IN MY BEGINNING
In the beginning there was simplicity.
—Richard Dawkins

In the beginning, I cannot say that I was confused. In fact, I had never really thought about the origin of life problem from a scientific perspective until I sat in a college classroom more than thirty years ago and listened to an instructor who tried to convince me that the “laws of probability” were against the mechanistic origin of life. I remember allowing that thought to swirl around in my head. The argument was compelling, and after all he had written a book on it. He then assigned a critique of the current theories as to the origin of life as a paper topic. As I recall, I was at a loss. I did not know what to write about except the foundation of the argument for the mechanism of synthesis of of organic compounds on the early earth. In particular, that assumption was that the early earth must have had a primal atmosphere very similar to that of the gas giants like Jupiter and Saturn. Their atmospheres likely represented that of the original accretion of the planets from the primordial disk.

That was the understanding of the first modern theorist on the origin of life. Alexandr Ivanovitch Oparin (1859-1927; see Figure 1) was a Russian biochemist who supposed that the early earth had a reducing atmosphere dominated by hydrogen, ammonia, and methane. He supposed that this mixture, given appropriate energy input like solar radiation and lightning might bring about the synthesis of a range of organic molecules that would come together as colloidal aggregates or coacervates. These would allow organic molecules like amino acids, lipids, nucleic acids, carbohydrates, and other carbon-containing molecules to be close enough for the reactions that would make chains or polymers like most biological molecules. Oparin supposed that the coacervates would tend to capture other dissolved organics and allow for the enlargement of the coacervate structure, a kind of prebiotic growth. Then, as the coacervates took up more organics from the water, a shortage of raw materials for the formation of the coacervates gave rise to a prebiotic natural selection thereby favoring those aggregates that were efficient. This process would eventually give rise to eubiotic or true cellular life.

Oparin wrote down his views in a book called The Origin of Life on Earth in 1924. He produced an expanded version of that work that was published posthumously in 1936, which was finally translated into English in 1938. Ironically, J.B.S. Haldane (1892-1964; see Figure 1) British Biochemist and geneticist published his view of the origin of life in 1929 (before he heard of Oparin’s ideas). Nevertheless, both men had remarkably similar views.

Like Oparin, Haldane supposed that the atmosphere of early earth had no oxygen. He further supposed that the oceans, also oxygen-free, were a mixture of dissolved CO$_2$ and ammonia, which could with the energy of ultraviolet light combine to form amino acids and chains of amino acids and other biopolymers. Thus, Haldane conceived of the oceans as a “hot, dilute soup” from which life sprang (This was the origin of the primordial soup concept). Then, the first cell emerged after acquiring a lipid membrane.

Norman Horowitz considered the pre-biotic soup concept and concluded that as early membrane-bound packets of organic material absorbed and assimilated simple organic components and constructed their biopolymers like proteins, the environments would become even more dilute. Thus, the “cells” would have been subject to a very strong selective pressure to develop efficient and effective pathways. This would have rapidly given rise to rudimentary metabolism, the most fundamental characteristic of life.
Biophysicist John Desmond Bernal (1901-1971) in 1951 said that a dilute soup would not have been able to assemble the precells. The mechanisms for the abiotic production of organic materials could not have made a “soup” thick enough for the spontaneous assembly of coacervates or membrane-bound precells. Instead, he believed that a catalytic surface was needed. For such a ubiquitous catalyst, he suggested clay particles. Organic materials would have been adsorbed onto the clay minerals, which are charged. This would have concentrated the organic matter such that reactions could have taken place just through their proximity on the clay particle.

FROM THEORY TO EXPERIMENT
One good experiment is worth a thousand models; but one good model can make a thousand experiments unnecessary.

-David Lloyd and Evgenii I Volkov

Until 1950 the modern theories of the origin of life remained in a theoretical plane. Then, Melvin Calvin, the discoverer of the Calvin Cycle in oxygen-requiring cells, bombarded a mixture of hydrogen, water and carbon dioxide with alpha particles in a cyclotron. The operation produced small organic molecules like formic acid, acetic acid, and formaldehyde. However, this particular mechanism of organic matter formation did not seem to apply to the early Earth and, therefore, had little impact on science.

On the other hand, Harold Urey (1893-1981) and his graduate student Stanley Miller did make a great impact in 1953 with an experiment that did seem germane to the origin of organic molecules on the early Earth. They assumed the Oparin-Haldane atmosphere and made a mixture of such gasses (methane, ammonia, hydrogen, and water) in an experimental setup that introduced sparks (as a simulation of lightning). Shortly, the inside of the reaction chamber began to turn dark with a tar-like coating and the water began to fill with an array of substances. When they took the apparatus apart, they found numerous small organic molecules, many of which were amino acids, the building blocks of proteins. This experiment demonstrated that questions about the formation of organic molecules on a prebiotic earth could be explored and tested. Thus, Urey and Miller made prebiotic chemistry a legitimate study. Optimism seemed warranted with the prompt discovery of the structure of DNA and the rapid sequence of discoveries that founded molecular biology. The molecular level of life suggested that a prebiotic form of natural selection could have given rise to life through chemical evolution.

Just how the simple organics came together to form chains or polymers of larger molecules necessary for life became the subject of intense debate. In general, the theorists took a bottom-up approach. That is, like the Urey-Miller experiment, they assumed certain conditions and then saw what could be produced. Given the products, what further steps would need to be taken, etc? This seemed a more fruitful approach than to consider life as it is and then try to take it apart in backward steps.

The potential mechanisms for prebiotic chemistry included tidal action, the polymerization through the alternate wet and dry of a tidal pool. The aerosol surfaces at the interface between the ocean and the atmosphere might have served to concentrate organics in the meniscus or aerosol bubbles in which reactions could take place. The catalytic influence of clays and other minerals like iron pyrite also were considered. In the mean time, Sidney Fox made protonoid compounds out of simple chains of amino acids by simulating conditions in hot volcanic springs. The organics thus generated spontaneously formed spheres that selectively took up other dissolved organic matter and “grew”. After they achieved a threshold size they “divided”. Fox’s protonoid spheres seemed to behave as though they were alive and such results seemed to fuel the enthusiasm.

However, the search for a mechanism of prebiotic chemistry became bogged down and then stopped in its tracks as the very assumptions of the Oparin-Haldane early earth atmosphere came under fire. Studies of the other earth-like
planets, Mars and Venus, suggested that the atmosphere that cooked out of the coalescing earth must have been similar and formed over a very short period of time, maybe 10-100 million years. The problem with the “new” atmosphere was that its composition was mainly CO$_2$, an almost inert gas. The other components, N$_2$ and water vapor were no better. Even with the energetic input of lightning and ultraviolet radiation, the yield of organic molecular building blocks would be woefully inadequate to the task of building prebiotic organic molecules like proteins.

At the same time that more was being learned about the conditions of the early earth, the evidence for the appearance of life on earth kept being moved back and back again. Finally, the discoveries of microfossils had been found from rocks that dated almost to the earliest time at which life could be supported, the end of the great bombardment. That was the time, whose results are still frozen on the dead surface of the moon. Some of those impacts imparted so much energy that they nearly boiled away the oceans. How could life have arisen in such a maelstrom? Where could the fragile incipient life have taken refuge?

DEEP OCEAN

These systems [hydrothermal vents] would have provided the combination of high temperatures and chemical environment (reducing conditions) necessary for converting carbon dioxide into organic material.

-Peter Ward and Donald Brownlee

The unusual chemistry necessary for the formation of small organics and the minerals that would serve as catalysts can be found at select locations on the ocean floor called hydrothermal vents. These are places in the deep ocean where the crust is thin and magma lies near the surface. Cracks in the rocks allow water to infiltrate and return super heated. Such water is chemically very active and is laden with chemicals that it gleans from the surrounding rocks on its way back. Such systems today support whole ecosystems of life that are driven solely by the chemical energy (and thermal energy) of the outflowing water.

The temperature and chemical gradients are quite extreme at the vents (see Figure 3). The ambient temperature at the ocean bottom hovers just above the freezing point whereas the water leaving the vents can be hundreds of degrees. In addition, the high pressures at such depths give water unusual properties (for example, it becomes less polar) that make water better suited as a medium for the production of small organics and their polymerization to form large biopolymers. The fine gradients and unusual chemistry produce narrow zones in which particular reactions can occur. These have been repeated experimentally and an array of small organics can be generated that rivals that of the Urey-Miller experimental design.

FIGURE 3. A diagram of a hydrothermal vent. Different reactions occur along the inside of the vent and at the plume that emerges from the tube.

Advantages of the hydrothermal vent theory are not restricted to questions of the proper chemistry and products. The vents that occur today also produce layers of iron pyrite, fool’s gold. This has been suggested as a possible mineral on which organic matter would accumulate and polymerize. The theory is that the mineral accreted organic matter around it and was a necessary component of the earliest life. Then, the lineage that gave rise to most living things evolved to do without it.

Hydrothermal vents as islands of life on the sea floor exploded into science awareness when the crew of the deep submersible Alvin descended 2.6 kilometers to a site of ocean floor spreading near the Galapagos Islands. They were amazed to see highly diverse communities flourishing well below the depth at which photosynthesis could occur. These communities were fueled by the chemical energy of the
plumes, a process called chemosynthesis. Later in 1985, John Baross and S. Hoffman suggested that the dominant chemosynthetic microbes (now called Archaea) adapted to high temperatures and pressures, also called thermal extremophiles hyperthermophiles, might represent the remnants of the earliest forms of living things. Curiously, many of the Archaea of thermal vents also have inclusions of iron pyrite. The decade following the proposal of Baross and Hoffman saw a surprising series of discoveries about the relationships of all living things. Particularly, it appeared as though living things fall into three distinct lineages: the Archaea, Eubacteria, and Eukaryota (see Figure 4). Figure 4 illustrates the difficulty of using the existing living groups to understand origin of life scenarios. Multiple lineages could have appeared during a time of chemical evolution, only one of which seems to have survived. This is the fundamental weakness of the top-down approach to the question of the origin of life. Thus, such evidence, though interesting, is too circumstantial to be strong support for the 'ventrists' point of view.

More compelling support from my perspective is the nature of the hydrothermal environment itself. It separates the delicate protolife structures from the vagaries of the surface environments. Particularly, deep hot environments that would be protected from ultraviolet radiation and buffered from the effects of ocean-boiling impacts are compelling as possible sites for incipient life to appear and take hold.

EXTRATERRESTRIAL CARBON
At a time when proposed solutions are still speculative, they are the driving force for the researches that will prove them right or wrong and will thereby put our thinking on a new and better track.

- Thomas Gold

In 1986 sensors trained on Halley’s Comet (see Figure 5) returned the startling information that it was not just a dirty snowball, but that it had a high concentration of organic material. In fact it was nearly 20% organic matter. Consistent with that estimate, the nucleus of the comet has a reflectance (albedo) that is as low as coal. Given the volume of the comet, the total volume of organic matter translated to an equivalence of 10% of the total organic biomass on the Earth. Such an astounding observation suggested that all of the organic matter on the Earth (and a significant portion of its ocean) could be accounted for by the accretion of at least ten Halley’s-sized comets. Given the accretion rate at the time of the great bombardment, that is very likely. The objection to this view is that comets, unless they have a somewhat “soft” impact, would vaporize any organic matter in them.

A rebuttal to that objection can be found in an ancient extraterrestrial rock (a chondrite; see Figure 6) that landed in Murchison Australia. When the Murchison Meteorite was analyzed the results indicated that it had an array of small organic molecules, including amino acids that rivaled those produced in the Urey-Miller Experiment. Thus, organic matter can survive the energies of impacts. These and similar finds indicate that sufficient organic matter for origin of life scenarios could be accounted for by the bombardment of comets and meteorites. Indeed, the environment of space could be ideal for the production of organic matter. So, the question of how carbon-containing molecules assembled themselves on the early Earth might have too many answers.
Suppose that the abundance of organic matter was just as high in the nebular cloud that gave rise to the solar system, the cloud from which the Earth accreted, then more than enough hydrocarbons should have been incorporated into the original mass of the Earth to account for all of its carbon, organic and inorganic. This was an old idea that was resurrected by Soviet scientists in the 1950’s when they tried to make sense of the distribution of petroleum deposits on the Earth. In this view, vast reservoirs of hydrocarbons are found deep within the Earth and are “cooking” out of the mantle-crust region to move up through permeable rock layers. Although originally proposed to account for a variety of puzzling attributes of petroleum, natural gas, and coal deposits, this theory has important implications for origin of life scenarios. Thomas Gold (b 1920; see Figure 7), an American astrophysicist who made important discoveries about the nature of pulsars, the magnetosphere, and the operation of the inner ear, popularized the abiogenic (non-living) source of petroleum. He countered the arguments that petroleum had cellular debris in it by proposing that the petroleum hydrocarbons served as a food source for deep-dwelling microbes, probably Archaea. If this view is correct, the realm of the Biosphere (living realm) goes very deep into the crust, a concept that Gold called the “deep, hot biosphere”, could account for many times the total biomass of the surface biosphere that we know about. More importantly, the heat and pressure in deep crustal regions, assuming that sufficient water also is present, would serve to form biopolymers, the constituents of life.

The combination of extraterrestrial and earthly sources for organic compounds seems sufficient to account for the amount of organic matter on our planet. Although, hydrocarbons are necessary, they alone are not sufficient to account for the appearance of life. Indeed, one of the most fundamental attributes of life is the transmission of information from one generation
to the next. How did that develop? How could concentrations of biopolymers become alive?

**RNA WORLD**

*To go from a bacterium to people is less of a step than to go from a mixture of amino acids to a bacterium.*

-Lynn Margulis

Consider the complexity of the cell and how it operates (see A Vital Science, from the Saturday Scientist last month and A Horse and Molecular Biology, this issue). Cells have membranes of phospholipid bilayers. They use and incorporate carbohydrates of ranges of complexity. They are controlled and regulated by certain proteins (enzymes), and given structural support by other proteins. More than that, though, they store and transmit information from one generation to the next through nucleic acids. How could such a remarkably complex, balanced system originate even if a full array of organic materials were present? An answer must recognize that the steps to complexity are small and not at all inevitable. In the final analysis it is time, immense periods of time, that makes the improbable possible. So, any reasonable scenario must rely on many small steps in the construction of complex systems. Those steps also must be fueled by energy: heat, ultraviolet light, chemical energy, pressure, tidal action, etc.

I have given some solutions earlier, particularly those that rely on mineral scaffolds to provide the catalytic and information foundation from which protolife appeared. Some consider even more simple systems. For example Nobel Laureate Manfred Eigen (b. 1927; see Figure 8) of Germany believes that proteins alone are enough to constitute an organized protobiotic structure. Through competition with other protoliving structures for amino acids (the building blocks of proteins), efficiency and effectiveness would be selected for.

The problem arises when scenarios try to account for the association of nucleic acids and proteins in the way that we see them in the Central Dogma of molecular biology (see A Horse and Molecular Biology). Usually, this produces a chicken and egg problem. That is, proteins require nucleic acids for their assembly, but DNA requires protein for its construction. Which came first? Freeman Dyson (b. 1923 England; see Figure 8), an American physicist attempts to solve the chicken and egg paradox by proposing that metabolism (protein-mediated operation) and replication (nucleic acid) appeared independently and fused in a kind of symbiosis.

The resolution to this problem seemed hopelessly complex and unreachable. However, years earlier and spinning off of his success with guessing the Central Dogma, Francis Crick (b. 1917, England; see Figure 8) with Leslie Orgel (b. 1927, England; see Figure 8) proposed that RNA, not DNA was the first information-bearing molecule. This theory languished in concept until 1986 when Thomas Cech (Figure 9) published evidence of an RNA molecule that could splice itself. Thus it could act simultaneously as a catalyst and an information molecule. This was the first real evidence for the possibility of an RNA World (a term coined the same year by Walter Gilbert).

The RNA World scenario proposes that protolife first organized itself into packages (presumably membrane-bound) of RNA that carried out the functions of metabolism and reproduction together. The function of metabolism then was co-opted by the more efficient and effective proteins (enzymes). The function of information storage then was transferred to the more stable DNA while RNA retained a role in reproduction and the translation
of information through the steps of the Central Dogma.

The problem with the RNA World scenario is that RNA is capricious as a molecule. Because it has a single strand, it is less stable than DNA and very sensitive to high temperatures. Because almost all origin of life scenarios suppose ambient high temperatures, this is an important consideration. Most theorists who support the RNA World assume that the form of RNA must have been more durable and able to survive in high temperatures.

PANSPERMIA

Once started, the robustness of life as demonstrated in the recent articles ensures its essential immortality. It survives and is repeatedly regenerated in the warm watery interiors of comets. The space between stars is littered with cometary debris, some of which contains the seeds of life.

—Chandra Wickramasinghe

Other views of life consider that it is so improbable and yet once started so robust that its spread through the cosmos is inevitable. That is the fundamental position of astronomers Chandra Wickramasinghe (b. 1939, Sri Lanka; Figure 10) and his mentor Fred Hoyle (1915-2001, England; see Figure 10). Though it was not a new idea, the theory of the spread of life through the cosmos, called Panspermia, is most commonly associated with them.

In the 1960’s Hoyle and Wickramasinghe were analyzing interstellar dust through spectral analysis. The spectrum had an unusual and inexplicable dip in the graph (Figure 10), which they thought might be interstellar carbon (graphite). However, the agreement between the absorption of graphite and interstellar dust was not very good. They tried a number of different possibilities, but in 1979 they found that dried bacteria provided an almost exact match with the observed spectrum.

After their 1979 discovery, Hoyle and Wickramasinghe continued to search the heavens for signs of life. Their exploration produced evidence for very complex organic molecules in interstellar dust. These they took as confirmation of the existence of the “seeds of life” in the cosmos. This unorthodox view is accepted by very few in the scientific community. However unpopular their views, their explanations are grounded in science and based on unbroken natural law. The concept might have confirmation with evidence of Martian life from ALH-84001 (the Martian meteorite; see Red Planets and Microbes). Sampling debris trails from comets, and capturing extraterrestrial microbial spores in the upper atmosphere might be an appropriate test of Panspermia. By and large, their theory is not accepted because alternate explanations can be offered without begging the question of how life
began. In light of the available evidence, “somewhere else” is just not very satisfying as an answer.

INTELLIGENT DESIGN AND A SEARCH FOR ANSWERS

The origin of life ... is maintained to be an event that transcends the laws of chemistry and physics.

-Donald England

Another point of view is that life arose as a creative act of an intelligent designer. This is the premise of “Creation Science”, now called Intelligent Design, a religious viewpoint that is cloaked in the mantle of science. The Creation Scientists, however, cannot propose theories that can be tested in such a way as to reject their fundamental theory. This is its essential flaw. “Creation Scientists” bring out problems with various mechanistic scenarios such as the complexity problem, the problem with the likelihood of spontaneous assembly of life, etc. These are legitimate questions when taken this far. However, to offer Intelligent Design as the only possible alternative is, at best, dishonest.

One objection that seems particularly compelling is the seeming violation of the second law of thermodynamics, an accepted law of physics. Surely, the violation of a law of physics would make mechanistic origin of life scenarios nonscientific. In fact, the second law, sometimes called entropy, says that disorder increases in closed systems. However, life is not a closed system. Indeed, the Earth is not a closed system. Energy flows through this system which provides the “force” to assemble macromolecules. That is why all origin of life scenarios are very careful about detailing the sources of energy and the types of energy gradients. Thus, to invoke the violation of the second law of thermodynamics as an explanation for why mechanistic origin of life scenarios could not happen is intellectually dishonest.

Why, although I received my college training in an atmosphere of “Creation Science”, do I reject it? Mainly because of what Don England said at the beginning of this section. He said that the origin of life was an “event that transcends the laws of chemistry and physics.” Science operates by attaching explanations to unbroken sequences of natural law, particularly the laws of chemistry and physics. That is the most fundamental tenet of science. By saying that his explanation somehow allowed the suspension of natural law, propels it into another intellectual dimension, that of religion.

However, if he insists that it is science, then he forces it into the category of pseudoscience.

Would mechanistic explanations be any better? What could we gain by such speculation and experimentation? In part, we can and have learned more about RNA. Our speculations, experimentations and observations have led to surprising results as to the ubiquitous nature of hydrocarbons, both on and off the world. Our search has led to the realization that three fundamental forms of life inhabit this planet. We may not know the precise steps that led to the appearance of life. Indeed, we still would not know even if we were able to put together nonliving components to form living entities. It is the search that defines science and our reward is the cornucopia of unexpected answers.

November 2003

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Jacques Monod (1971): *Life was so unlikely that its a priori probability was virtually zero.*

Manfred Eigen (1971): *The origin of life was inevitable based on appropriate conditions and laws of physics.*

**QUESTIONS TO THINK ABOUT**

1. What is the Oparin-Haldane Hypothesis?

2. Who produced the first experimental evidence to support the Oparin-Haldane Hypothesis?

3. What was the great bombardment? What implications might it have for an emergence of life scenarios?

4. What is meant by the last common ancestor?

5. Why are comets now considered sources of hydrocarbons for the early earth?

6. Who is Thomas Gold? What is his view of the earth’s biosphere? How might this have implications for our search for life elsewhere?

7. What is the RNA World? Who first proposed such a thing?

8. What is meant by panspermia? What evidence exists for it?

9. What is wrong with the “Creation Science” fundamental assumption as expressed by Don England?