Origin of Life: A Scientific Approach

Dr. Deepa Srivastava
Life Trustee
Agyanashrya trust

The Origin of Life:

The origin of life has been debated for a long time. Various theories have been put forward for its explanation, such as life on earth arose spontaneously, life on earth has always existed, life on earth came about through a supernatural act of creation by an intelligent Being, life was seeded from space etc.

Science is supposed to be about things that are observable. That is, science can probe only things that we can detect with our five senses. Science also must be repeatable. This means that when an experiment or observation is repeated, we get the same results. These restrictions on science have led to what we call the scientific method, the general rules that we follow in doing science. The scientific investigation of the origin of life presents us with at least two problems. First, since life began before people were around, we hardly can observe the process. Second, since the origin of life appears to have been a unique event, we hardly can repeat it.

Scientific Theories for the Origin of Life

Since its inception in 1924, the Primordial Soup Theory has gained a firm following in scientific circles. The theory states that a young Earth possessed a reducing atmosphere and, following exposure to various forms of energy, basic compounds were formed. These compounds are then said to have accumulated in a 'soup' from which life evolved.

The question how and why did life evolve from this collection of simple elements and compounds revolves around abiogenesis, which is the process by which a living organism forms naturally from non-living matter. There are eight existing theories for this initial abiogenesis.

1. BENEATH THE ICE

Some evidence indicates that, around three billion years ago, Earth's oceans were covered with ice. This ice may have been hundreds of metres thick and was mainly due to the sun being much less fierce than it is nowadays. This theory contends that the ice may have protected the compounds, allowing them to interact and, thereby, creating life.

2. ELECTRICITY

This theory says that electricity can produce simple sugars and amino acids from simple elements in the atmosphere. This leads to the theory that lightning may have been responsible for the origins of life, primarily by striking through rich volcanic clouds.

3. PANSPERMIA

Panspermia is the proposal that life on Earth didn't actually begin on Earth at all. Rocks, and other debris from impacts, are plentiful. In fact, rocks from Mars have been found here on Earth, and it has been suggested they any one of these would have brought microbes that could have kick-started life.

4. RNA

Ribonucleic acid (RNA) is today most known for its role in the expression of genes. To put it simply, DNA unzips, revealing the necessary gene that is being called for by the body, then RNA is transcribed from single nucleotides, copying the revealed segment for gene expression.

This theory states that all life sprouted from a complex RNA world.

5. SIMPLE METABOLISM AND REACTIONS

In contrast to the RNA theory, this approach suggests that the primordial soup simply continued to react with itself over time, producing more and more complex molecules, eventually yielding life. This is the most simple of the standing theories, and is difficult to dismiss.

6. CLAY BREEDING GROUND

Research at the University of Glasgow, in Scotland, has given rise to the theory that life on Earth may have evolved in clay. It is suggested that clay may have served as an area of concentrated chemical activity, providing a breeding ground for DNA and other components.

7. SUBMARINE HYDROTHERMAL VENTS

Submarine hydrothermal vents, or deep-sea vents, contain vast and diverse ecosystems. The nutrient rich environment filled with reactive gases and catalysts, creates a habitat teeming with life. Studies suggest that life may have originated from within these vents, a theory that cannot be ignored.

8. THE NEW THEORY

The newest addition to this mix of theories has been clearly articulated by the Massachusetts Institute of Technology in the USA (though a series of individuals have contributed over the years). The contention from supporters of this idea is that life evolved out of necessity, following the laws of nature, rather than through any accident or freak occurrence. In a number of papers, physicists have argued that the occurrence of life is a matter of inevitability, and they have a sound formula to support their claims.

The newmodels that physicists have come up with are formulated on previously established theories in physics, and they conclude that matter will generally develop into systems that, when “driven by an external source of energy” and “surrounded by a heat bath,” become increasingly efficient at dissipating energy. Studies have shown that populations of random atoms, when exposed to energy, will shuffle and organise themselves to dissipate energy more efficiently. It is suggested that this re-modelling would eventually lead to life.

So, this new theory may be viewed as an addition to the simple metabolism and reaction theory above, but with energy, such as is provided by the sun, as the catalyst.

This theory was touched upon by Charles Darwin himself, but was dismissed. However, the new research from MIT is backed up by mathematical and scientific evidence. Only time and further research can truly tell if there really is any energy in these claims.

In the beginning, there were simple chemicals. And they produced amino acids that eventually became the proteins necessary to create single cells. And the single cells became plants and animals. Recent research is revealing how the primordial soup created the amino acid building blocks, and there is widespread scientific consensus on the evolution from the first cell into plants and animals. But it's still a mystery how the building blocks were first assembled into the proteins that formed the machinery of all cells. Now, two long-time University of North Carolina scientists - Richard Wolfenden, PhD, and Charles Carter, PhD - have shed new light on the transition from building blocks into life some 4 billion years ago.

“Our work shows that the close linkage between the physical properties of amino acids, the genetic code, and protein folding was likely essential from the beginning, long before large, sophisticated molecules arrived on the scene," said Carter, professor of biochemistry and biophysics at the UNC School of Medicine. "This close interaction was likely the key factor in the evolution from building blocks to organisms.”

Their findings, published in companion papers in the *Proceedings of the National Academy of Sciences*, fly in the face of the problematic “RNA world” theory, which posits that RNA - the molecule that today plays roles in coding, regulating, and expressing genes - elevated itself from the primordial soup of amino acids and cosmic chemicals to give rise first to short proteins called peptides and then to single-celled organisms.

Wolfenden and Carter argue that RNA did not work alone; in fact, it was no more likely that RNA catalysed peptide formation than it was for peptides to catalyse RNA formation.

The finding adds a new layer to the story of how life evolved billions of years ago.

Let us now take the stepwise development of the scientific approach.

The Hadean Earth is thought to have had a secondary atmosphere, formed through degassing of the rocks that accumulated from planetesimal impactors. At first, it was thought that the Earth's atmosphere consisted of hydrogen compounds—methane, ammonia and water vapour—and that life began under such reducing conditions, which are conducive to the formation of organic molecules. During its formation, the Earth lost a significant part of its initial mass, with a nucleus of the heavier rocky elements of the protoplanetary disk remaining. According to later models, suggested by study of ancient minerals, the atmosphere in the late Hadean period consisted largely of water vapour, nitrogen and carbon dioxide, with smaller amounts of carbon monoxide, hydrogen, and sulphur compounds. As Earth lacked the gravity to hold any molecular hydrogen, this component of the atmosphere would have been rapidly lost during the Hadean period, along with the bulk of the original inert gases. The solution of carbon dioxide in water is thought to have made the seas slightly acidic, giving it a pH of about 5.5.The atmosphere at the time has been characterized as a "gigantic, productive outdoor chemical laboratory." It may have been similar to the mixture of gases released today by volcanoes, which still support some abiotic chemistry.

Oceans may have appeared first in the Hadean Eon, as soon as two hundred million years (200 Ma) after the Earth was formed, in a hot 100 °C (212 °F) reducing environment, and the pH of about 5.8 rose rapidly towards neutral. This has been supported by the dating of 4.404 Ga-old zircon crystals from metamorphosed quartzite of Mount Narryer in the Western Australia Jack Hills of the Pilbara. Despite the likely increased volcanism and existence of many smaller tectonic "platelets," it has been suggested that between 4.4 and 4.3 Ga (billion year), the Earth was a water world, with little if any continental crust, an extremely turbulent atmosphere and a hydrosphere subject to intense ultraviolet (UV) light, from a T Tauri stage Sun, cosmic radiation and continued bolide impacts.

The Hadean environment would have been highly hazardous to modern life. Frequent collisions with large objects, up to 500 kilometres (310 mi) in diameter, would have been sufficient to sterilize the planet and vaporize the ocean within a few months of impact, with hot steam mixed with rock vapour becoming high altitude clouds that would completely cover the planet. After a few months, the height of these clouds would have begun to decrease but the cloud base would still have been elevated for about the next thousand years. After that, it would have begun to rain at low altitude. For another two thousand years, rains would slowly have drawn down the height of the clouds, returning the oceans to their original depth only 3,000 years after the impact event.

Earliest biological evidence for life

The most commonly accepted location of the root of the tree of life is between a monophyletic domain Bacteria and a clade formed by Archaea and Eukaryota of what is referred to as the "traditional tree of life" based on several molecular studies starting with C. Woese. More recently Peter Ward has established an alternative view which is rooted in abiotic RNA synthesis which becomes enclosed within a capsule and then creates RNA ribozyme replicates. It is proposed that this then bifurcates between Dominion Ribosa (hypothetical Domain Ribosa or RNA life), and after the loss of ribozymes RNA viruses as Domain Viorea, and Dominion Terroa, which after creating a large cell within a lipid wall, creating DNA the 20 based amino acids and the triplet code, is established as the last universal common ancestor or LUCA, of earlier phylogenic trees.

Precambrian stromatolites in the Siyeh Formation, Glacier National Park. In 2002, a paper in the scientific journal *Nature* suggested that these 3.5 Ga (billion years) old geological formations contain fossilized cyanobacteria microbes. This suggests they are evidence of one of the earliest life forms on Earth.

The earliest life on Earth existed more than 3.5 billion years ago, during the Eoarchean Era when sufficient crust had solidified following the molten Hadean Eon. The earliest physical evidence so far found consists of microfossils in the Nuvvuagittuq Greenstone Belt of Northern Quebec, in "banded iron formation" rocks at least 3.77 billion and possibly 4.28 billion years old. This finding suggested that there was almost instant development of life after oceans were formed. The structure of the microbes was noted to be similar to bacteria found near hydrothermal vents in the modern era, and provided support for the hypothesis that abiogenesis began near hydrothermal vents.

Also noteworthy is biogenic graphite in 3.7 billion-year-old metasedimentary rocks from south-western Greenland and microbial mat fossils found in 3.48 billion-year-old sandstone from Western Australia. Evidence of early life in rocks from Akilia Island, near the Isua supracrustal belt in south-western Greenland, dating to 3.7 billion years ago have shown biogenic carbon isotopes. In other parts of the Isua supracrustal belt, graphite inclusions trapped within garnet crystals are connected to the other elements of life: oxygen, nitrogen, and possibly phosphorus in the form of phosphate, providing further evidence for life 3.7 billion years ago. At Strelley Pool, in the Pilbara region of Western Australia, compelling evidence of early life was found in pyrite-bearing sandstone in a fossilized beach, that showed rounded tubular cells that oxidized sulphur by photosynthesis in the absence of oxygen. Further research on zircons from Western Australia in 2015 suggested that life likely existed on Earth at least 4.1 billion years ago.

Traditionally it was thought that during the period between 4.28 and 3.8 Ga, changes in the orbits of the giant planets may have caused a heavy bombardment by asteroids and cometsthat pockmarked the Moon and the other inner planets (Mercury, Mars, and presumably Earth and Venus). This would likely have repeatedly sterilized the planet, had life appeared before that time.

The time periods between such devastating environmental events give time windows for the possible origin of life in the early environments. If the deep marine hydrothermal setting was the site for the origin of life, then abiogenesis could have happened as early as 4.0 to 4.2 Ga. If the site was at the surface of the Earth, abiogenesis could only have occurred between 3.7 and 4.0 Ga.

In 2016, a set of 355 genes likely present in the Last Universal Common Ancestor (LUCA) of all organisms living on Earth was identified The results “depict LUCA as anaerobic, CO_2-fixing, H_2-dependent with a Wood–Ljungdahl pathway, N_2-fixing and thermophilic. LUCA’s biochemistry was replete with FeS clusters and radical reaction mechanisms. Its cofactors reveal dependence upon transition metals, flavins, S-adenosyl methionine, coenzyme A, ferredoxin, molybdopterin, corrins and selenium. Its genetic code required nucleoside modifications and S-adenosylmethionine-dependent methylations.” The results depict methanogenicclostridia as a basal clade in the 355 phylogenies examined, and suggest that LUCA inhabited an anaerobic hydrothermal vent setting in a geochemically active environment rich in H_2, CO_2 and iron. M.D. Brazier has shown that the tiny fossils discovered came from a hot poisonous world of the toxic gases methane, ammonia, carbon dioxide and hydrogen sulphide. An analysis of the conventional threefold tree of life shows thermophilic and hyperthermophilic bacteria and archaea are closest to the root, suggesting that life may have evolved in a hot environment.

Spontaneous generation

Belief in spontaneous generation of certain forms of life from non-living matter goes back to Aristotle . This belief was paired with a belief in heterogenesis, i.e., that one form of life derived from a different form. Classical notions of spontaneous generation held that certain complex; living organisms are generated by decaying organic substances. According to Aristotle, it was a readily observable truth that aphids arise from the dew that falls on plants, flies from putrid matter, mice from dirty hay, crocodiles from rotting logs at the bottom of bodies of water, and so on.

In 1665, Robert Hooke published the first drawings of a microorganism. Hooke was followed in 1676 by Antonie van Leeuwenhoek, who drew and described microorganisms that are now thought to have been protozoa and bacteria. Many felt the existence of microorganisms was evidence in support of spontaneous generation, since microorganisms seemed too simplistic for sexual reproduction, and asexual reproduction through cell division had not yet been observed. Using a broad range of experiments ranging from sealed and open meat incubation and the close study of insect reproduction he became, by the 1680s, convinced that spontaneous generation was incorrect.

The alternative seemed to be biogenesis: that every living thing came from a pre-existing living thing.

In 1768, Lazzaro Spallanzani demonstrated that microbes were present in the air, and could be killed by boiling. In 1861, Louis Pasteur performed a series of experiments that demonstrated that organisms such as bacteria and fungi do not spontaneously appear in sterile, nutrient-rich media, but could only appear by invasion from without.

By the middle of the 19th century, the theory of biogenesis had accumulated so much evidential support, due to the work of Pasteur and others, that the alternative theory of spontaneous generation had been effectively disproven. John Desmond Bernal, a pioneer in X-ray crystallography, suggested that earlier theories such as spontaneous generation were based upon an explanation that life was continuously created as a result of chance events.

Biogenesis and abiogenesis:

The term biogenesis is usually credited to either Henry Charlton Bastian or to Thomas Henry Huxley.

Two theories were put forward:

1. **Hypothesis of Biogenesis:** Living matter always arises by the agency of pre-existing living matter.
2. **Hypothesis of Abiogenesis:** Living matter may be produced by non-living matter.

Idea of Louis Pasteur and Charles Darwin

Louis Pasteur remarked, about a finding of his in 1864 which he considered definitive, "Never will the doctrine of spontaneous generation recover from the mortal blow struck by this simple experiment." One alternative was that life's origins on Earth had come from somewhere else in the Universe. Periodically resurrected. Bernal said that this approach "is equivalent in the last resort to asserting the operation of metaphysical, spiritual entities... it turns on the argument of creation by design by a creator or demiurge." Such a theory, Bernal said, was unscientific. A theory popular around the same time was that life was the result of an inner "life force", which in the late 19th century was championed by Henri Bergson.

The idea of evolution by natural selection proposed by Charles Darwin put an end to these metaphysical theologies. According to Darwin the original spark of life may have begun in a "warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity and carbon present, that a proteine compound was chemically formed ready to undergo still more complex changes."

"Primordial soup" hypothesis

No new notable research or theory on the subject appeared until 1924, when Alexander Oparin reasoned that atmospheric oxygen prevents the synthesis of certain organic compounds that are necessary building blocks for the evolution of life. According to Oparin a "primeval soup" of organic molecules could be created in an oxygenless atmosphere through the action of sunlight. These would combine in ever more complex ways until they formed coacervates droplets. These droplets would "grow" by fusion with other droplets, and "reproduce" through fission into daughter droplets, and so have a primitive metabolism in which factors that promote "cell integrity" survive, and those that do not become extinct. Many modern theories of the origin of life still take Oparin's ideas as a starting point.

Robert Shapiro has summarized the "primordial soup" theory of Oparin and J. B. S. Haldane in its "mature form" as follows:

The early Earth had a chemically reducing atmosphere.

1. This atmosphere, exposed to energy in various forms, produced simple organic compounds ("monomers").
2. These compounds accumulated in a "soup" that may have concentrated at various locations (shorelines, oceanic vents etc.).

3. By further transformation, more complex organic polymers – and ultimately life – developed in the soup.

About this time, Haldane suggested that the Earth's prebiotic oceans (quite different from their modern counterparts) would have formed a "hot dilute soup" in which organic compounds could have formed. Bernal called this idea *biopoiesis* or *biopoiesis*, the process of living matter evolving from self-replicating but non-living molecules, and proposed that biopoiesis passes through a number of intermediate stages.

One of the most important pieces of experimental support for the "soup" theory came in 1952. Stanley L. Miller and Harold C. Urey performed an experiment that demonstrated how organic molecules could have spontaneously formed from inorganic precursors under conditions like those posited by the Oparin-Haldane hypothesis. The now-famous Miller–Urey experiment used a highly reducing mixture of gases – methane, ammonia, and hydrogen, as well as water vapour – to form basic organic monomers such as amino acids. The mixture of gases was cycled through an apparatus that delivered electrical sparks to the mixture. After one week, it was found that about 10% to 15% of the carbon in the system was then in the form of a racemic mixture of organic compounds, including amino acids, which are the building blocks of proteins. This provided direct experimental support for the second point of the "soup" theory, and it is around the remaining two points of the theory that much of the debate now centres.

Bernal showed that based upon this and subsequent work there is no difficulty in principle in forming most of the molecules we recognize as the basic molecules of life from their inorganic precursors. The underlying hypothesis held by Oparin, Haldane, Bernal, Miller and Urey, for instance, was that multiple conditions on the primeval Earth favoured chemical reactions that synthesized the same set of complex organic compounds from such simple precursors. A 2011 reanalysis of the saved vials containing the original extracts that resulted from the Miller and Urey experiments, using current and more advanced analytical equipment and technology, has uncovered more biochemicals than originally discovered in the 1950s. One of the more important findings was 23 amino acids, far more than the five originally found. However, Bernal said that "it is not enough to explain the formation of such molecules, what is necessary, is a physical-chemical explanation of the origins of these molecules that suggests the presence of suitable sources and sinks for free energy."

More recent studies, in October 2017, support the notion that life may have begun right after the Earth was formed as RNA molecules emerging from "warm little ponds."

Proteinoid microspheres:

In trying to uncover the intermediate stages of abiogenesis mentioned by Bernal, Sidney W. Fox in the 1950s and 1960s studied the spontaneous formation of peptide structures (small chains of amino acids) under conditions that might plausibly have existed early in Earth's history. In one of his experiments, he allowed amino acids to dry out as if puddled in a warm, dry spot in prebiotic conditions. He found that, as they dried, the amino acids formed long, often cross-linked, thread-like, submicroscopic polypeptide molecules now named "proteinoid microspheres".In another experiment to set suitable conditions for life to form, Fox collected volcanic material from a cinder cone in Hawaii. He discovered that the temperature was over 100 °C (212 °F) just 4 inches (100 mm) beneath the surface of the cinder cone, and suggested that this might have been the environment in which life was created—molecules could have formed and then been washed through the loose volcanic ash into the sea. He placed lumps of lava over amino acids derived from methane, ammonia and water, sterilized all materials, and baked the lava over the amino acids for a few hours in a glass oven. A brown, sticky substance formed over the surface, and when the lava was drenched in sterilized water, a thick, brown liquid leached out. The amino acids had combined to form proteinoids, and the proteinoids had combined to form small globules that Fox called "microspheres". His proteinoids were not cells, although they formed clumps and chains reminiscent of cyanobacteria, but they contained no functional nucleic acids or any encoded information.

Current models:

There is no single, generally accepted model for the origin of life. Scientists have proposed several plausible theories, which share some common elements. While differing in the details, these theories are based on the framework laid out by Alexander Oparin (in 1924) and by J. B. S. Haldane (in 1925), who postulated the molecular or chemical evolution theory of life. According to them, the first molecules constituting the earliest cells "were synthesized under natural conditions by a slow process of molecular evolution and these molecules then organized into the first molecular system with properties with biological order." Oparin and Haldane suggested that the atmosphere of the early Earth may have been chemically reducing in nature, composed primarily of methane (CH_4), ammonia (NH_3), water (H_2O), hydrogen sulphide (H_2S), carbon dioxide (CO_2) or carbon monoxide (CO), and phosphate (PO_4^{3-}), with molecular oxygen (O_2) and ozone (O_3) either rare or absent. According to later models, the atmosphere in the late Hadean period consisted largely of nitrogen (N_2) and carbon dioxide, with smaller amounts of carbon monoxide, hydrogen (H_2), and sulfur compounds; while it did lack molecular oxygen and ozone, it was not as chemically reducing as Oparin and Haldane supposed. In the atmosphere proposed by Oparin and Haldane, electrical activity can produce certain basic small molecules (monomers) of life, such as amino acids. The Miller–Urey experiment reported in 1953 demonstrated this.

Bernal coined the term *biopoiesis* in 1949 to refer to the origin of life. In 1967, he suggested that it occurred in three "stages":

1. The origin of biological monomers
2. The origin of biological polymers
3. The evolution from molecules to cells

Bernal suggested that evolution commenced between stages 1 and 2. Bernal regarded the third stage – discovering methods by which biological reactions were incorporated behind a cell's boundary – as the most difficult. Modern work on the way that cell membranes self-assemble, and the work on micropores in various substrates may be a halfway house towards the development of independent free-living cells.

The chemical processes that took place on the early Earth are called *chemical evolution*. Both Manfred Eigen and Sol Spiegelman demonstrated that evolution, including replication, variation, and natural selection, can occur in populations of molecules as well as in organisms. Spiegelman took advantage of natural selection to synthesize the Spiegelman Monster, which had a genome with just 218 nucleotide bases, having deconstructively evolved from a 4500-base bacterial RNA. Eigen built on Spiegelman's work and produced a similar system further degraded to just 48 or 54 nucleotides – the minimum required for the binding of the replication enzyme.

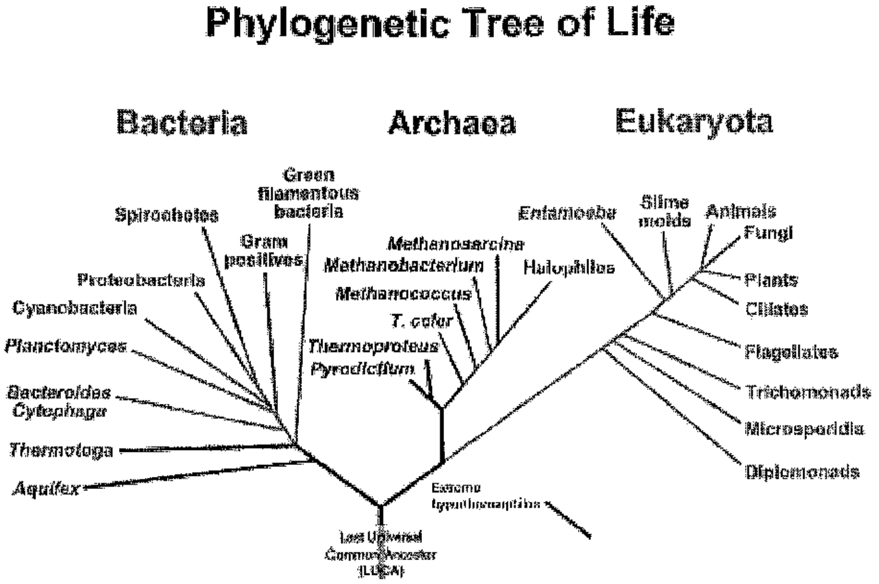
Following on from chemical evolution came the initiation of biological evolution, which led to the first cells. No one has yet synthesized a "protocell" using basic components with the necessary properties of life (the so-called "bottom-up-approach"). Without such a proof-of-principle, explanations have tended to focus on chemosynthesis. However, some researchers work in this field, notably Steen Rasmussen and Jack W. Szostak. Others have argued that a "top-down approach" is more feasible. One such approach, successfully attempted by Craig Venter and others at J. Craig Venter Institute, involves engineering existing prokaryotic cells with progressively fewer genes, attempting to discern at which point the most minimal requirements for life are reached.

The NASA strategy on abiogenesis states that it is necessary to identify interactions, intermediary structures and functions, energy sources, and environmental factors that contributed to the diversity, selection, and replication of evolvable macromolecular systems. Emphasis must continue to map the chemical landscape of potential primordial informational polymers. The advent of polymers that could replicate, store genetic information, and exhibit properties subject to selection likely was a critical step in the emergence of prebiotic chemical evolution.

Chemical origin of organic molecules:

The elements, except for hydrogen and helium, ultimately derive from stellar nucleosynthesis. On 12 October 2016, astronomers reported that the very basic chemical ingredients of life — the carbon-hydrogen molecule(CH, or methylidyne radical), the carbon-hydrogen positive ion (CH+) and the carbon ion (C+) — are largely the result of ultraviolet light from stars, rather than other forms of radiation from supernovae and young stars, as thought earlier. Complex molecules, including organic molecules, form naturally both in space and on planets. There are two possible sources of organic molecules on the early Earth:

1. Terrestrial origins – organic molecule synthesis driven by impact shocks or by other energy sources (such as UV light, redox coupling, or electrical discharges; e.g., Miller's experiments)
2. Extra-terrestrial origins – formation of organic molecules in interstellar dust clouds, which rain down on planets.



3.

A cladogram demonstrating extreme hyperthermophiles at the base of the phylogenetic tree of life.

Based on recent computer model studies, the complex organic molecules necessary for life may have formed in the protoplanetary disk of dust grains surrounding the Sun before the formation of the Earth. According to the computer studies, this same process may also occur around other stars that acquire planets.

Estimates of the production of organics from these sources suggest that the Late Heavy Bombardment before 3.5 Ga within the early atmosphere made available quantities of organics comparable to those produced by terrestrial sources.

It has been estimated that the Late Heavy Bombardment may also have effectively sterilized the Earth's surface to a depth of tens of metres. If life evolved deeper than this, it would have also been shielded from the early high levels of ultraviolet radiation from the T Tauri stage of the Sun's evolution. Simulations of geothermically heated oceanic crust yield far more organics than those found in the Miller-Urey experiments. In the deep hydrothermal vents, Everett Shock has found "there is an enormous thermodynamic drive to form organic compounds, as seawater and hydrothermal fluids, which are far from equilibrium, mix and move towards a more stable state." Shock has found that the available energy is maximized at around 100 – 150 degrees Celsius, precisely the temperatures at which the hyperthermophilicbacteria and thermoacidophilic archaea have been found, at the base of the phylogenetic tree of life closest to the Last Universal Common Ancestor (LUCA).

The accumulation and concentration of organic molecules on a planetary surface is also considered an essential early step for the origin of life. Identifying and understanding the mechanisms that led to the production of prebiotic molecules in various environments is critical for establishing the inventory of ingredients from which life originated on Earth, assuming that the abiotic production of molecules ultimately influenced the selection of molecules from which life emerged.

Chemical synthesis:

While features of self-organization and self-replication are often considered the hallmark of living systems, there are many instances of abiotic molecules exhibiting such characteristics under proper conditions. Stan Palasek suggested based on a theoretical model that self-assembly of ribonucleic acid (RNA) molecules can occur spontaneously due to physical factors in hydrothermal vents. Virus self-assembly within host cells has implications for the study of the origin of life, as it lends further credence to the hypothesis that life could have started as self-assembling organic molecules.

Multiple sources of energy were available for chemical reactions on the early Earth. For example, heat (such as from geothermal processes) is a standard energy source for chemistry. Other examples include sunlight and electrical discharges (lightning). Unfavourable reactions can also be driven by highly favourable ones, as in the case of iron-sulfur chemistry. For example, this was probably important for carbon fixation (the conversion of carbon from its inorganic form to an organic one). Carbon fixation via iron-sulfur chemistry is highly favourable, and occurs at neutral pH and 100 °C (212 °F). Iron-sulfur surfaces, which are abundant near hydrothermal vents, are also capable of producing small amounts of amino acids and other biological metabolites.

Formamide produces all four ribonucleotides and other biological molecules when warmed in the presence of various terrestrial minerals. Formamide is ubiquitous in the Universe, produced by the reaction of water and hydrogen cyanide (HCN). It has several advantages as a biotic precursor, including the ability to easily become concentrated through the evaporation of water. Although HCN is poisonous, it only affects aerobic organisms (eukaryotes and aerobic bacteria), which did not yet exist. It can play roles in other chemical processes as well, such as the synthesis of the amino acid glycine.

In 1961, it was shown that the nucleic acid purine base adenine can be formed by heating aqueous ammonium cyanide solutions. Other pathways for synthesizing bases from inorganic materials were also reported. Leslie E. Orgel and colleagues have shown that freezing temperatures are advantageous for the synthesis of purines, due to the concentrating effect for key precursors such as hydrogen cyanide. Research by Stanley L. Miller and colleagues suggested that while adenine and guanine require freezing conditions for synthesis, cytosine and uracil may require boiling temperatures. Research by the Miller group notes the formation of seven different amino acids and 11 types of nucleobases in ice when ammonia and cyanide were left in a freezer from 1972 to 1997. Other work demonstrated the formation of s-triazines(alternative nucleobases), pyrimidines (including cytosine and uracil), and adenine from urea solutions subjected to freeze-thaw cycles under a reductive atmosphere (with spark discharges as an energy source).The explanation given for the unusual speed of these reactions at such a low temperature is eutectic freezing. As an ice crystal forms, it stays pure: only molecules of water join the growing crystal, while impurities like salt or cyanide are excluded. These impurities become crowded in microscopic pockets of liquid within the ice, and this crowding causes the molecules to collide more often. Mechanistic exploration using quantum chemical methods provide a more detailed understanding of some of the chemical processes involved in chemical evolution, and a partial answer to the fundamental question of molecular biogenesis.

At the time of the Miller–Urey experiment, scientific consensus was that the early Earth had a reducing atmosphere with compounds relatively rich in hydrogen and poor in oxygen (e.g., CH_4 and NH_3 as opposed to $CO_2$and nitrogen dioxide (NO_2)). However, current scientific consensus describes the primitive atmosphere as either weakly reducing or neutral. Such an atmosphere would diminish both the amount and variety of amino acids that could be produced, although studies that include iron and carbonate minerals (thought present in early oceans) in the experimental conditions have again produced a diverse array of amino acids. Other scientific research has focused on two other potential reducing environments: outer space and deep-sea thermal vents.

The spontaneous formation of complex polymers from abiotically generated monomers under the conditions posited by the "soup" theory is not at all a straightforward process. Besides the necessary basic organic monomers, compounds that would have prohibited the formation of polymers were also formed in high concentration during the Miller–Urey and Joan Oró experiments. The Miller–Urey experiment, for example, produces many substances that would react with the amino acids or terminate their coupling into peptide chains.

In March 2015 by John D. Sutherland and others found that a network of reactions beginning with hydrogen cyanide and hydrogen sulphide, in streams of water irradiated by UV light, could produce the chemical components of proteins and lipids, as well as those of RNA, while not producing a wide range of other compounds. The researchers used the term "cyanosulphidic" to describe this network of reactions.

Autocatalysis:

Auto catalysts are substances that catalyse the production of themselves and therefore are "molecular replicators." The simplest self-replicating chemical systems are autocatalytic, and typically contain three components: a product molecule and two precursor molecules. The product molecule joins together the precursor molecules, which in turn produce more product molecules from more precursor molecules. The product molecule catalyses the reaction by providing a complementary template that binds to the precursors, thus bringing them together. Such systems have been demonstrated both in biological macromolecules and in small organic molecules. Systems that do not proceed by template mechanisms, such as the self-reproduction of micelles and vesicles, have also been observed.

It has been proposed that life initially arose as autocatalytic chemical networks. British ethologist Richard Dawkins wrote about autocatalysis as a potential explanation for the origin of life in his 2004 book *The Ancestor's Tale.* In his book, Dawkins cites experiments performed by Julius Rebek Jr. and his colleagues in which they combined amino adenosine and pentafluorophenyl esters with the auto catalyst amino adenosine triacid ester (AATE). One product was a variant of AATE, which catalysed the synthesis of themselves. This experiment demonstrated the possibility that auto catalysts could exhibit competition within a population of entities with heredity, which could be interpreted as a rudimentary form of natural selection.

In the early 1970s, Manfred Eigen and Peter Schuster examined the transient stages between the molecular chaos and a self-replicating hypercycle in a prebiotic soup. In a hypercycle, the information storing system (possibly RNA) produces an enzyme, which catalyses the formation of another information system, in sequence until the product of the last aids in the formation of the first information system. Mathematically treated, hypercycles could create quasispecies, which through natural selection entered into a form of Darwinian evolution. A boost to hypercycle theory was the discovery of ribozymes capable of catalysing their own chemical reactions. The hypercycle theory requires the existence of complex biochemicals, such as nucleotides, which do not form under the conditions proposed by the Miller–Urey experiment.

Geoffrey W. Hoffmann has shown that an early error-prone translation machinery can be stable against an error catastrophe of the type that had been envisaged as problematical for the origin of life, and was known as "Orgel's paradox."

Hoffmann has furthermore argued that a complex nucleation event as the origin of life involving both polypeptides and nucleic acid is compatible with the time and space available in the primitive oceans of Earth. Hoffmann suggests that volcanic ash may provide the many random shapes needed in the postulated complex nucleation event. This aspect of the theory can be tested experimentally.

Homochirality:

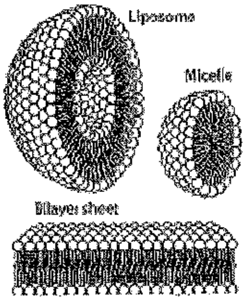
Homochirality refers to the geometric property of some materials that are composed of chiral units. Chiral refers to nonsuperimposable 3D forms that are mirror images of one another, as are left and right hands. Living organisms use molecules that have the same chirality ("handedness"): with almost no exceptions, amino acids are left-handed while nucleotides and sugars are right-handed. Chiral molecules can be synthesized, but in the absence of a chiral source or a chiral catalyst, they are formed in a 50/50 mixture of both enantiomers (called a racemic mixture). Known mechanisms for the production of non-racemic mixtures from racemic starting materials include: asymmetric physical laws, such as the electroweak interaction; asymmetric environments, such as those caused by circularly polarized light, quartz crystals, or the Earth's rotation, statistical fluctuations during racemic synthesis, and spontaneous symmetry breaking.

Once established, chirality would be selected for. A small bias (enantiomeric excess) in the population can be amplified into a large one by asymmetric autocatalysis, such as in the Soai reaction.In asymmetric autocatalysis, the catalyst is a chiral molecule, which means that a chiral molecule is catalyzing its own production. An initial enantiomeric excess, such as can be produced by polarized light, then allows the more abundant enantiomer to outcompete the other.

Clark has suggested that homochirality may have started in outer space, as the studies of the amino acids on the Murchison meteorite showed that L-alanine is more than twice as frequent as its D form, and L-glutamic acid was more than three times prevalent than its D counterpart. Various chiral crystal surfaces can also act as sites for possible concentration and assembly of chiral monomer units into macromolecules. Compounds found on meteorites suggest that the chirality of life derives from abiogenic synthesis, since amino acids from meteorites show a left-handed bias, whereas sugars show a predominantly right-handed bias, the same as found in living organisms.

Self-enclosement, reproduction, duplication and the RNA world:

Protocells:



The three main structures phospholipids form spontaneously in solution: the liposome (a closed bilayer), the micelle and the bilayer.

A protocell is a self-organized, self-ordered, spherical collection of lipids proposed as a stepping-stone to the origin of life. A central question in evolution is how simple protocell first arose and differed in reproductive contribution to the following generation driving the evolution of life. Although a functional protocell has not yet been achieved in a laboratory setting, there are scientists who think the goal is well within reach.

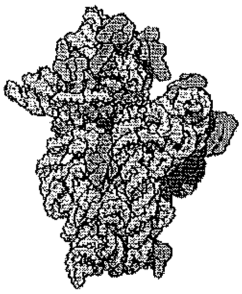
Self-assembled vesicles are essential components of primitive cells. The second law of thermodynamics requires that the Universe move in a direction in which entropy increases, yet life is distinguished by its great degree of organization. Therefore, a boundary is needed to separate life processes from non-living matter. Researchers Irene A. Chen and Jack W. Szostak amongst others, suggest that simple physicochemical properties of elementary protocells can give rise to essential cellular behaviours, including primitive forms of differential reproduction competition and energy storage. Such cooperative interactions between the membrane and its encapsulated contents could greatly simplify the transition from simple replicating molecules to true cells. Furthermore, competition for membrane molecules would favour stabilized membranes, suggesting a selective advantage for the evolution of cross-linked fatty acids and even the phospholipids of today. Such micro-encapsulation would allow for metabolism within the membrane, the exchange of small molecules but the prevention of passage of large substances across it. The main advantages of encapsulation include the increased solubility of the contained cargo within the capsule and the storage of energy in the form of a electrochemical gradient.

A 2012 study led by Armen Y. Mulkidjanian of Germany's University of Osnabrück, suggests that inland pools of condensed and cooled geothermal vapour have the ideal characteristics for the origin of life. Scientists confirmed in 2002 that by adding a montmorillonite clay to a solution of fatty acid micelles (lipid spheres), the clay sped up the rate of vesicles formation 100-fold.

Another protocell model is the Jeewanu. First synthesized in 1963 from simple minerals and basic organics while exposed to sunlight, it is still reported to have some metabolic capabilities, the presence of semipermeable membrane, amino acids, phospholipids, carbohydrates and RNA-like molecules.

Electrostatic interactions induced by short, positively charged, hydrophobic peptides containing 7 amino acids in length or fewer, can attach RNA to a vesicle membrane, the basic cell membrane.

RNA world:



Molecular structure of the ribosome 30S subunit from *Thermus thermophilus.* Proteins are shown in blue and the single RNA chain in orange.

The RNA world hypothesis describes an early Earth with self-replicating and catalytic RNA but no DNA or proteins. It is generally accepted that current life on Earth descends from an RNA world, although RNA-based life may not have been the first life to exist. This conclusion is drawn from many independent lines of evidence, such as the observations that RNA is central to the translation process and that small RNAs can catalyse all of the chemical groups and information transfers required for life. The structure of the ribosome has been called the "smoking gun," as it showed that the ribosome is a ribozyme, with a central core of RNA and no amino acid side chains within 18 angstroms of the active site where peptide bond formation is catalysed. The concept of the RNA world was first proposed in 1962 by Alexander Rich, and the term was coined by Walter Gilbert in 1986.

Possible precursors for the evolution of protein synthesis include a mechanism to synthesize short peptide cofactors or form a mechanism for the duplication of RNA. It is likely that the ancestral ribosome was composed entirely of RNA, although some roles have since been taken over by proteins. Major remaining questions on this topic include identifying the selective force for the evolution of the ribosome and determining how the genetic code arose.

Viral origins:

Recent evidence for a "virus first" hypothesis, which may support theories of the RNA world, has been suggested. One of the difficulties for the study of the origins of viruses is their high rate of mutation; this is particularly the case in RNA retroviruses like HIV. A 2015 study compared protein fold structures across different branches of the tree of life, where researchers can reconstruct the evolutionary histories of the folds and of the organisms whose genomes code for those folds. They argue that protein folds are better markers of ancient events as their three-dimensional structures can be maintained even as the sequences that code for those begin to change. Thus, the viral protein repertoire retain traces of ancient evolutionary history that can be recovered using advanced bioinformatics approaches. Those researchers think that "the prolonged pressure of genome and particle size reduction eventually reduced virocells into modern viruses (identified by the complete loss of cellular makeup), meanwhile other coexisting cellular lineages diversified into modern cells." The data suggest that viruses originated from ancient cells that co-existed with the ancestors of modern cells. These ancient cells likely contained segmented RNA genomes.

RNA synthesis and replication:

A number of hypotheses of formation of RNA have been put forward. As of 1994, there were difficulties in the explanation of the abiotic synthesis of the nucleotides cytosine and uracil. Subsequent research has shown possible routes of synthesis; for example, formamide produces all four ribonucleotides and other biological molecules when warmed in the presence of various terrestrial minerals. Early cell membranes could have formed spontaneously from proteinoids, which are protein-like molecules produced when amino acid solutions are heated while in the correct concentration of aqueous solution. These are seen to form micro-spheres which are observed to behave similarly to membrane-enclosed compartments. Other possible means of producing more complicated organic molecules include chemical reactions that take place on clay substrates or on the surface of the mineral pyrite.

Factors supporting an important role for RNA in early life include its ability to act both to store information and to catalyse chemical reactions (as a ribozyme); its many important roles as an intermediate in the expression of and maintenance of the genetic information (in the form of DNA) in modern organisms; and the ease of chemical synthesis of at least the components of the RNA molecule under the conditions that approximated the early Earth. Relatively short RNA molecules have been synthesized, capable of replication. Such replicase RNA, which functions as both code and catalyst provides its own template upon which copying can occur. Jack W. Szostak has shown that certain catalytic RNAs can join smaller RNA sequences together, creating the potential for self-replication. If these conditions were present, Darwinian natural selection would favour the proliferation of such autocatalytic sets, to which further functionalities could be added. Such autocatalytic systems of RNA capable of self-sustained replication have been identified. The RNA replication systems, which include two ribozymes that catalyse each other's synthesis, showed a doubling time of the product of about one hour, and were subject to natural selection under the conditions that existed in the experiment. In evolutionary competition experiments, this led to the emergence of new systems which replicated more efficiently. This was the first demonstration of evolutionary adaptation occurring in a molecular genetic system.

Depending on the definition, life started when RNA chains began to self-replicate, initiating the three mechanisms of Darwinian selection: heritability, variation of type, and differential reproductive output. The fitness of an RNA replicator (its per capita rate of increase) would likely be a function of its intrinsic adaptive capacities, determined by its nucleotide sequence, and the availability of resources. The three primary adaptive capacities may have been: (1) replication with moderate fidelity, giving rise to both heritability while allowing variation of type, (2) resistance to decay, and (3) acquisition of process resources. These capacities would have functioned by means of the folded configurations of the RNA replicators resulting from their nucleotide sequences.

Carl Zimmer has speculated that the chemical conditions, including the presence of boron, molybdenum and oxygen needed for the initial production of RNA, may have been better on early Mars than on early Earth. If so, life-suitable molecules originating on Mars may have later migrated to Earth via meteor ejections.

Pre-RNA world:

It is possible that a different type of nucleic acid, such as PNA, TNA or GNA, was the first to emerge as a self-reproducing molecule, only later replaced by RNA. Larralde *et al.*, say that "the generally accepted prebiotic synthesis of ribose, the formose reaction, yields numerous sugars without any selectivity." and they conclude that their "results suggest that.the backbone of the first genetic material could not have contained ribose or other sugars because of their instability." The ester linkage of ribose and phosphoric acid in RNA is known to be prone to hydrolysis.

Pyrimidine ribonucleosides and their respective nucleotides have been prebiotically synthesized by a sequence of reactions which by-pass the free sugars, and are assembled in a stepwise fashion by using nitrogenous or oxygenous chemistries. Sutherland has demonstrated high yielding routes to cytidine and uridine ribonucleotides built from small 2 and 3 carbon fragments such as glycolaldehyde, glyceraldehyde or glyceraldehyde-3-phosphate, cyanamide and cyanoacetylene. One of the steps in this sequence allows the isolation of enantiopure ribose aminooxazoline if the enantiomeric excess of glyceraldehyde is 60% or greater. This can be viewed as a prebiotic purification step, where the said compound spontaneously crystallized out from a mixture of the other pentose aminooxazolines. Ribose aminooxazoline can then react with cyanoacetylene in a mild and highly efficient manner to give the alpha cytidine ribonucleotide. Photoanomerization with UV light allows for inversion about the 1' anomeric centre to give the correct beta stereochemistry. In 2009 they showed that the same simple building blocks allow access, via phosphate controlled nucleobase elaboration, to 2',3'-cyclic pyrimidine nucleotides directly, which are known to be able to polymerize into RNA. This paper also highlights the possibility for the photo-sanitization of the pyrimidine-2', 3'-cyclic phosphates.

Origin of biological metabolism:

Metabolism-like reactions could have occurred naturally in early oceans, before the first organisms evolved. Metabolism may predate the origin of life, which may have evolved from the chemical conditions in the earliest oceans. Reconstructions in laboratories show that some of these reactions can produce RNA, and some others resemble two essential reaction cascades of metabolism: glycolysis and the pentose phosphate pathway that provide essential precursors for nucleic acids, amino acids and lipids. A study at the University of

Düsseldorf created phylogenic trees based upon 6 million genes from bacteria and archaea, and identified 355 protein families that were probably present in the LUCA. They were based upon an anaerobic metabolism fixing carbon dioxide and nitrogen. It suggests that the LUCA evolved in an environment rich in hydrogen, carbon dioxide and iron.

Following are some observed discoveries and related hypotheses.

Iron–sulfur world:

In the 1980s, Günter Wächtershäuser, encouraged and supported by Karl R. Popper, postulated in his iron–sulfur world, a theory of the evolution of pre-biotic chemical pathways as the starting point in the evolution of life. It systematically traces today's biochemistry to primordial reactions which provide alternative pathways to the synthesis of organic building blocks from simple gaseous compounds.

In contrast to the classical Miller experiments, which depend on external sources of energy (simulated lightning, ultraviolet irradiation), "Wächtershäuser systems" come with a built-in source of energy: sulphides of iron (iron pyrite) and other minerals. The energy released from redox reactions of these metal sulphides is available for the synthesis of organic molecules, and such systems may have evolved into autocatalytic sets constituting self-replicating, metabolically active entities predating the life forms known today. Experiments with such sulphides in an aqueous environment at 100 °C produced a relatively small yield of dipeptides(0.4% to 12.4%) and a smaller yield of tripeptides (0.10%) although under the same conditions, dipeptides were quickly broken down.

Several models reject the self-replication of a "naked-gene", postulating instead the emergence of a primitive metabolism providing a safe environment for the later emergence of RNA replication. The centrality of the Krebs cycle (citric acid cycle) to energy production in aerobic organisms, and in drawing in carbon dioxide and hydrogen ions in biosynthesis of complex organic chemicals, suggests that it was one of the first parts of the metabolism to evolve. Concordantly, geochemist Michael Russell has proposed that "the purpose of life is to hydrogenate carbon dioxide" (as part of a "metabolism-first," rather than a "genetics-first," scenario). Physicist Jeremy England of MIT has proposed that life was inevitable from general thermodynamic considerations: "... when a group of atoms is driven by an external source of energy (like the sun or chemical fuel) and surrounded by a heat bath (like the ocean or atmosphere), it will often gradually restructure itself in order to dissipate increasingly more energy. This could mean that under certain conditions, matter inexorably acquires the key physical attribute associated with life." One of the earliest incarnations of this idea was put forward in 1924 with Oparin's notion of primitive self-replicating vesicles which predated the discovery of the structure of DNA. Variants in the 1980s and 1990s include Wächtershäuser's iron–sulfur world theory and models introduced by Christian de Duve based on the chemistry of thioesters. More abstract and theoretical arguments for the plausibility of the emergence of metabolism without the presence of genes include a mathematical model introduced by Freeman Dyson in the early 1980s and Stuart Kauffman's notion of collectively autocatalytic sets, discussed later that decade.

Orgel summarized his analysis by stating, "There is at present no reason to expect that multistep cycles such as the reductive citric acid cycle will self-organize on the surface of FeS/FeS_2 or some other mineral."[It is possible that another type of metabolic pathway was used at the beginning of life. For example, instead of the reductive citric acid cycle, the "open" acetyl-CoA pathway (another one of the five recognized ways of carbon dioxide fixation in nature today) would be compatible with the idea of self-organization on a metal sulphide surface. The key enzyme of this pathway, carbon monoxide dehydrogenase/acetyl-CoA synthase, harbours mixed nickel-iron-sulfur clusters in its reaction centres and catalyzes the formation of acetyl-CoA (similar to acetyl-thiol) in a single step. There are increasing concerns, however, that prebiotic thiolated and thioester compounds are thermodynamically and kinetically unfavourable to accumulate in presumed prebiotic conditions (i.e. hydrothermal vents).

Zn-world hypothesis:

The Zn-world (zinc world) theory of Armen Y. Mulkidjanian is an extension of Wächtershäuser's pyrite hypothesis. Wächtershäuser based his theory of the initial chemical processes leading to informational molecules (RNA, peptides) on a regular mesh of electric charges at the surface of pyrite that may have facilitated the primeval polymerization by attracting reactants and arranging them appropriately relative to each other. The Zn-world theory specifies and differentiates further. Hydrothermal fluids rich in H_2S interacting with cold primordial ocean (or Darwin's "warm little pond") water leads to the precipitation of metal sulphide particles. Oceanic vent systems and other hydrothermal systems have a zonal structure reflected in ancient volcanogenic massive sulphide deposits (VMS) of hydrothermal origin. They reach many kilometres in diameter and date back to the Archean Eon. Most abundant are pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and sphalerite (ZnS), with additions of galena (PbS) and alabandite (MnS). ZnS and MnS have a unique ability to store radiation energy, e.g. from UV light. During the relevant time window of the origins of replicating molecules, the primordial atmospheric pressure was high enough (>100 bar, about 100 atmospheres) to precipitate near the Earth's surface, and UV irradiation was 10 to 100 times more intense than now; hence the unique photosynthetic properties mediated by ZnS provided just the right energy conditions to energize the synthesis of informational and metabolic molecules and the selection of photostable nucleobases.

The Zn-world theory has been further filled out with experimental and theoretical evidence for the ionic constitution of the interior of the first proto-cells before archaea, bacteria and proto-eukaryotes evolved. Archibald Macallum noted the resemblance of body fluids such as blood and lymph to seawater; however, the inorganic composition of all cells differ from that of modern seawater, which led Mulkidjanian and colleagues to reconstruct the "hatcheries" of the first cells combining geochemical analysis with phylogenomic scrutiny of the inorganic ion requirements of universal components of modern cells. The authors conclude that ubiquitous, and by inference primordial, proteins and functional systems show affinity to and functional requirement for K^+, Zn^{2+}, Mn^{2+}, and phosphate. Geochemical reconstruction shows that the ionic composition conducive to the origin of cells could not have existed in what we today call marine settings but is compatible with emissions of vapour-dominated zones of what we today call inland geothermal systems. Under the oxygen depleted, CO_2-dominated primordial atmosphere, the chemistry of water condensates and exhalations near geothermal fields would resemble the internal milieu of modern cells. Therefore, the precellular stages of evolution may have taken place in shallow "Darwin ponds" lined with porous silicate minerals mixed with metal sulphides and enriched in K^+, Zn^{2+}, and phosphorus compounds.

Deep sea vent hypothesis:

The deep sea vent, or alkaline hydrothermal vent, theory posits that life may have begun at submarine hydrothermal vents, William Martin and Michael Russell have suggested "that life evolved in structured iron monosulphide precipitates in a seepage site hydrothermal mound at a redox, pH, and temperature gradient between sulphide-rich hydrothermal fluid and iron(II)-containing waters of the Hadean ocean floor. The naturally arising, three-dimensional compartmentation observed within fossilized seepage-site metal sulphide precipitates indicates that these inorganic compartments were the precursors of cell walls and membranes found in free-living prokaryotes. The known capability of FeS and NiS to catalyse the synthesis of the acetyl-methylsulphide from carbon monoxide and methyl sulphide, constituents of hydrothermal fluid, indicates that pre-biotic syntheses occurred at the inner surfaces of these metal-sulphide-walled compartments..." These form where hydrogen-rich fluids emerge from below the sea floor, as a result of serpentinization of ultra-mafic olivine with seawater and a pH interface with carbon dioxide-rich ocean water. The vents form a sustained chemical energy source derived from redox reactions, in which electron donors (molecular hydrogen) react with electron acceptors (carbon dioxide). These are highly exothermic reactions.

Michael Russell demonstrated that alkaline vents created an abiogenic proton motive force (PMF) chemiosmotic gradient, in which conditions are ideal for an abiogenic hatchery for life. Their microscopic compartments "provide a natural means of concentrating organic molecules," composed of iron-sulfur minerals such as mackinawite, endowed these mineral cells with the catalytic properties envisaged by Wächtershäuser. This movement of ions across the membrane depends on a combination of two factors:

1. Diffusion force caused by concentration gradient—all particles including ions tend to diffuse from higher concentration to lower.

2. Electrostatic force caused by electrical potential gradient—cations like protons H^+ tend to diffuse down the electrical potential, anions in the opposite direction.

These two gradients taken together can be expressed as an electrochemical gradient, providing energy for abiogenic synthesis. The proton motive force can be described as the measure of the potential energy stored as a combination of proton and voltage gradients across a membrane (differences in proton concentration and electrical potential).

Jack W. Szostak suggested that geothermal activity provides greater opportunities for the origination of life in open lakes where there is a build-up of minerals. In 2010, based on spectral analysis of sea and hot mineral water, Ignat Ignatov and Oleg Mosin demonstrated that life may have predominantly originated in hot mineral water. The hot mineral water that contains bicarbonate and calcium ions has the most optimal range.This case is similar to the origin of life in hydrothermal vents, but with bicarbonate and calcium ions in hot water. This water has a pH of 9–11 and is possible to have the reactions in seawater. According to Melvin Calvin, certain reactions of condensation-dehydration of amino acids and nucleotides in individual blocks of peptides and nucleic acids can take place in the primary hydrosphere with pH 9-11 at a later evolutionary stage.Some of these compounds like hydrocyanic acid (HCN) have been proven in the experiments of Miller. This is the environment in which the stromatolites have been created. David Ward of University described the formation of stromatolites in hot mineral water at the Yellowstone National Park. Stromatolites survive in hot mineral water and in proximity to areas with volcanic activity.Processes have evolved in the sea near geysers of hot mineral water. In 2011, Tadashi Sugawara from the University of Tokyo created a protocell in hot water.

Experimental research and computer modelling suggest that the surfaces of mineral particles inside hydrothermal vents have catalytic properties similar to those of enzymes and are able to create simple organic molecules, such as methanol (CH_3OH) and formic, acetic and pyruvic acid out of the dissolved CO_2 in the water.

The research reported above by William F. Martin in July 2016 supports the thesis that life arose at hydrothermal vents, that spontaneous chemistry in the Earth's crust driven by rock–water interactions at disequilibrium thermodynamically underpinned life's origin and that the founding lineages of the archaea and bacteria were H2-dependent autotrophs that used CO2 as their terminal acceptor in energy metabolism.Martin suggests, based upon this evidence that LUCA "may have depended heavily on the geothermal energy of the vent to survive."

Thermosynthesis:

Today's bioenergetic process of fermentation is carried out by either the aforementioned citric acid cycle or the Acetyl-CoA pathway, both of which have been connected to the primordial Iron–sulfur world. In a different approach, the thermosynthesis hypothesis considers the bioenergetic process of chemiosmosis, which plays an essential role in cellular respiration and photosynthesis, more basal than fermentation: the synthase enzyme, which sustains chemiosmosis, is proposed as the currently extant enzyme most closely related to the first metabolic process.

First, life needed an energy source to bring about the condensation reaction that yielded the peptide bonds of proteins and the phosphodiester bonds of RNA. In a generalization and thermal variation of the binding change mechanism of today's ATP synthase, the "first protein" would have bound substrates (peptides, phosphate, nucleosides, RNA 'monomers') and condensed them to a reaction product that remained bound until after a temperature change it was released by thermal unfolding.

The energy source under the thermosynthesis hypothesis was thermal cycling, the result of suspension of protocells in a convection current, as is plausible in a volcanic hot spring; the convection accounts for the self-organization and dissipative structure required in any origin of life model. The still ubiquitous role of thermal cycling in germination and cell division is considered a relic of primordial thermosynthesis.

By phosphorylating cell membrane lipids, this "first protein" gave a selective advantage to the lipid protocell that contained the protein. This protein also synthesized a library of many proteins, of which only a minute fraction had thermosynthesis capabilities. As proposed by Dyson,it propagated functionally: it made daughters with similar capabilities, but it did not copy itself. Functioning daughters consisted of different amino acid sequences.

Whereas the Iron–sulfur world identifies a circular pathway as the most simple, the thermosynthesis hypothesis does not even invoke a pathway: ATP synthase's binding change mechanism resembles a physical adsorption process that yields free energy, rather than a regular enzyme's mechanism, which decreases the free energy. It has been claimed that the emergence of cyclic systems of protein catalysts is implausible.

Other models:

Clay hypothesis:

Montmorillonite, an abundant clay, is a catalyst for the polymerization of RNA and for the formation of membranes from lipids. A model for the origin of life using clay was forwarded by Alexander Graham Cairns-Smith in 1985 and explored as a plausible mechanism by several scientists. The clay hypothesis postulates that complex organic molecules arose gradually on pre-existing, non-organic replication surfaces of silicate crystals in solution.

At the Rensselaer Polytechnic Institute, James P. Ferris' studies have also confirmed that clay minerals of montmorillonite catalyse the formation of RNA in aqueous solution, by joining nucleotides to form longer chains.[252]

In 2007, Bart Kahr from the University of Washington and colleagues reported their experiments that tested the idea that crystals can act as a source of transferable information, using crystals of potassium hydrogen phthalate. "Mother" crystals with imperfections were cleaved and used as seeds to grow "daughter" crystals from solution. They then examined the distribution of imperfections in the new crystals and found that the imperfections in the mother crystals were reproduced in the daughters, but the daughter crystals also had many additional imperfections. For gene-like behaviour to be observed, the quantity of inheritance of these imperfections should have exceeded that of the mutations in the successive generations, but it did not. Thus Kahr concluded that the crystals "were not faithful enough to store and transfer information from one generation to the next."

Gold's "deep-hot biosphere" model

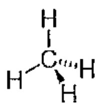
In the 1970s, Thomas Gold proposed the theory that life first developed not on the surface of the Earth, but several kilometres below the surface. It is claimed that discovery of microbial life below the surface of another body in our Solar System would lend significant credence to this theory. Thomas Gold also asserted that a trickle of food from a deep, unreachable, source is needed for survival because life arising in a puddle of organic material is likely to consume all of its food and become extinct. Gold's theory is that the flow of such food is due to out-gassing of primordial methane from the Earth's mantle; more conventional explanations of the food supply of deep microbes (away from sedimentary carbon compounds) is that the organisms subsist on hydrogen released by an interaction between water and (reduced) iron compounds in rocks.

Panspermia

Panspermia is the hypothesis that life exists throughout the Universe, distributed by meteoroids, asteroids, comets, planetoids, and, also, by spacecraft in the form of unintended contamination by microorganisms.

Panspermia hypothesis does not attempt to explain how life first originated, but merely shifts it to another planet or a comet. The advantage of an extraterrestrial origin of primitive life is that life is not required to have formed on each planet it occurs on, but rather in a single location, and then spread about the galaxy to other star systems via cometary and/or meteorite impact.[258] Evidence to support the hypothesis is scant, but it finds support in studies of Martian meteorites found in Antarctica and in studies of extremophile microbes' survival in outer space tests.

Extraterrestrial organic molecules:



Methane is one of the simplest organic compounds

An organic compound is any member of a large class of gaseous, liquid, or solid chemicals whose molecules contain carbon. Carbon is the fourth most abundant element in the Universe by mass after hydrogen, helium, and oxygen.Carbon is abundant in the Sun, stars, comets, and in the atmospheres of most planets.Organic compounds are relatively common in space, formed by “factories of complex molecular synthesis” which occur in molecular clouds and circumstellar envelopes, and chemically evolve after reactions are initiated mostly by ionizing radiation. Based on computer model studies, the complex organic molecules necessary for life may have formed on dust grains in the protoplanetary disk surrounding the Sun before the formation of the Earth. According to the computer studies, this same process may also occur around other stars that acquire planets.

Observations suggest that the majority of organic compounds introduced on Earth by interstellar dust particles are considered principal agents in the formation of complex molecules, thanks to their peculiar surface-catalytic activities. Studies reported in 2008, based on $^{12}C/^{13}C$ isotopic ratios of organic compounds found in the Murchison meteorite, suggested that the RNA component uracil and related molecules, including xanthine, were formed extraterrestrially. On 8 August 2011, a report based on NASAstudies of meteorites found on Earth was published suggesting DNA components (adenine, guanine and related organic molecules) were made in outer space.Scientists also found that the cosmic dust permeating the Universe contains complex organics ("amorphous organic solids with a mixed aromatic–aliphatic structure") that could be created naturally, and rapidly, by stars. Sun Kwok of The University of Hong Kong suggested that these compounds may have been related to the development of life on Earth said that "If this is the case, life on Earth may have had an easier time getting started as these organics can serve as basic ingredients for life."

Glycolaldehyde, the first example of an interstellar sugar molecule, was detected in the star-forming region near the centre of our galaxy. It was discovered in 2000 by Jes Jorgensen and Jan M. Hollis. In 2012, Jorgensen's team reported the detection of glycolaldehyde in a distant star system. The molecule was found around the protostellar binary IRAS 16293-2422 400 light years from Earth. Glycolaldehyde is needed to form RNA, which is similar in function to DNA. These findings suggest that complex organic molecules may form in stellar systems prior to the formation of planets, eventually arriving on young planets early in their formation.Because sugars are associated with both metabolism and the genetic code, two of the most basic aspects of life, it is thought the discovery of extraterrestrial sugar increases the likelihood that life may exist elsewhere in our galaxy.

NASA announced in 2009 that scientists had identified another fundamental chemical building block of life in a comet for the first time, glycine, an amino acid, which was detected in material ejected from comet Wild 2 in 2004 and grabbed by NASA's *Stardust* probe. Glycine has been detected in meteorites before. Carl Pilcher, who leads the NASA Astrobiology Institute, commented that "The discovery of glycine in a comet supports the idea that the fundamental building blocks of life are prevalent in space, and strengthens the argument that life in the Universe may be common rather than rare."Comets are encrusted with outer layers of dark material, thought to be a tar-like substance composed of complex organic material formed from simple carbon compounds after reactions initiated mostly by ionizing radiation. It is possible that a rain of material from comets could have brought significant quantities of such complex organic molecules to Earth. Amino acids which were formed extraterrestrially may also have arrived on Earth via comets. It is estimated that during the Late Heavy Bombardment, meteorites may have delivered up to five million tons of organic prebiotic elements to Earth per year.

Polycyclic aromatic hydrocarbons (PAH) are the most common and abundant of the known polyatomic molecules in the observable universe, and are considered a likely constituent of the primordial sea. In 2010, PAHs, along with fullerenes (or "buckyballs"), have been detected in nebulae. In March 2015, NASA scientists reported that, for the first time, complex DNA and RNA organic compounds of life, including uracil, cytosine and thymine, have been formed in the laboratory under outer space conditions, using starting chemicals, such as pyrimidine, found in meteorites. Pyrimidine, like PAHs, the most carbon-rich chemical found in the Universe, may have been formed in red giant stars or in interstellar dust and gas clouds.A group of Czech scientists reported that all four RNA-bases may be synthesized from formamide in the course of high-energy density events like extraterrestrial impacts.

Lipid world:

The lipid world theory postulates that the first self-replicating object was lipid-like. It is known that phospholipids form lipid bilayers in water while under agitation—the same structure as in cell membranes. These molecules were not present on early Earth, but other amphiphilic long-chain molecules also form membranes. Furthermore, these bodies may expand (by insertion of additional lipids), and under excessive expansion may undergo spontaneous splitting which preserves the same size and composition of lipids in the two progenies. The main idea in this theory is that the molecular composition of the lipid bodies is the preliminary way for information storage, and evolution led to the appearance of polymer entities such as RNA or DNA that may store information favourably. Studies on vesicles from potentially prebiotic amphiphiles have so far been limited to systems containing one or two types of amphiphiles. This in contrast to the output of simulated prebiotic chemical reactions, which typically produce very heterogeneous mixtures of compounds. Within the hypothesis of a lipid bilayer membrane composed of a mixture of various distinct amphiphilic compounds there is the opportunity of a huge number of theoretically possible combinations in the arrangements of these amphiphiles in the membrane. Among all these potential combinations, a specific local arrangement of the membrane would have favoured the constitution of a hypercycle, actually a positive feedback composed of two mutual catalysts represented by a membrane site and a specific compound trapped in the vesicle. Such site/compound pairs are transmissible to the daughter vesicles leading to the emergence of distinct lineages of vesicles which would have allowed Darwinian natural selection.[297]

Polyphosphates:

A problem in most scenarios of abiogenesis is that the thermodynamic equilibrium of amino acid versus peptides is in the direction of separate amino acids. What has been missing is some force that drives polymerization. The resolution of this problem may well be in the properties of polyphosphates. Polyphosphates are formed by polymerization of ordinary monophosphate ions PO_4^{-3}. Several mechanisms of organic molecule synthesis have been investigated. Polyphosphates cause polymerization of amino acids into peptides. They are also logical precursors in the synthesis of such key biochemical compounds as adenosine triphosphate (ATP). A key issue seems to be that calcium reacts with soluble phosphate to form insoluble calcium phosphate (apatite), so some plausible mechanism must be found to keep calcium ions from causing precipitation of phosphate. There has been much work on this topic over the years, but an interesting new idea is that meteorites may have introduced reactive phosphorus species on the early Earth.

PAH world hypothesis:

Polycyclic aromatic hydrocarbons (PAH) are known to be abundant in the Universe, including in the interstellar medium, in comets, and in meteorites, and are some of the most complex molecules so far found in space.

Other sources of complex molecules have been postulated, including extraterrestrial stellar or interstellar origin. For example, from spectral analyses, organic molecules are known to be present in comets and meteorites. In 2004, a team detected traces of PAHs in a nebula.In 2010, another team also detected PAHs, along with fullerenes, in nebulae. The use of PAHs has also been proposed as a precursor to the RNA world in the PAH world hypothesisThe Spitzer Space Telescope has detected a star, HH 46-IR, which is forming by a process similar to that by which the Sun formed. In the disk of material surrounding the star, there is a very large range of molecules, including cyanide compounds, hydrocarbons, and carbon monoxide. In September 2012, NASA scientists reported that PAHs, subjected to interstellar medium conditions, are transformed, through hydrogenation, oxygenation and hydroxylation, to more complex organics—"a step along the path toward amino acids and nucleotides, the raw materials of proteins and DNA, respectively."Further, as a result of these transformations, the PAHs lose their spectroscopic signature which could be one of the reasons "for the lack of PAH detection in interstellar ice grains, particularly the outer regions of cold, dense clouds or the upper molecular layers of protoplanetary disks."

NASA maintains a database for tracking PAHs in the Universe. More than 20% of the carbon in the Universe may be associated with PAHs, possible starting materials for the formation of life. PAHs seem to have been formed shortly after the Big Bang, are widespread throughout the Universe, and are associated with new stars and exoplanets.

Radioactive beach hypothesis:

Zachary Adam claims that tidal processes that occurred during a time when the Moon was much closer may have concentrated grains of uranium and other radioactive elements at the high-water mark on primordial beaches, where they may have been responsible for generating life's building blocks.According to computer models, a deposit of such radioactive materials could show the same reactions that found in the Oklo uranium ore seam in Gabon. Such radioactive beach sand might have provided sufficient energy to generate organic molecules, such as amino acids and sugars from acetonitrile in water. Radioactive monazite material also has released soluble phosphate into the regions between sand-grains, making it biologically "accessible." Thus amino acids, sugars, and soluble phosphates might have been produced simultaneously, according to Adam. Radioactive actinides, left behind in some concentration by the reaction, might have formed part of organometallic complexes. These complexes could have been important early catalysts to living processes.

John Parnell has suggested that such a process could provide part of the "crucible of life" in the early stages of any early wet rocky planet, so long as the planet is large enough to have generated a system of plate tectonics which brings radioactive minerals to the surface. As the early Earth is thought to have had many smaller plates, it might have provided a suitable environment for such processes.

Thermodynamic dissipation:

The 19th-century Austrian physicist Ludwig Boltzmann first recognized that the struggle for existence of living organisms was neither over raw material nor energy, but instead had to do with entropy production derived from the conversion of the solar spectrum into heat by these systems. Boltzmann thus realized that living systems, like all irreversible processes, were dependent on the dissipation of a generalized chemical potential for their existence. In his book "What is Life", the 20th-century Austrian physicist Erwin Schrödinger emphasized the importance of Boltzmann's deep insight into the irreversible thermodynamic nature of living systems, suggesting that this was the physics and chemistry behind the origin and evolution of life. However, irreversible processes, and much less living systems, could not be conveniently analysed under this perspective until Lars Onsager, and later Ilya Prigogine,developed an elegant mathematical formalism for treating the "self-organization" of material under a generalized chemical potential. This formalism became known as Classical Irreversible Thermodynamics and Prigogine was awarded the Nobel Prize in Chemistry in 1977 "for his contributions to non-equilibrium thermodynamics, particularly the theory of dissipative structures". The analysis of Prigogine showed that if a system were left to evolve under an imposed external potential, material could spontaneously organize (lower its entropy) forming what he called "dissipative structures" which would increase the dissipation of the externally imposed potential (augment the global entropy production). Non-equilibrium thermodynamics has since been successfully applied to the analysis of living systems, from the biochemical production of ATP to optimizing bacterial metabolic pathways [313] to complete ecosystems.

In his "Thermodynamic Dissipation Theory of the Origin and Evolution of Life", KaroMichaelian has taken the insight of Boltzmann and the work of Prigogine to its ultimate consequences regarding the origin of life. This theory postulates that the hallmark of the origin and evolution of life is the microscopic dissipative structuring of organic pigments and their proliferation over the entire Earth surface.Present day life augments the entropy production of Earth in its solar environment by dissipating ultraviolet and visible photons into heat through organic pigments in water. This heat then catalyzes a host of secondary dissipative processes such as the water cycle, ocean and wind currents, hurricanes, etc. Michaelian argues that if the thermodynamic function of life today is to produce entropy through photon dissipation in organic pigments, then this probably was its function at its very beginnings. It turns out that both RNA and DNA when in water solution are very strong absorbers and extremely rapid dissipaters of ultraviolet light within the 230–290 nm wavelength (UV-C) region, which is a part of the Sun's spectrum that could have penetrated the prebiotic atmosphere. In fact, not only RNA and DNA, but many fundamental molecules of life (those common to all three domains of life) are also pigments that absorb in the UV-C, and many of these also have a chemical affinity to RNA and DNA.Nucleic acids may thus have acted as acceptor molecules to the UV-C photon excited antenna pigment donor molecules by providing an ultrafast channel for dissipation. Michaelian has shown using the formalism of non-linear irreversible thermodynamics that there would have existed during the Archean a thermodynamic imperative to the abiogenic UV-C photochemical synthesis and proliferation of these pigments over the entire Earth surface if they acted as catalysts to augment the dissipation of the solar photons. By the end of the Archean, with life-induced ozone dissipating UV-C light in the Earth's upper atmosphere, it would have become ever more improbable for a completely new life to emerge that didn't rely on the complex metabolic pathways already existing since now the free energy in the photons arriving at Earth's surface would have been insufficient for direct breaking and remaking of covalent bonds. It has been suggested, however, that such changes in the surface flux of ultraviolet radiation due to geophysical events affecting the atmosphere could have been what promoted the development of complexity in life based on existing metabolic pathways, for example during the Cambrian explosion.

Many salient characteristics of the fundamental molecules of life (those found in all three domains) all point directly to the involvement of UV-C light in the dissipative structuring of incipient life. Some of the most difficult problems concerning the origin of life, such as enzyme-less replication of RNA and DNA, homochirality of the fundamental molecules, and the origin of information encoding in RNA and DNA, also find an explanation within the same dissipative thermodynamic framework by considering the probable existence of a relation between primordial replication and UV-C photon dissipation. Michaelian suggests that it is erroneous to expect to describe the emergence, proliferation, or even evolution, of life without overwhelming reference to entropy production through the dissipation of a generalized chemical potential, in particular, the prevailing solar photon flux.

Multiple genesis:

Different forms of life with variable origin processes may have appeared quasi-simultaneously in the early history of Earth. The other forms may be extinct (having left distinctive fossils through their different biochemistry—e.g., hypothetical types of biochemistry). It has been proposed that:

The first organisms were self-replicating iron-rich clays which fixed carbon dioxide into oxalic and other dicarboxylic acids. This system of replicating clays and their metabolic phenotype then evolved into the sulphide rich region of the hot spring acquiring the ability to fix nitrogen. Finally phosphate was incorporated into the evolving system which allowed the synthesis of nucleotides and phospholipids. If biosynthesis recapitulates biopoiesis, then the synthesis of amino acids preceded the synthesis of the purine and pyrimidine bases. Furthermore the polymerization of the amino acid thioesters into polypeptides preceded the directed polymerization of amino acid esters by polynucleotides.

Fluctuating hydrothermal pools on volcanic islands or proto-continents:

Armid Mulkidjanian and co-authors think that the marine environments did not provide the ionic balance and composition universally found in cells, as well as of ions required by essential proteins and ribozymes found in virtually all living organisms, especially with respect to K^+/Na^+ ratio, Mn^{2+}, Zn^{2+} and phosphate concentrations. The only known environments that mimic the needed conditions on Earth are found in terrestrial hydrothermal pools fed by steam vents. Additionally, mineral deposits in these environments under an anoxic atmosphere would have suitable pH (as opposed to current pools in an oxygenated atmosphere), contain precipitates of sulphide minerals that block harmful UV radiation, have wetting/drying cycles that concentrate substrate solutions to concentrations amenable to spontaneous formation of polymers of nucleic acids, and a continual supply of abiotically generated organic molecules, both by chemical reactions in the hydrothermal environment, as well as by exposure to UV light during transport from vents to adjacent pools. Their hypothesized pre-biotic environments are similar to the deep-oceanic vent environments most commonly hypothesized, but add additional components that help explain peculiarities found in reconstructions of the Last Universal Common Ancestor (LUCA) of all living organisms.

Bruce Damer and David Deamer have come to the conclusion that cell membranes cannot be formed in salty seawater, and must therefore have originated in freshwater. Before the continents formed, the only dry land on Earth would be volcanic islands, where rainwater would form ponds where lipids could form the first stages towards cell membranes. These predecessors of true cells are assumed to have behaved more like a superorganism rather than individual structures, where the porous membranes would house molecules which would leak out and enter other protocells. Only when true cells had evolved would they gradually adapt to saltier environments and enter the ocean.

Colin Garcia *et al.* (2016) discuss the advantages and disadvantages of hydrothermal vents as primitive environments.They mention the exergonic reactions in such systems could have been a source of free energy that promoted chemical reactions, additional to their high mineralogical diversity which implies the induction of important chemical gradients, thus favoring the interaction between electron donors and acceptors. Colín-García *et al.* (2016) also summarize a set of experiments proposed to test the role of hydrothermal vents in prebiotic synthesis.

Information theory:

A theory that speaks to the origin of life on Earth and other rocky planets posits life as an information system in which information content grows because of selection. Life must start with minimum possible information, or minimum possible departure from thermodynamic equilibrium, and it requires thermodynamically free energy accessible by means of its information content. The most benign circumstances, minimum entropy variations with abundant free energy, suggest the pore space in the first few kilometres of the surface. Free energy is derived from the condensed products of the chemical reactions taking place in the cooling nebula.

Jeewanu can be kept very close to the footing of a protocell:

Of all different types of microstructures only the Jeewanu of Bahadur does not require high temperature and big molecules for their formation and are prepared using simple chemicals and the abundantly available source of energy viz. sunlight which was falling on the earth even since it was formed. Due to these reasons, it is easily possible to accept it as the primitive protocell, according to Briggs (1965).

In 1964, the work on Jeewanu was confirmed independently by Briggs in England in his paper "The formation of cell like structures by the action of light on primitive earth hydrosphere" in the fourth International conference on photobiology held at Oxford in 1964. In the Journal of British Interplanetary Society and Space Flight, he further confirmed some more work on Jeewanu in 1965. Later in 1969, the work on Jeewanu was further confirmed by Mueller and Rudin. (Mueller. and Rudin, D. 1969)

According to Bahadur, life originated in water having essential organic and inorganic materials on exposure to sunlight. Firstly the biochemical like amino acids, small peptides, nucleic acid bases, sugars, phospholipids and organic acids, were synthesized and secondly these biochemical got organized synergistically into specific nonlinear systems, the microstructures called Jeewanu which were capable of adaptability and evolved to the present day cell.(Bahadur et al, 1963, Bahadur, 1967)

The initial experiments in the preparation of Jeewanu required long periods of exposure. In 1970, Bahadur and Ranganayaki prepared photo chemically Jeewanu in the aqueous mixture of 20 ml of mineral solution, 40 ml of 3%w/ammonium molybdate and 20 ml 36% w/v formaldehyde on exposure to visible radiations emitted by the fluorescent light and this needed only 40 minutes of exposure when turbidity began to appear. (Bahadur and Ranganayaki, 1970)

It is quit probable that molybdenum might have played an important role in the origin of life as it is widely distributed in nature and shows enzyme and catalytic properties in many biological reactions. Ammonium salt of molybdenum was used in the preparation of Jeewanu to provide a source of nitrogen.

Diammonium hydrogen phosphate was used throughout the investigation because phosphates are essential for many physiological functions and when mixed with formaldehyde in presence of sunlight, it forms various phosphoric acids which in turn take part in the synthesis of amino acids.

Minerals play a vital role in a number of biological processes. The mineral solution having sodium, potassium, magnesium, calcium, manganese, iron sulphate and chlorides, which are the chief constituents of all the living cells, has been used with a view that they may assist in the metabolism taking place within the microstructures called Jeewanu in performing biological functions.

Formaldehyde was also an important chemical used during the entire course of investigation because it provides a source of carbon in the parental environmental medium, is a strong antiseptic and no terrestrial living an grow in more than 2% of formaldehyde. It is the most abundantly found organic compound present in numerous galaxies and in space. Another reason for using formaldehyde was that it can be easily formed by the interaction of short ultra violet on an aqueous solution of carbon dioxide and the primitive atmosphere in which the life originated comprised of carbon dioxide, nitrogen and water vapours.

In the modified Jeewanu the silicon molybdenum Jeewanu soluble sodium ortho silicate has been added because silica plays an important role in biogenesis and is the quite abundant material found on earth. Cairns-Smith (1966) suggested that as the bond between silicon and oxygen atoms are about halfway between covalent and ionic type, silica might have played an important role as primitive genetic material.

Lastly sunlight was used as the source of energy, because in all probability it was available in abundance since the very beginning of the earth. Thus to epitomize the whole thing, it is clear that the conditions found in the prebiological era and that created by Bahadur were quite similar.

The simplicity of the chemicals employed in the preparation of Jeewanu elucidates the fact that such structures could have easily autosynthesised under natural conditions on the primitive earth. Thus these autopoetic systems the Jeewanu can be kept very close to the footing of a protocell and this allowed and inspired scientists to study the Jeewanu from different angles.

Jeewanu are similar to present day cell in chemical composition but differ from the common micro organism in that they cannot be grown on any known bacterial culture medium, are produced in a medium having 7% formaldehyde in which no micro organism can survive, and can be prepared under sterilized conditions.

The Jeewanu differ from crystal in the following points:

1. A crystal grows from outside, mostly from the molecules preformed in the medium, Jeewanu have boundary wall, grow from within and have internal structures and most of the material which comprises Jeewanu is about in the parental environmental medium but is synthesized inside the Jeewanu.
2. The formation of new crystal is not through the parent crystal and is independent whereas in Jeewanu, budding and the formation of new Jeewanu from the parent Jeewanu has been observed.
3. Crystals have a geometrical structure and are thoroughly homogeneous but in Jeewanu discrete boundary wall and internal structures have been observed.

Jeewanu are stable and show properties of biological order. Many biochemicals are present in Jeewanu. The elemental composition of molybdenum Jeewanu is C 13.87%, H 2.87%, N 9.22%, Mo 39.21%, P 2.11%, Fe 0.18%, Mn 0.005%, Mg and K 0.003%, Ca 0.006% and Na 0.10% (Huffman, 1981)

Jeewanu have distinct boundary wall and intricate internal structure. Bahadur, 1966) The molybdenum Jeewanu can be fixed with chromic acid and subsequently stained with gentian violet, eosin, Sudan black, methyl green and haematoxylin and different locales catch different stains. (Bahadur and Gupta, 1972; Gupta, V.K. 1980; Verma, P. 1980) Jeewanu contain nucleic acid bases, purines and pyrimidines. (Ranganayaki, Raina and Bahadur, 1972; Upadhyaya, G. 197;, Gupta, V.K. 1980; Srivastava, 1980) A number of natural amino acids are also present in Jeewanu. (Bahadur and Ranganayaki, 1970; Maurya 1977; Srivastava, M. 1977) Jeewanu also contain sugars as ribose, dioxyribose, fructose and glucose. (Bahadur and Ranganayaki, 1970) The presence of phosphor lipids (Singh, 1973) and organic acids of kreb's cycle (Sharma, 1977) in Jeewanu has been reported.

The photochemicaly formed Jeewanu show esterase like, catalase like and phosphatase like activities. (Briggs, 1964, 1965) It has been reported that Jeewanu has ATP ase like, urease like and peroxidase like activities. (Bahadur and Ranganayaki, 1970) Bahadur and Gupta (1972) reported the presence of acid phosphatase like activity in the molybdenum Jeewanu.

Antibiotics like penicillin, tetracycline, chloromycetin and sulpha drugs affect the formation of and growth of Jeewanu if present in the parental environmental medium during exposure to sunlight. (Bahadur et al, 1975, Pradhan, 1977)

The functional approach to the origin of life led by Bahadur and Ranganayaki (1980) to study the photochemical splitting of water and fixation of nitrogen and carbon dioxide by abiogenically prepared microstructures is an important aspect of understanding the process of life synthesis.

Jeewanu mixture showed the presence of a photochemical reversible electron transfer system. (Bahadur, 1967) Ferredoxin is an iron sulphur protein, which is the most widely distributed biochemical and is found in all the living cells of the present day and act as electron carriers in many biological transformations. Ferredoxin like material has been detected in Jeewanu. (Rao, Morris and Hall, 1978; Rao et al, 1980; Bahadur et al, 1980) Further Jeewanu liberates hydrogen in the presence of sodium dithionate or illuminated chloroplasts and the enzyme hydrogenase. (Rao et al, 1978)

Jeewanu also has nitrogenase like activity. (Bahadur, Ranganayaki, Smith and Folsome, 1980; Smith et al, 1981) Nitrogenase system has two constituents. One is a Fe-S protein and other is Mo-Fe-S protein. (Schrauzer, 1977) The function of Fe-S protein could be performed by the Ferredoxin like material of Jeewanu and a large concentration of molybdenum may form a material similar in function to Mo-Fe-S protein fraction. Thus the catalytic activity of nitrogenase enzyme could be possible by Jeewanu. The nitrogenase like activity has been confirmed by using D_2O. It has been observed that the proton needed for the reduction of inorganic carbon comes from the water molecules in its environment. (Bahadur et al, 1980) The D_2O test was further confirmed y Smith, Folsome and Bahadur in 1981 indicating that the proton are supplied by the cleavage of water in the formation of CHD=CHD from CH=CH of the overhead space of the mixture. The presence of nitrogenase like activity in Jeewanu indicated the ability of Jeewanu to fix nitrogen.

Schrauzer suggested the following scheme of diimine formation using molybdenum cystein complex as the first step in the nitrogen fixation. (Fig. 1)In this process Mo VI takes two protons from water in presence of light and forms Mo IV and oxygen is given out. Then Mo IV combines with nitrogen to form a nitrogen complex which when hydrolyzed gives diimine and itself gets oxidized to Mo VI. A part of diimine s then decomposed to give N_2 and H_2 while a part disproportionate into hydrazine and nitrogen. This hydrazine on reduction gives ammonia. Mo VI is reduced to Mo IV in presence of water and organo molybdenum micro structures in sunlight. But the ionic reaction of nitrogen fixation, decomposition and disproportionation takes place both in light and dark. For the fixation of nitrogen, the disproportionation reaction is needed while for the production of hydrogen the decomposition reaction is needed. In this system, the problem of production of hydrogen and fixation of nitrogen are closely related and investigations are being done to get a condition under which disproportion reaction is inhibited to produce good quality of hydrogen and the decomposition of diimine is inhibited to fix a good quantity of nitrogen.

It has been observed that if carbon dioxide is passed through an aqueous mixture of Jeewanu and the mixture is exposed to sunlight a part of carbon dioxide is converted into unoxygenic organic compound. (Ranganayaki. S., Kumar, S. and Bahadur, K. 1981) Kumar in 1981 reported that if 0.5% of sodium bicarbonate solution is mixed with aqueous mixture of Jeewanu and the whole mixture is exposed to sunlight the carbon of bicarbonate is converted into organic material. If $H^{14}CO_3^-$ is used as inorganic source, ^{14}C was detected in the organic material formed in the irradiated mixture. (Smith, Folsome and Bahadur, 1981)

Jeewanu were also tested for their water splitting ability in sunlight. It has been observed that if an aqueous mixture of Jeewanu is shaken vigorously and exposed to sunlight, after about 15 minutes of exposure, bubbles of gas start coming out of the mixture. (Bahadur, Ranganayaki and Gupta, 1981) In 1980 Murti collected the gas by downward displacement method and tested the gas and reported it to be hydrogen.

As Jeewanu show the properties of splitting of water and are able to fix carbon dioxide and nitrogen, an attempt has been made in our laboratory to prepare different type of Jeewanu by incorporating different materials to enhance their water splitting capacity. Some of the different types of Jeewanu prepared in our laboratory with success is the silicon molybdenum Jeewanu (Bahadur, M. thesis, 1986, Kharbanda thesis, 1987, Tondon, R. thesis, 1987), Molybdenum Jeewanu (Tondon, R. thesis, 1987), Mercury molybdenum Jeewanu (Tondon, R. thesis, 1987), Boron molybdenum Jeewanu (Khare, Y. thesis, 1989), mercury boron silicon molybdenum Jeewanu (Khare, Y. thesis, 1989). A detailed study of the motion observed in various types of Jeewanu has been done by Vandana Mathur in 1989. Mathur, V. thesis, 1989). The effect of transitional metal ions e.g. $Ti^{3+,}$ Zn^{2+} and Co^{2+} on the functional properties of different types of Jeewanu have also been studied by various scientists successfully. (Bahadur, M. 1986, Kharbanda, M. 1987, Tondon, R. 1987, Khare, Y. 1989).The study of the kinetics of Jeewanu, the autopoetic eukaryote was done by Srivastava. D. in1992.

The study of Jeewanu, the autopoetic eukaryote and its functional properties have revealed a process of utilization of solar energy and also its conversion to chemical bonds which perhaps nature did a few billion years back to initiate the formation of life on earth. In Algae the chloroplast-ferredoxin-hydrogenase system helps in splitting water. These microstructures have ferredoxin like material in them. Thus these microstructures can be used to split water and use the hydrogen formed as a source of energy in future.

Conclusion:

Recently a lot of work is done on abiogenesis some of which are as follows:

In 2001 Louis Allamandola demonstrated that organic material can be synthesized in deep space using a "Chill vacuum chamber"--a lot of biomolecules: nitriles, ethers, alcohols, ring-like hydrocarbons, and others.

In a complementary experiment, Jennifer Blank at Lawrence Berkeley National Laboratory reported: "Through subsequent chemical analysis, the team discovered that the initial amino acids in the mixture had linked together to form peptides, from which proteins can be formed."

In 2010 Craig Venter and his colleagues inserted a wholly artificial chromosome into a bacterial cell and produced the first artificial life form (a.k.a. "dial-a-genome"). While it may seem like artificial abiogenesis, it nevertheless involved some major cheating: the artificial chromosome was constructed using gene sequences of an *existing* organism.

As of 2011, Lee Cronin at the University of Glasgow is trying to start an evolutionary process in polyoxometalate-based "cells".

In 2014 a group of researchers managed to produce all four components of RNA by simulating an asteroid impact in primordial conditions.

A 2015 paper showed that the chemical precursors for the synthesis of amino acids, lipids and nucleotides, which would be required in a primitive cell, could have all arisen simultaneously through reactions driven by ultraviolet light. In 2015 the lander *Philae* discovered 16 organic compounds, four of which had never been detected on a comet before, on the comet 67P/Churyumov–Gerasimenko. Many of the organic compounds are important building-blocks of life.

In 2015, NASA scientists studying the origin of life managed to reproduce uracil, cytosine, and thymine from an ice sample containing pyrimidine under conditions found in space. A 2016 study showed that the building blocks of life can be replicated in deep-sea vents. These experiments have for the first time demonstrated that RNA molecules can form in alkaline hydrothermal chimneys.

Thus recent abiogenesis experiments performed show that Jeewanu can be considered much nearer to present day cell as it has already been proved to contain most of the essential ingredients and properties shown by present dayliving systems.

Unfortunately the work on Jeewanu has not got due recognition.

According to me, the work on Jeewanu needs much more attention of the present day scientists and it can not only prove to be a way forward in the field of Origin of life but also a good means to produce an alternative source of energy as it has the capacity to split water as already proved by scientists associated with the work on Jeewanu.

References:

1. ^ Jump up to:[a] [b] [c] [d] [e] *Dodd, Matthew S.; Papineau, Dominic; Grenne, Tor; Slack, John F.; Rittner, Martin; Pirajno, Franco; O'Neil, Jonathan; Little, Crispin T. S. (1 March 2017). "Evidence for early life in Earth's oldest hydrothermal vent precipitates". Nature. 543 (7643): 60–64. Bibcode:2017Natur.543...60D. doi:10.1038/nature21377. Archived from the original on 8 September 2017. Retrieved 2 March2017.*
2. ^ Jump up to:[a] [b] [c] *Zimmer, Carl (1 March 2017). "Scientists Say Canadian Bacteria Fossils May Be Earth's Oldest". The New York Times. Archivedfrom the original on 2 March 2017. Retrieved 2 March 2017.*
3. *. London: Royal Society. 361 (1470): 869–885. doi:10.1098/rstb.2006.1834. ISSN 0962-8436. PMC 1578735 . PMID 16754604.*
4. Jump up^ *Staff (9 May 2017). "Oldest evidence of life on land found in 3.48-billion-year-old Australian rocks". Phys.org. Archived from the original on 10 May 2017. Retrieved 13 May 2017.*
5. Jump up^ *"Researchers uncover 'direct evidence' of life on Earth 4 billion years ago". Deutsche Welle. Retrieved 5 March 2017.*
6. ^ Jump up to:[a] [b] *Johnston, Ian (2 October 2017). "Life first emerged in 'warm little ponds' almost as old as the Earth itself - Charles Darwin's famous idea backed by new scientific study". The Independent. Archived from the original on 3 October 2017. Retrieved 2 October 2017.*

7. Jump up^ *Wolpert, Stuart (19 October 2015). "Life on Earth likely started at least 4.1 billion years ago — much earlier than scientists had thought". ULCA. Archived from the original on 20 October 2015. Retrieved 20 October 2015.*
8. Jump up^ *Gomes, Rodney; Levison, Hal F.; Tsiganis, Kleomenis; Morbidelli, Alessandro (26 May 2005). "Origin of the cataclysmic Late Heavy Bombardment period of the terrestrial planets". Nature. 435 (7041): 466–469. Bibcode:2005Natur.435..466G. doi:10.1038/nature03676. PMID 15917802.*
9. Jump up^ *Maher, Kevin A.; Stevenson, David J. (18 February 1988). "Impact frustration of the origin of life". Nature. 331 (6157): 612–614. Bibcode:1988Natur.331..612M. doi:10.1038/331612a0. PMID 11536595.*
10. Jump up^ *Wade, Nicholas (25 July 2016). "Meet Luca, the Ancestor of All Living Things". The New York Times. Archived from the original on 28 July 2016.*
11. Jump up^ Darwin 1887, p. 18: "It is often said that all the conditions for the first production of a living organism are now present, which could ever have been present. But if (and oh! what a big if!) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, &c., present, that a proteine compound was chemically formed ready to undergo still more complex changes, at the present day such matter would be instantly devoured or absorbed, which would not have been the case before living creatures were formed." — Charles Darwin, 1 February 1871
12. Jump up^ *Miller, Stanley L. (15 May 1953). "A Production of Amino Acids Under Possible Primitive Earth Conditions". Science. Washington, D.C.: American Association for the Advancement of Science. 117 (3046): 528–529. Bibcode:1953Sci...117..528M. doi:10.1126/science.117.3046.528. ISSN 0036-8075. PMID 13056598.*
13. Jump up^ *Parker, Eric T.; Cleaves, Henderson J.; Dworkin, Jason P.; et al. (5 April 2011). "Primordial synthesis of amines and amino acids in a 1958 Miller* H_2S*-rich spark discharge experiment" (PDF). Proc. Natl. Acad. Sci. U.S.A. Washington, D.C.: National Academy of Sciences. 108 (14): 5526–5531. Bibcode:2011PNAS..108.5526P. doi:10.1073/pnas.1019191108. ISSN 0027-8424. PMC 3078417. PMID 21422282. Archived (PDF) from the original on 24 September 2015. Retrieved 8 June 2015.*
14. Jump up^ *Martin, William F. (January 2003). "On the origins of cells: a hypothesis for the evolutionary transitions from abiotic geochemistry to chemoautotrophic prokaryotes, and from prokaryotes to nucleated cells". Phil Trans Royal Society A. 358 (1429): 59–83. doi:10.1098/rstb.2002.1183. PMC 1693102. PMID 12594918.*
15. Jump up^ *Vlassov, Alexander V.; Kazakov, Sergei A.; Johnston, Brian H.; et al. (August 2005). "The RNA World on Ice: A New Scenario for the Emergence of RNA Information". Journal of Molecular Evolution. Berlin: Springer-Verlag. 61 (2): 264–273. Bibcode:2005JMolE..61..264V. doi:10.1007/s00239-004-0362-7. ISSN 0022-2844. PMID 16044244.*
16. Jump up^ *"Exploring Life's Origins: Protocells". Exploring Life's Origins: A Virtual Exhibit. Arlington County, VA: National Science Foundation. Archived from the original on 28 February 2014. Retrieved 18 March2014.*
17. ^ Jump up to:[a] [b] [c] *Chen, Irene A. (8 December 2006). "The Emergence of Cells During the Origin of Life". Science. Washington, D.C.: American Association for the Advancement of Science. 314 (5805): 1558–1559. doi:10.1126/science.1137541. ISSN 0036-8075. PMID 17158315. Archived from the original on 7 September 2015. Retrieved 15 June2015.*
18. Jump up^ *Orgel, Leslie E. (October 1994). "The origin of life on Earth". Scientific American. Stuttgart: Georg von Holtzbrinck Publishing Group. 271 (4): 76–83. Bibcode:1994SciAm.271d..76O. doi:10.1038/scientificamerican1094-76. ISSN 0036-8733. PMID 7524147.*
19. Jump up^ *Nelson, Kevin E.; Levy, Matthew; Miller, Stanley L. (11 April 2000). "Peptide nucleic acids rather than RNA may have been the first genetic molecule". Proc. Natl. Acad. Sci. U.S.A. Washington, D.C.: National Academy of Sciences. 97 (8): 3868–3871. Bibcode:2000PNAS...97.3868N. doi:10.1073/pnas.97.8.3868. ISSN 0027-8424. PMC 18108. PMID 10760258.*
20. Jump up^ *Schirber, Michael (1 March 2010). "First Fossil-Makers in Hot Water". Astrobiology Magazine. New York: NASA. Archived from the original on 14 July 2015. Retrieved 19 June 2015.*
21. Jump up^ *Perry, Caroline (7 February 2011). "Clay-armored bubbles may have formed first protocells" (Press release). Cambridge, MA: Harvard University. EurekAlert!. Archived from the original on 14 July 2015. Retrieved 20 June 2015.*
22. Jump up^ *Wenhua Huang; Ferris, James P. (12 July 2006). "One-Step, Regioselective Synthesis of up to 50-mers of RNA Oligomers by Montmorillonite Catalysis". Journal of the American Chemical Society. Washington, D.C.: American Chemical Society. 128 (27): 8914–8919. doi:10.1021/ja061782k. ISSN 0002-7863. PMID 16819887.*
23. Jump up^ *AbouMrad, Ninette; Vinogradoff, Vassilissa; Duvernay, Fabrice; et al. (2015). "Laboratory experimental simulations: Chemical evolution of the organic matter from interstellar and cometary ice analogs" (PDF). Bulletin de la Société Royale des Sciences de Liège. Liège, Belgium: Sociétéroyale des sciences de Liège. 84: 21–32. Bibcode:2015BSRSL..84...21A. ISSN 0037-9565. Archived from the original on 13 April 2015. Retrieved 6 April 2015.*
24. ^ Jump up to:[a] [b] *Michaelian, Karo (2017). "Microscopic dissipative structuring and proliferation at the origin of life". Heliyon. 3 (10): e00424. doi:10.1016/j.heliyon.2017.e00424. PMC 5647473. PMID 29062973.*
25. Jump up^ *Michaelian, K (2012). "HESS Opinions 'Biological catalysis of the hydrological cycle: Life's thermodynamic function'". Hydrology and Earth System Sciences. 16 (8): 2629–45. arXiv:0907.0040. Bibcode:2012HESS...16.2629M. doi:10.5194/hess-16-2629-2012.*
26. Jump up^ *Hartman, Hyman (October 1998). "Photosynthesis and the Origin of Life". Origins of Life and Evolution of Biospheres. Kluwer Academic Publishers. 28 (4–6): 515–521. Bibcode:1998OLEB...28..515H. doi:10.1023/A:1006548904157. ISSN 0169-6149. PMID 11536891.*
27. Jump up^ *Damer, Bruce; Deamer, David (13 March 2015). "Coupled Phases and Combinatorial Selection in Fluctuating Hydrothermal Pools: A Scenario to Guide Experimental Approaches to the Origin of Cellular Life". Life. Basel, Switzerland: MDPI. 5 (1): 872–887. doi:10.3390/life5010872. ISSN 2075-1729. PMC 4390883. PMID 25780958.*
28. *Abelson, P.H. (1966), Proc. Natl. Acad. Sci., U.S.A., 55, 1365.*
29. *Aristotle, Greek Philospher, (382-322 B.C.*
30. *Bahadur K. , Ranganayaki S. , Smith A. and Folsome C. (1980), Natl. Acad. Sci., India, Golden Jubilee Commemoration, Vol. 181-198.*

31. Bahadur K. and Ranganayaki S. (1980) (origin of life, a functional approach, M/S Ram Narain Lal and Beni Prasad, Allahabad, India.

32. Bahadur, K. (1967), Zbl. Bakt, 121, (2), 291-319.

33. Bahadur, K. and Gupta, J.L.(1972), Zbl. Bakt.,127(11),643-648

34. Bahadur, K. and Kumar, S. and Gupta, V.R., (1981), Proc. Nat. acad. Sci., India, II, 231-240.

35. Bahadur, K. and Kumar, S., (1980), Ravista do. Institute de. antibioticos Recife, vol. 20(No)(1/2),105.

36. Bahadur, K. and Ranganayaki, S. and Santamaria, L. (1958), Nature, 182, 1668.

37. Bahadur, K. and Ranganayaki, S. (1957), J. Acad. Sci. U.S.S.R, 754-55.

38. Bahadur, K.(1954),Photosynthesis of aminoacids from paraformaldehyde and potassium nitrate, Nature,173,1141.

39. Bahadur, K. and Ranganayaki, S. (1970), J. Brit. Interplanetary Soc., Vol. 23(12), 813-829.

40. Bahadur, K. and Ranganayaki, S.(1957), Proc. Natl. Acad. Sci. India, 26A, II, 154-162.

41. Bahadur, K. and Ranganayaki, S.(1966), Vijanana Parishad Anusandhan Patrika, 9(4), 171-82.

42. Bahadur, K. and Ranganayaki, S., (1964), Zbl. Bakt., 117(2), 567,574.

43. Bahadur, K. and Ranganayaki, S., kumar, A. and Srivastava, P., (1966), Zbl. Bakt., 120 (2), 740-52.

44. Bahadur, K. and Ranganayaki, S., Singh, V.P. and Kumar, S., (1975), Ravista do. Institute de. antibioticos Recife, vol. 15(No)(1/2), 33-36 .

45. Bahadur, K. and Ranganayaki, S., Verma,H.C., Srivastava R.B., Agarwal,K.M.L., Pandey, R.S.Saxsena, I., Malviya, A.N., Kumar, V., Perti, O.N. and Pathak, H.D.,(1963), Vijanana Parishad Anusandhan Patrika, 6, 63-117.

46. Bahadur, K. (1963), Vijanana Parishad Anusandhan Patrika, 6, 94-117.

47. Bahadur, M., (1986), in 'Studies in the Origin of Life', D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.

48. Bahadur,K. and Agarwal, K.M.L.(1964), Zbl. Bakt., 117, (2), 585-602.

49. Bahadur,K.,(1964-a), Zbl. Bakt., 117, (2), 585-602.

50. Bahadur,K.,(1964-b), Zbl. Bakt., 118, (2),671-694.

51. Bahadur,K.,(1966), in "Synthesis of Jeerwanu, the protocell", M/S Ram Narayan Lal Beni Prasad, Allahabad, India.

52. Bahadur,K.,(1967), Zbl. Bakt., 121(2), 291-319.

53. Baturin, G.N., Kochenov, A.V. and Shinkus, K.M., (1967), Geokhimiya, I, 41-50.

54. Bayer, A. (1870), Ber. 3, 63.

55. Beck, M. (1979), Kemiai. Koglemenyek, 50, 223-240.

56. Bernal, J.D., (1951), 'The Physical Basis of Life', Routledge and KeganParl, Lond.

57. Bhattacharya, S., (1982), "The study of Cytology of the primitive autotrophs", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.

58. Blum, H.F., (1961), American Scientist, 49(4), 479-501.

59. Blum, H.F., (1961), American Scientist, 49(4), 474-479.

60. Briggs, M.H. (1965), Space Flight, 7(4), 129-131.

61. Briggs, M.H., (1964), in 4th International Congress on Photoboilogy, Oxford, Aug. 1964, referred in Bahadur, K., 'Synthesis of Jeewanu, The Protocell', Zbl. Bakt. II, Abt., 121,312-315, 1967.

62. Butlerov, E.A. (1861), Justus Leibigs Ann. Chem., 120,295.

63. Cairns-Smith, A.G. (1971), The Life Puzzle, Oliver and Boyd, Edinburgh, 69, 71, 81,116-127, 131.

64. Cairns-Smith, A.G., (1966), J.Theoret. Biol., 10, 53-58.

65. Changeux, J.P., (1965), Scientific American, 212, 36.

66. Cloude, P.E., (1973), Econ. Creol., 68, 1135-1143.

67. Coehn, A. and Grote,S. (1912),Hernst Festechr, 136.

68. Dhar, N.R. and Ram, A. (1932), Nature, 129-205.

69. Dobritskaya, Yu. I., (1967), Agrokhimuja, 3, 81-91.

70. Dokuchaev, V.V., (1966), Soil inst. Moscow, Pochvovedenic, (9), 97-102.

71. Egami, F. and Yanagawa,H., ((1977), Proc. Japan Acad., 53, 45-52.

72. Egami, F., Kobayashi, Y. and Yanagawa, H., (1980), J. Biochem., 87, 855-869.

73. Engel, F.,(1933), Dialectic of Nature, Patizdat, Russian.

74. Fox, S.W., Harada, K. and Kendrick, J. (1959), Science, 129, 3357, 12.

75. *Ganti T. (2003): The principles of life(Oxford University Press,Oxford,U.K.)*

76. *Gautam, G.R., (1986), ' Studies in the Biological Martix' D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

77. *Goldacre, R.J., (1958), in 'Surface Phenomenon in Chemistry and Biology', Dennilli, J.F., Pankhurst, K.G.A. and Riddiford, A.C., 278-98, Pergamon Press, New York.*

78. *Groth, W.E. and Suess, H. (1938), Naturwissen Schaften, 26, 77.*

79. *Gupta, V.K., (1984), 'Perspective in Cytology and Genetics', (Ed.Mauna, G.K. and Sinha, V.), 4, 205-208.*

80. *Gupta, V.K.,(1980), " Cytological investigation of photo chemically formed self-sustaining molecular associations" D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad,Allahabad, India.*

81. *Haber, F. and Franck, J. (1944), Sitzhr, Preuss, Akad, Wiess, Physik, Math Klasse, 250.*

82. *Haldane, J.B.S., (1929), Rationalist Ann.: Science and Human Life, Harper Bros, New York and London, (1933), 148-49.*

83. *Hall, D.O. and Evans, M.C.W. (1969), Nature, 223, 1342.*

84. *Hall, D.O. (1973), Academic Brassileira de cienias, vol. 45, 'Supplements in New Trends in Photobiology', 71.*

85. *Harada, T. (1931), Ind. Eng. Chem., 23, 1424.*

86. *Harrara, A.L. (1942), Science, 96, 14.*

87. *Horowitz, N.H., (1959), Proc. First. Intern. Symp. 'Origin of Life on Earth', Moscow, Aug. (1957), Pergamon PressLondon, 106-107.*

88. *Huffman, J.F., Jn. (1981), Huffman Laboratories INC, Colorado, 111, 2790.*

89. *Ingram, V.M., The Biosynthesis of Macromolecules, Benjamin, New York. 1965,*

90. *Johnson, C.A., (1968), in 'Encyclopedia of the Chemical Events', 130, Beinhole.*

91. *Kamaluddin, Yanagawa, H. and Egami, F., (1979), J. Biochem., 85, 1503-7.*

92. *Keosan, J., (1968), Origin of Life, Reinhold, New York.*

93. *Kererwani, G. (1986), " A Study of the relationship between Jeewanu Structure and their ability of Photochemical Splitting of Water and Fixation of Nitrogen", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

94. *Kharbanda, M., (1987), "Study of the Chemical Transformation of Photochemically formed Organo-Molybdenum Microstructures", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

95. *Khare, Y., (1989), "Photochemical Splitting of Water by Organo- Molybdenum Jeewanu", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

96. *Kiemaier, F. and Haisch, K.H., (1963), Z. Tier Physiol. Tierenachr, Fuitermittee, 18(3), 159-92.*

97. *Kovalev, V.A. and Bensman, V. R., (1967), Dokl. Acad. Nauk., Beloruss, S.S.R., 11 (7), 624-8.*

98. *Kumar, R. (1983), "Studies in Primitive Photo Autotrouphs", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

99. *Kumar, S., (1981), "Studies in the Photochemical Molecular Evolution in Aqueous Systems", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

100. *Lawrence, H., (1965), Allen, Advan. Astrn. Astrophy. 3, 1-2.*

101. *Lipman, C.H., (1920), Amer. Museum, Novitates, 588.*

102. *Mastuno, K., (1986), Technological University of Nagaoka, Systems Laboratory, Nagaoka, Japan, 949-54.*

103. *Mathur, V. (1989), "Studies in the origin of Life", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

104. *Maurya, H.K., (1977), "Studies in the Abiogenesis of Amino Acids", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

105. *Mehta, R. (1984)," Study of the photolytic dissociation of water by Jeewanu, the Primitive Autotrophs", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India*

106. *Melevanya, E.M. (1963), Vopr. Pitaniya, 22(2), 63-6.*

107. *Miller S.L. and Urey H.C. (1959), Science, 130,245.*

108. *Mitchell, P., (1954), Symp. Soc. Exp. Biol. 8, 254.*

109. *Mueller, P. and Rudin, D.O., (1970), "Current Topics in Bioenergetics", 3, 157.*

110. *Murthy, M. S. V.B.S.N., (1980), "Photosynthesis of Amino Acids", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

111. *Neilands, J.B., (1972), Structure and Bonding, 11, 145.*

112. *Nyberg and Marwin, (1970), Canadian J. Plant Science, 50(2), 198-200.*

113. *Oparin, A.I. (1953), "The Origin of Life", Dovor publication, Inc. New York.*

114. *Oparin, A.I., (1924), Proiskhozhdenie zhizni, Izd.Moskovskii Robochii, Moscow.*

115. *Oparin, A.I., (1957), "The Origin of Life on Earth", Academic Press, New York.*

116. *Oparin, A.I., (1959), "The Origin of Life on Earth", Pergamon Press, New York.*

117. *Oparin, A.I., (1963), "Life –its Nature, Origin and Development", Academic Press, New York.*

118. *Pant, (1966), "The Book of Biochemistry", Technical Publication of India, 33, 93.*

119. *Pattee, H.H. (1966), in "Natural Automata and useful simulations, Pattee,H., Edelsack, E., Fein, I. and Callahan, A. (EDS), Spartan Books, New York, 77.*

120. *Pauling, L. (1960), "The Nature of the Chemical Bond", Cornell University Press, New York, 3rd Edition.*

121. *Pirie, N.W. (1959), First Intern. Symp., Origin of Life on the Earth, Moscow,1957, Pergamon Press, ed., London, 117-118*

122. *Pirie, N.W., (1937), "Perspectives in Biochemistry", Cambridge University Press.*

123. *Pirie, N.W., (1959), "The Origin of Life on Earth", Clark, F. and Synge, R.L.M.(Eds), Pergamon Press, London, 77-83.*

124. *Pirie, N.W., (1959), "The Origin of Life on Earth", Oparin, A.I. et al, Pergamon Press, London, 76.*

125. *Pradhan, D.N., (1977), "Effect of Antibiotics and Sulphur Drugs on the Formation of Abiogenic microstructures", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.*

126. *Raina, V., (1973), "Studies in Some Aspects of Abiogenesis of Organic Compounds of Biochemical Interests", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.*

127. *Rake, G. and Dnovick, (1946), J. Bact., 52,223.*

128. *Ramsperger, H.C. (1925), J. Am. Chem. Soc., 47, 79.*

129. *Ranganayaki, S., Raina, V. and Bahadur, K., (1972), J. Brit. Interplanatary. Soc., 27, 251-254.*

130. *Rao K.K., Morris P. and Hall D.O. (1978), presented at the workshop meeting on Hydrogenase, their catalytic activity, structures and functions, held at Gottingen.*

131. *Rao, K.K., Adams, A.W.W., Morris, P., Hall, D.O., Ranganayaki, S. and Bahadur, K. (1978), Abst. presented at the Biological Application of Solar Energy Symp. at Madurai, India, Proc. Base, (1978), Gnannman,A., Krishnamurthy, S. and Kahn, J.S.(eds), The Macmillan Co. of India, Madras, 201-204.*

132. *Robinowitch, F.I. (1945), "Photosynthesis" Vol. I, Inter Science publication, New York, 82.*

133. *Schrauzer, G.N. and Guth, T.D., (1977), J. Am. Chem. Soc., 99(22), 7189-7193.*

134. *Sharma, K., (1977), "Studies in Abiogenesis and Biopoiesis", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.*

135. *Shetternberg, L.E. et al, (1967), Dokl. Akad. Nauk. SSSR, 173(2), 435-7.*

136. *Sillen, L.G., (1961), in 'Oceanography', Sears, M., ed., A.A.H.S., Washington, D.C., 549-581.*

137. *Sillen, L.G., (1965), Arkiv. Kemi., 24, 431.*

138. *Sillen, L.G., (1967), Science, 156, 1189-1197.*

139. *Singh, S. and Singh, B., (1966), J. Indian Soc. Soil Sci. 14(1), 19-23.*

140. *Singh, Y.P., (1973), "Studies in Abiogenesis of Phospholipids", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.*

141. *Smirnova, B.I. and Smirnova, D.P., (1967), Creol. Geokhim. Goryuch. Iskop., No. 11, 94-8.*

142. *Smith A.E., Folsome C. and Bahadur K., (1981), Experientia, 37, 357.*

143. *Smith, A.E., Silver, J.J. and Steinmann, G., (1968), Experentia, 25(3), 255-258.*

144. *Smith, D.W. and Hanawatt, P.C., (1965), BioPhy. Soc. 9th Annual Meeting, San Francisco.*

145. *Spence, J.T. (1965) Utah State Univ. Logan, Z. (Ed), Naturwissen Med, GrundlagenFersch, 2 (3), 267-83.*

146. *Srivastava, M. (1977), "Studies in Abiogenesis ofAminoAcids", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.*

147. *Srivastava, P.L., (1984), "Comparitive Cytological Study of Jeewanu, The Protocell and Marigranules", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.*

148. *Srivastava, S., (1980), "Histochemical and cytological studies of Antibiotics treated photosynthetic microstructures", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

149. *Steinmann, G., Kenyon, D.H. and Calvin, M., (1965), Nature, 206,707.*

150. *Synder, L.E., Buhl, D. Zuckerman B. and Palmer, P. (1969), Physical Review Letters22 (13), 679.*

151. *Tayarentseva, M. Perker, M.Z. and Derozhkina, L.M., (1966), Vestal. Acad. Navak. Bebarues. S.S.R. Ser. Sel. Skagaspod, Navuk. 4, 21-3.*

152. *Tian, A. (1916), Am. Phys. Paris, 5, 248.*

153. *Tondon, R. (1987)," Studies in Molecular Evolution", D.Phil. Thesis, Dept. of Chem. Univ. of Allahabad, Allahabad, India.*

154. Umbreit, W.W., Buris, R.H. and Srauffer, J.F., (1951), " Manomeric Techniques and Tissue Metabolism", Burgess publisher Co.

155. Underwood, E.J>, (1971), "Trace Elements in Human and Animal Nutrition", Academic Press, New York, 208.

156. Upadhaya, G. (1977), 'Cytological and Histological Studies of Self Sustaining Coecervates", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.

157. Valla, B.L., (1959), Physiol. Rev., 39, 443.

158. Verma, M.L., (1970), "Studies in Abiogenesis of molecular Associations", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.

159. Verma, P. (1981), "The studu of Cytology of Photochemically formed Microsructures", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.

160. Verma, P.K., (1980), "Cytological Studies of Photochemically formed Jeewanu, The Protocell", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.

161. Wald, G. (1974), "Origin of Life", 5, 5-27.

162. Weiss, A., (1963), in 'Clays and Clay Minerals', 10th Conference, Swineford, A. (Ed), Pergamon Press, 191-224.

163. Werner, J.R., Rich, A. and Hall, C.E. (1962), Science, 138,139.

164. Zhukhoriaskaya, A.L., Zamyathina, A.A. and Wakashev, K.I., (1966), Dokl. Akad. Nauk. Belovass, S.S.R., 10, (11), 891-3.

165. Srivastava, D., (1991), "Study of the kinetics of Jeewanu the Autopoietic Eukaryote", D.Phil. Thesis, Dept. of Chemistry, Univ. of Allahabad, Allahabad, India.

166. Srivastava, D., (2017),Title: "Study of the effect of varying the concentration of zinc sulphate in the PEM on the morphological features of the 1.531211 BMJ24 Jeewanu (both PUOC and PUAC)." published in International Journal of Engineering Research and General Science (IJERGS),ISSN:2091-2730,Vol. 5,Issue 4, pp.66-71, July August,2017,Scientific Journal Impact Factor(SJIF) Value is 3.843,Index Copernicus(IC) Value for 2014 is 78.71

167. Srivastava, D., (2017)Title: "Study of the effect of varying the concentration of zinc sulphate in the PEM on the pH and blue colour intensity of the PEM of 1.531211 BMJ24 Jeewanu (both PUOC and PUAC)." published in International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization), (IJIRSET), ISSN (online):2319-8753, ISSN (Print): 2347-6710, vol. 6, Issue 7, July 2017, pp 13466-13472. DOI: 10.15680/IJIRSET. 2017.0607207. Impact Factor is 6.209

168. Srivastava, D., (2016)Title: "Effect of addition of NaCl on the functional properties of BMJ24 Jeewanu prepared under anoxygenic conditions (PUAC) in the water and in phosphate buffer of pH 6, 7 and 8 under anoxygenic conditions." published in International Journal of Engineering Research and General Science (IJERGS),ISSN:2091-2730, Vol. 4,Issue 6, pp.266-272, November-December,2016

169. Srivastava, D., (2016),Title: "Effect of addition of NaCl on the functional properties of BMJ24 Jeewanu prepared under anoxygenic conditions (PUAC) in the water and in phosphate buffer of pH 6, 7 and 8 under oxygenic conditions." published in International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization), (IJIRSET), ISSN (online):2319-8753, ISSN (Print): 2347-6710, vol. 5, Issue 12, December 2016, pp 21135-21140. DOI: 10.15680/IJIRSET. 2016.0512040. Impact Factor is 6.209

170. Srivastava, D., (2016),Title: "Study of the effect of NaCl addition to the PEM on the functional properties of BMJ24 Jeewanu prepared under oxygenic conditions (PUOC) in water and in phosphate buffer of pH 6, 7 and 8 under anoxygenic conditions." published in International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization), (IJIRSET), ISSN (online):2319-8753, ISSN (Print): 2347-6710, vol. 5, Issue 11, November 2016, pp 20046-20052. DOI: 10.15680/IJIRSET. 2016.0511081. Impact Factor is 6.209

171. Srivastava, D., (2016),Title: "Effect of NaCl addition to the PEM on the functional properties of BMJ24 Jeewanu prepared under oxygenic conditions (PUOC) in water and in phosphate buffer of pH 6, 7 and 8 under oxygenic conditions." published in International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization), (IJIRSET), ISSN (online):2319-8753, ISSN (Print): 2347-6710, vol. 5, Issue 10, October 2016, pp 18666-1871. DOI: 10.15680/IJIRSET. 2016.0510088. Impact Factor is 6.209

172. Srivastava, D., (2016),Title: "Variation in the blue colour intensity and the pH of the PEM of 1.531211SMJ29 silicon molybdenum Jeewanu when the PEM is irradiated with clinical mercury lamp and sunlight" published in International Journal of Engineering Research and General Science (IJERGS),ISSN:2091-2730, Vol. 4,Issue 5, pp.22-25, September-October,2016,Scintific Journal Impact Factor(SJIF) Value is 3.843,Index Copernicus(IC) Value for 2014 is 78.71

173. Srivastava, D., (2016),Title: "Study of the effect of addition of Sodium Chloride on the pH and blue colour intensity of the PEM of the BMJ24 Jeewanu" published in International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization), (IJIRSET), ISSN (online):2319-8753, ISSN (Print): 2347-6710, vol. 5, Issue 9, September 2016, pp16819-16824. DOI: 10.15680/IJIRSET. 2016.0509044. Impact Factor is 6.209

174. Srivastava, D., (2016),"Morphological changes in (0 + 15):30:10:20:10:10 SMJ8 Jeewanu on adding methanol and ammonium molybdate to the PEM of the Jeewanu both before and after exposure to Sunlight up to a total of 32 hours" published in International Journal of Advanced Research (Int.J.Adv.Res.), ISSN: 2320-5407, vol.4, Issue 8, 2016, pp1612-1614. DOI: 10.21474/IJAR01/1370. Impact Factor is 5.336

175. Srivastava, D., (2016), "Effect of irradiation of the PEM of 1.531211SMJ29 Jeewanu with clinical mercury lamp and sunlight of the morphological features of the silicon molybdenum Jeewanu" , International Journal of Engineering Research and General Science (IJERGS), Vol. 4,Issue 4, pp.372-376.

176. *Srivastava,D.,(2016),"Effect of addition of Methanol and Ammonium Molybdate to (0+15):30:10:20:10:10 SMJ8 Jeewanu on the pH and colour intensity of the PEM of the Jeewanu both before and after Exposure to Sunlight up to a Total of 32 Hours" ,International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization), (IJIRSET), vol. 5, Issue 8, August 2016, page15500-15504. DOI: 10.15680/IJIRSET. 2016. 0508201*

177. *Srivastava, D., (2016), "Study of the Effect of Variation in the Concentration of Mineral Solution in the PEM of 1.531211SMJ 38 before and after Exposure to Sunlight, on Morphology of 1.531211 SMJ 38". Int J Recent Sci Res. 7(4), pp. 10648-10651.*

178. *Srivastava. D., (2016), Effect of variation in the concentration of mineral solution on pH and colour intensity of the PEM of 1.531211 SMJ38 Jeewanu before and after exposure to sunlight, International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization), (IJIRSET), vol. 5, Issue 5, May 2016, pp 8065 8068. DOI: 10.15680/IJIRSET. 2016. 0505111.*

179. *Srivastava. D., (2012), "Effect of increase of concentration of formaldehyde in the PEM of 1.531211 SMJ8 on the proton release and degree of Mo* $^{6+}$ *reduction to Mo* $^{4+}$ *during the exposure to sunlight", Journal of Natural Science Research(IISTE), Vol 2, No.7, 2012, pp 56-59.*

180. *Srivastava. D., (2012), "Effect of variation in the concentration of ammonium molybdate in the parental environmental medium (PEM) on the pH and the photochemical reduction of Mo 6+ to Mo 4+ in the PEM of the Silicon Molybdenum Jeewanu 1.531211 SMJ8 both before and after exposure" , International Journal of Scientific and Engineering Research (IJSER), Vol 3, Issue 6, June-2012,pp750-754. DOI: 10. 14299/000000.*

181. *Srivastava. D., (2010), "Effect of Addition of Higher Concentration of Mineral Solution in the PEM on the colour intensity and the pH of the PEM during the formation of the Silicon Molybdenum Jeewanu SMJ8", Journal of International Academy of Physical Sciences, Vol. 14 No.1 (2010), pp. 131-136.*

Assistant Professor
Department of Chemistry
C.M.P. Degree College
Allahabad
email:srivastava.deepa@ymail.com