante Arrhenius, proposed a comprehensive theory known as **panspermia.** He suggested that the actual space travelers were the spores of bacteria that could survive the long periods at cold temperatures (some bacterial spores in Carlsbad, New Mexico, survived for 250 million years and were recently revived), and instead of traveling on meteors that burned when plummeting through the atmosphere, these spores moved alone, floating through interstellar space, pushed by the physical pressure of starlight.

The main problem with this theory, overlooked by Arrhenius, is that ultraviolet light would kill bacterial spores long before they ever had a chance to reach our planet's atmosphere. This explains the next modification to the theory.

Francis Crick, who along with James Watson received the Nobel Price for discovering the structure of DNA, coauthored an article with Leslie Orgel, a biochemist, in 1973. Their article, "Directed Panspermia," was followed by the book *Life Itself,* in which Crick suggests that microorganisms, due to their compact durability, may have been packaged and sent along on a spaceship with the intention of infecting other distant planets. The only link missing from Crick's hypothesis was a motive.

Probing Space for Clues of Life's Origins on Earth

Recent information concerning the origin of life has opened new avenues of research. To the surprise of many, spacecraft that flew past Halley's Comet in 1986 sent back information showing the comet was composed of far more organic matter than expected. From that, and additional evidence, some have concluded that the universe is awash with the chemical precursors of life. Lynn Griffiths, chief of the life sciences division of the National Aeronautics and Space Administration, said "everywhere we look, we find biologically important processes and substances."

We have known for years, from fossil evidence, that bacteria appeared on earth about 3.5 billion years ago, a little more than 1 billion years after the solar system formed. The great challenge has been to learn how, within that first billion years, simple organic chemicals evolved into more complex ones, then into proteins, genetic material, and living, reproducing cells.

As this current theory stands, it is felt that some 4 billion years ago, following the formation of the solar system, vast quantities of elements essential to life, including such complex organic molecules as amino acids, were showered onto earth and other planets by comets, meteorites, and interstellar dust. Now seen as the almost inevitable outcome of **chemical evolution,** these organic chemicals evolved into more complex molecules, then into proteins, genetic material, and living, reproducing cells.

Unfortunately, no traces of earth's chemical evolution during the critical first billion years survive, having all been obliterated during the subsequent 3.5 billion years. Biologists and chemists now feel, however, that clues concerning the first stages in the origin of life on earth can be found by looking elsewhere in the solar system. Planetary scientists are to be launching new probes that will eventually investigate these questions, looking for evidence revealing the paths of chemical evolution that may have occurred, or may still be occurring, on planets, moons, comets, and asteroids.

KEY TERMS

chemical evolution	scientific method	vital force
creationist	scientist	vital principle
microspheres	spontaneous generation	vitalist doctrine
panspermia		

SELF-TEST

Multiple-Choice Questions

1. People who believe the biblical explanation that the world and all its creatures were created in six days are known as:
   a. evolutionary biologists
   b. molecular biologists
   c. systematists
   d. cladists
   e. creationists

2. Scientists use what they call ____________, which allows them to test hypotheses and theories and to develop concepts and ideas.
   a. Occam's razor
   b. religious dogma
   c. religious faith
   d. scientific method
   e. creation science

3. Aristotle believed insects and frogs were generated from nonliving components in moist soil. This early hypothesis concerning the origin of living organisms is known as ____________.
   a. evolution
   b. spontaneous generation
   c. materialism
   d. creationism
   e. Aristotelian generation

4. Adherents of the ____________ maintained that life processes were not solely determined by the laws of the physical universe, but rather, they also depend on some vital force, or vital principle.
   a. dogmatic principle
   b. Darwinian approach
   c. vitalist doctrine
   d. Lamarckian principle
   e. all of the above

5. The composition of today's atmosphere differs markedly from that found here when life was just beginning to evolve. At that time the atmosphere contained far more ____________.
   a. hydrogen
   b. oxygen
   c. potassium
   d. iridium
   e. all of the above

6. When the chemical conditions of the early oceans and atmosphere are duplicated in the lab and provided with an energy source in the form of electric sparks, ____________ (has) have been formed.
   a. life
   b. organic molecules
   c. amino acids
   d. a and b
   e. b and c

7. ____________ (has) have been shown to serve as a support and as a catalyst for the diversity of organic molecules involved in what we define as living processes.
   a. quartz crystals
   b. gold
   c. plutonium
   d. clay
   e. all of the above

8. When researchers heated amino acids under dry conditions, long polypeptide chains were produced. When these chains were placed in a hot-water solution and then allowed to cool, the polypeptides coalesced into small spheres called ____________, within which certain substances were trapped. Molecules that make more molecules could have become enclosed in such cell-like containments.
   a. cells
   b. cell membranes
   c. cell walls
   d. microspheres
   e. all of the above

9. It was proposed that germs would have been carried to earth from another part of the universe via meteorites. Such transport was finally discounted, however, because ____________.
   a. heat generated during entry into the earth's atmosphere would burn any germs to a crisp
   b. no such life was ever found on meteorites
   c. nothing could possibly survive interstellar space
   d. all of the above
   e. none of the above

10. ____________, the comprehensive theory proposed in 1905 by the Swedish chemist Svante Arrhenius, stated that spores of bacteria that could survive the long periods of cold traveled alone through interstellar space, pushed along by the physical pressure of starlight.
    a. panspermia
    b. Arrheniusism
    c. microspermia
    d. germspermia
    e. intergalactic sporesia

Answers

1. e	4. c	7. d	10. a
2. d	5. a	8. d	
3. b	6. e	9. a	

Questions to Think About

1. Briefly discuss the major theories concerning the origin of life. Give their strong points and their weak points.
2. What is the role that clay is theorized by some to have played in the origin of life?
3. Researchers have experimentally searched for life's beginnings by duplicating the chemical conditions of the early oceans and atmosphere in the lab. Describe some of their results and the implications they hold for the origin of life.
4. Discuss some of the proposed explanations for the origin of life on earth that suggest life came here from another place.
5. What recent clues to life's origins on earth have come from space probes?