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Theories of the Origin and Early Evolution of Life

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tect the animals and their habitats, and to promote a sense of stewardship of the environment. Goodall's Roots and Shoots children's program, for example, promotes environmental education and compassion toward the Earth's living things. She originally began the program in the hopes of influencing young people in Africa. The program quickly spread and now has chapters worldwide. Goodall has also been influential in establishing wildlife sanctuaries in Africa, including one in Congo and another in Uganda. Fossey's research and educational efforts were instrumental in gaining governmental protection for mountain gorillas in Rwanda.

These sanctuaries, along with habitat protection and educational efforts, will help ensure that primatologists can continue to study the Great Apes for years to come, and to learn whether humans and other primates are as closely related behaviorally as they are genetically.

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Theories of the Origin and Early Evolution of Life

Overview

After the theory of spontaneous generation was discredited, only religious explanations were offered to explain the origin of life. Alexander Oparin (1894-1980), an atheist, suggested that natural chemical reactions produced biological molecules that came together to form the first living thing. Later, Stanley Miller tested this hypothesis and produced chemical "building blocks" but not life itself. In spite of much progress, there is still no clear consensus on how life originated on Earth. Some scientists are even looking to outer space for the origin of life.

Background

The first scientist to synthesize a molecule normally produced by living organisms was Friedrich Wöhler (1800-1882). In 1828, he accidentally made urea by heating ammonium cyanate. This finding helped dispel a theory known as "vitalism," which taught that living things and their components possessed a "vital force." At the time, scientists believed that living things consisted of "organic matter" driven by that vital force which separated them from non-living things. Wöhler's discovery suggested that life forms, like non-living forms, were composed of molecules that obey the laws of chemistry and physics. Further, it might be possible to produce other molecules of life by experimental or natural means.

Around the time that Charles Darwin (1809-1882) proposed his theory of evolution by natural selection (1859), two other scientists, Rudolf Virchow (1821-1902) and Louis Pasteur (1822-1895) showed that another commonly held theory was false. Spontaneous generation is the term that describes the formation of living things from non-living starting material. Scientists believed that worms, insects, mice, and microscopic organisms simply "arose" from decaying meat, grain, broth, or even dirty underwear. The theory seemed reasonable at the time because no one had any idea of the complexity or the multitude of interactive molecules that make up even the simplest bacteria. For them, a cell was only "protoplasm," not much more complicated than gelatin.

Pasteur and Virchow discredited spontaneous generation and laid the groundwork for

the biogenic law which asserts that life comes only from life. This principle became a key component of the cell theory: every cell is made from a pre-existing cell. The implication of their work was that only God could have created the first life that would subsequently reproduce. Their demonstration was so effective that it virtually prevented any research on the origin of life for decades.

In the 1920s, a Russian chemist named Alexander Oparin coined the term "primordial soup" and suggested that the building blocks of life could spontaneously form and then coalesce together to form the first living cell. In his view, the basic components of cells (lipids, carbohydrates, amino acids) aggregate together, forming what he called "coacervates." Presumably, these coacervates would eventually carry out rudimentary metabolism and some would reproduce. Oparin also proposed that the atmosphere of the early Earth differed from the present one by having reducing gases such as hydrogen, methane, and ammonia in abundance. The British physiologist J.B.S. Haldane (1892-1964) independently concurred with Oparin, proposing that oxygen was absent during the origin of life because it would have prevented the formation of important organic molecules. This assumption about the atmosphere was not based on experimental evidence but on an understanding of the requirements for producing the desired molecules.

Oparin's hypothesis was tested in the early 1950s by Stanley Miller, a graduate student in Harold Urey's (1893-1981) laboratory, at the University of Chicago. Miller designed an apparatus that would simulate a reducing atmosphere and the presumed conditions of the early Earth. He used a spark discharge to mimic lightning and provide the energy required for the organic synthesis reactions. Miller's chamber lacked oxygen because this gas would prevent the formation of the desired molecules. In a short time, Miller found that the chamber produced 13 of the 20 amino acids found in proteins. Variations of this type of experiment were later shown to produce carbohydrates and the nitrogen-containing bases of nucleotides found in DNA and RNA. The work of Urey and Miller was hailed as producing the "building blocks of life."

However, producing such "building blocks" is not the same as producing life and was not qualitatively different than Wohler synthesizing urea. Chemical synthesis of building blocks is complicated by several factors. When amino acids are synthesized, a mixture of right- and left-handed molecules are produced. However, only the left-handed version is found in proteins. When carbohydrates are produced, many different sugars are made. However, the ribose and deoxyribose found in nucleotides are not made in appreciable amounts. Polymerization of amino acids into proteins and nucleotides into RNA and DNA is also a problem. Even then, these molecules are not living—they cannot reproduce themselves, carry out metabolism, and lack a boundary.

Later, Sydney Fox heated amino acids and they reacted together to form "proteinoids." Unlike normal proteins which are linear polymers of amino acids linked by peptide bonds, the proteinoids were branched polymers with both peptide and non-peptide bonds. The proteinoids could aggregate into microspheres and absorb various molecules. The aggregates were observed to enlarge and split into smaller fragments, although this could hardly be called reproduction.

As scientists began to unravel how the amino acid sequence of proteins is coded for in DNA and how DNA is replicated, there arose a paradox. The sequence of amino acids in a protein is not random but determined by the exact sequence of nucleotides in DNA. Therefore, a meaningful DNA sequence is required to produce a functional protein. However, proteins and enzymes are necessary in the replication of DNA, the transcription of mRNA, and the production of the nucleotides themselves. A conceptual difficulty arose because one could not start life with either proteins or DNA since each is so dependent on the other.

The conundrum was apparently resolved by Walter Gilbert (1932-), who proposed that life originated in an "RNA world." He suggested that the first living things consisted solely of RNA—that proteins and DNA were later developments. This was based on the observation that proteins are translated from mRNA with the help of tRNA and rRNA. Scientists also found that RNA could be reverse transcribed into DNA, a process carried out by the HIV virus. Further, certain RNA called ribozymes carry out limited catalytic activities like enzymes. RNA, then, appears to have the perfect combination of features to be the first molecules of life. However, the relative instability of nucleotides at high temperatures, the lack of appreciable ribose, and the inability for RNA to replicate itself pose serious problems for this hypothesis. Therefore, some scientists are sug-

gesting a pre-RNA world that would later give rise to the RNA world. They have proposed clay to serve in this role.

However the first living cell arose, it must have done so very quickly. Many scientists believe that the Earth is about 4.5 billion years old and that the Earth would be much too hot to support life until about 4 billion years ago. J. William Schopf described fossil bacteria found in structures called stromatolites that according to radiometric dating were 3.5-3.8 billion years old. These microfossils, apparently a type of filamentous blue-green algae found in pre-Cambrian rocks, are supposedly the oldest fossil evidence of life on Earth. If these assumptions are correct, this would imply that life appeared on Earth as soon as it possibly could since a considerable amount of time would seem necessary between the origin of life and the formation of the complex cells in the stromatolites.

Early scientists classified living things into basically two categories: plant and animal. As more types of organisms were discovered it became clear that this type of classification was inadequate. Robert Whittaker developed the five kingdom classification system. Monera is the kingdom for bacteria and prokaryotic cells. Protista consists mostly of single-celled eukaryotic organisms with some colonial forms included. The remaining three kingdoms, plant, fungi, and animal, are all multicellular eukaryotes.

Such a system appears to reflect evolution since bacteria are the simplest organisms followed by protists. Plants, fungi, and animals are more complicated and arguably equidistant from the other two kingdoms. The discovery of Archeans has complicated this scenario. These cells, found in harsh conditions such as high salt and very high temperatures, were initially believed to be the first cells and led to true bacteria later. But upon further study, they are in many ways more similar to the eukaryotic kingdoms than they are to true bacteria, except that they are prokaryotes.

Eukaryotic cells share many features in common in spite of their differences. They have membrane-bound organelles such as the nucleus and mitochondria while prokaryotic cells lack them. The origin of these subcellular structures is unknown, since it has been established that a cell cannot simply "create" them once they have been lost. During cell division, the components of the organelles or the organelles themselves are divided between the two daughter cells. Lynn Margulis (1938-) proposed the endosymbiont hypothesis to explain the origin of organelles, including the mitochondria. According to this view, the mitochondria and other organelles were once bacteria that were internalized by another larger cell. Since the mitochondria, for example could use oxygen to produce energy, this gave an advantage to the cell that protected it. The endosymbiont hypothesis has been widely accepted, although recent data on protein targeting suggests the origin of organelles may not be so simple.

Impact

Once Pasteur and Virchow discredited the theory of spontaneous generation it became difficult to discuss the origin of life outside a theological context. Scientists conducted research on evolution but not on the origin of life until Oparin reopened the field. Because Oparin was in Soviet Russia, a nation committed to atheism, he was able to develop a naturalistic theory for origin of life. One could also argue that his commitment to atheism forced him to devise an origin of life consistent with that view. Nonetheless, Oparin's work paved the way for Stanley Miller.

The elegance and simplicity of the work by Stanley Miller producing amino acids from a gaseous mixture has dominated the field of origin of life research for decades. Although scientists now question his choice of starting material and debate the conditions of the early Earth, they have been slow to offer a better alternative. Therefore, Miller's experiment continues to play a prominent role in textbooks in spite of the difficulties with it. Some have suggested life arose in deep sea vents in the ocean or in lagoons near volcanoes instead of in the atmosphere. The most radical suggestion is that the molecules of life, or even life itself, was carried to Earth from outer space, a theory called panspermia.

If life could arise by natural processes on Earth, then some suggest the same conditions and processes may occur elsewhere as well. In 1969, a meteorite was found to contain organic compounds including the same amino acids in a similar ratio to Miller's experiment. This observation has provided hope to the possibility of finding life on another planet. The desire to understand the origin of life has helped to fuel the SETI (Search for Extraterrestrial Intelligence) project in spite of the current lack of evidence for extraterrestrial life.

Theories of the origin of life are likely to remain controversial because uncertainty will always remain. If scientists do create life in the

lab, it would still not prove that such a process occurred in the past.

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Cracking the Genetic Code

Overview

"Cracking" the genetic code was one of the most exciting discoveries of the twentieth century. Although philosophers and early scientists had long pondered the nature of inheritance, it was not until 1953 that James Watson (1928-) and Francis Crick (1916-) announced that they had determined that the code for life resides in the molecular structure of deoxyribonucleic acid (DNA). This announcement began a frenzy of investigation that still continues today. One of the hottest topics in science at the end of the twentieth century is molecular biology.

Many scientists have added to the knowledge of the genetic code. In 1955 Mahlon B. Hoagland (1921-) isolated transfer ribonucleic acid (tRNA) while Robert Holley (1922-1993) described the complete structure of tRNA in 1965. In 1956 George Palade (1912-), working with the small structures (organelles) within the cytoplasm of the cell, discovered ribosomes, the protein factories of the cell. In 1967 Charles Yanofsky (1927-) and Sydney Brenner (1927-) described the organization of base groups that make up a protein. Marshall Nirenberg (1912-) and his team cracked the genetic code with a description of how the base pairs are related to twenty amino acids. These scientists laid the foundation for biotechnology and genetic engineering.

Background

A few scientists in the 1800s argued that the nature of living organisms could be reduced to basic chemistry and physics. Most were resigned to the prospect that the mystery of life and its mechanisms would never be solved. While a Swiss scientist in 1869 isolated the chemical DNA from pus cells, he did not recognize the importance of his finding.

At the beginning of the twentieth century, scientists had determined that nucleic acids were in all cells. Likewise, they knew that cells had three key ingredients: a ribose or deoxyribose sugar, a phosphate, and bases made of nitrogen and carbon. In 1938 Warren Weaver used the term "molecular biology" for the first time in an annual report to the Trustees of the Rockefeller Foundation. The foundation was supporting research into x-ray crystallography, which became instrumental in cracking the genetic code.

The 1940s, including the events of World War II, encouraged a new frenzy of scientific thinking that led to exciting discoveries in many fields, ranging from nuclear physics to biochemistry. In 1944 O.T. Avery (1877-1955) and his colleagues identified a substance, named deoxyribonucleic acid, that was able to change one strain of bacteria into another. The science of molecular biology was built on the work of sci-