

Evolution

Origin of Life

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Origin of Life

Life is tenacious, and it completely permeates the surface layer of the planet. We find life beneath the deepest ocean, on the highest mountain, in the driest desert and the coldest glacier, and deep down in the rocks and sediments

Not knowing what conditions are needed for the emergence of life, it is only possible to speculate about its existence elsewhere in the universe.

Man has always been perplexed about the origin of life on earth. For centuries, a number of theories/hypotheses has been suggested to explain the origin.

Mythological Approach

Theory of Special Creation

Earlier, life was thought to be created by some supernatural force in a very short time. Most of the major religions of the world and civilization believe it to be a supernatural phenomenon of the past. By the traditional Judeo-Christian the whole world and all the species were created in just six days. Whereas, the Hindu Philosophy vividly describe the origin and evolution of life in the various incarnations of the Lord Vishnu.

Ancient and Medieval Approach

Theory of Panspermia Cosmozoic theory

Proposed by Richter (1865) and supported by Arrhenius

Life on earth arose elsewhere perhaps on a distant planetary body encircling a distant star and was transported to the earth surface by space resistant spores or some other means

This theory is supported by the discovery of carbon containing meteorites and these compounds range from carbohydrate to amino acids. But the amino acids contained in these meteorites had no optical activity and some of them do not appear in the proteins.

This theory due to Richter is not acceptable because of the fact that ;

If the size of the spore is large it will not be easily ejected from the planet on which it occurs and if it is small, it will not reach the earth because of the radiation pressure from the sun. In addition the ultraviolet radiations from the Sun will kill the ejected particles within about one day of interplanetary travel. This idea was proposed by Shklovskii and Sagan.

Theory of Spontaneous generation or Abiogenesis

Ancient Greeks, Chinese and Egyptians believed in spontaneous generation of life i.e. from non living things

According to Epicurus and Aristotle insects originated from sweat and crocodiles from mud.

Thales, Anaximander, Newton and Descartes supported this idea.

Theory of Biogenesis

Various experiments were performed to test the theory of spontaneous generation of life.

Redi's Experiment

Performed by Francisco Redi

He cooked a few pieces of meat and put them in three separate jars covered :

- (ii) with parchment paper
- (iii) with muslin cloth
- (iv) left open without any covering.

He observed

- (i) flies laid eggs but no maggots appeared
- (ii) flies laid eggs but no maggots appeared
- (iii) Maggots appeared in the jar left open.

Conclusion: Maggots do not appear spontaneously but arise from the eggs of the parent flies.

Spallanzani's experiment (by Abe Spallanzani) also proved that life doesn't originate spontaneously. According to him, air carries microorganisms or germs which germinate under favourable conditions when moisture and food is available

Pasteur's Experiment by Louis Pasteur

He mixed a mixture of sugar and yeast powder in a flask with water and carried out the following experiment:

Poured the nutrient solution into the flask.

Bent the neck of the flask in the shape of S using heat.

Liquid was boiled for several minutes so that preexisting bacteria are killed within the flask.

Solution was cooled which remained sterile and devoid of any growth of life for months.

Later when the neck was broken and flask was tilted, liquid came in contact with the microorganism or the dust particles. Bacterial colonies or molds appeared within few days.

Biochemical Origin

This theory proposed that organic compounds arose abiogenetically without intervention of living substances before. In 1922, a Russian biochemist Oparin delivered a lecture in Botanical Society in Moscow on the origin of life and outlined the conditions that were existing at the time of origin of life. Oparin and Haldane independently suggested that the primitive atmosphere of the earth was reducing and that organic compounds were formed in such an atmosphere.

This hypothesis was further explained with experimental support by Stanley Miller, Urey, Fox, Ponnampersuma and several others.

The present biochemical theory has separated the entire process into the following steps:

Origin of earth and its primitive atmosphere:

The earliest or primary atmosphere was undoubtedly like that of the outer "gas giants" of the solar system, consisting primarily of hydrogen and helium, with lesser quantities of methane, ammonia, and water vapor. More recent work suggests that much of this primary atmosphere may have been lost to the space during the short history of earth's molten period. According to this view, the primary atmosphere was replaced by out-gassing from the interior of the planet as it cooled. Based on the analysis of present-day out gassing from volcanoes, the secondary atmosphere was made up primarily of nitrogen, carbon dioxide, and water, with relatively little hydrogen, compared to the primary atmosphere. Secondary reactions would

have added gases such as ammonia and methane to this atmospheric "mix". The actual ratio of the various gases that made up the atmosphere at the time of the origin of life may never be known. What is important is that none of the models for the atmosphere include free oxygen. Lack of oxygen is consistent and comparable with the known atmospheres on any of the planets of the solar system i.e. the atmosphere on the earth was chemically of the reducing kind.

As the solid crust got formed with the initial cooling of the earth, much of the water that would make up the oceans was resident in the atmosphere in the form of water vapor. Astronomical evidence suggests that the Sun was sufficiently less energetic in terms of output during this period such that, as the surface cooled, much of this water might have been accumulated as ice. Fortunately, both methane and carbon dioxide are "greenhouse gases", which helped to retain solar energy as the planet cooled, resulting in the formation of liquid oceans as water vapor condensed from the atmosphere. The mode of ocean formation (a single sustained condensation event or multiple events) and timing of ocean formation are conjectural. The oldest sedimentary rock record (metamorphosed) from the Ishua Series in Greenland suggests that significant liquid water was indeed present by 3.8 Ga

Source and forms of energy on primitive earth:

Solar radiation or UV radiation

Electric discharge

Heat (e.g. from volcanic eruptions)

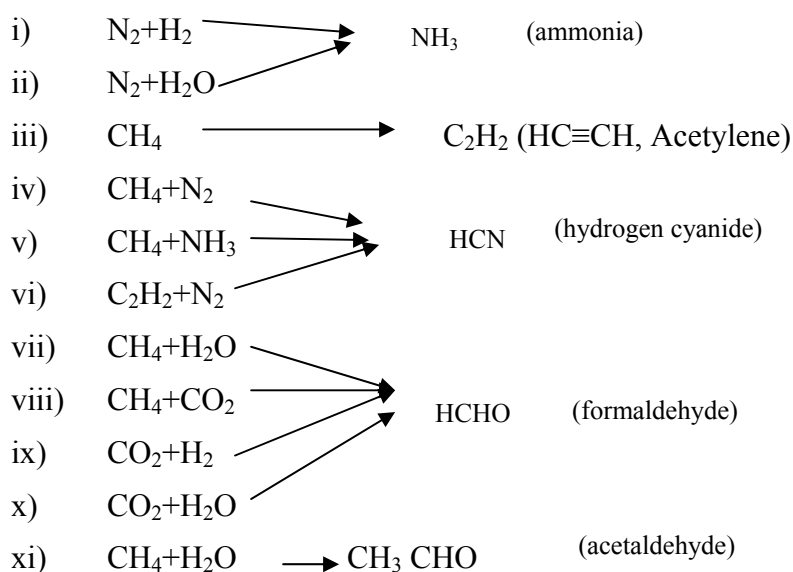
Ionization radiations and cosmic rays

Chemical origin of life or Chemogeny

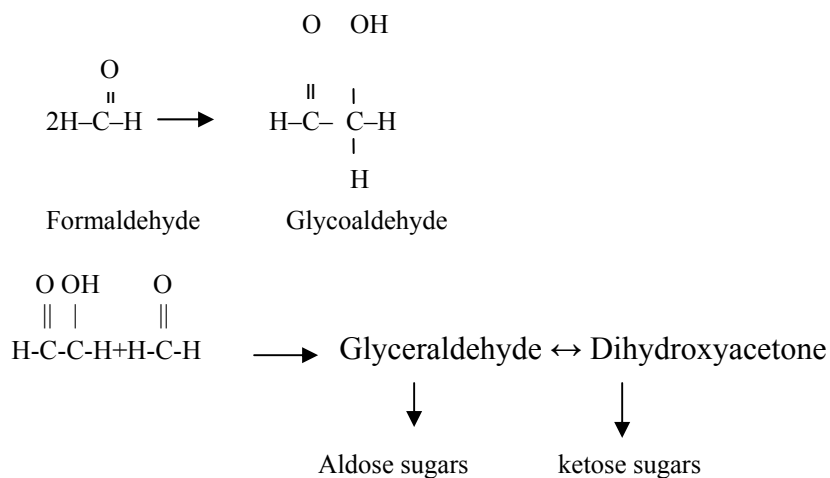
Oparin suggested that from the gases available on primitive earth more and more complex organic compounds were formed under the influence of various energy sources.

Step I: Origin of organic compounds

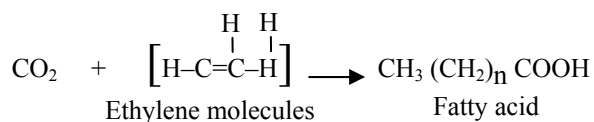
- a) Formation of hydrocarbons: A variety of simple hydrocarbons were formed in the following ways.



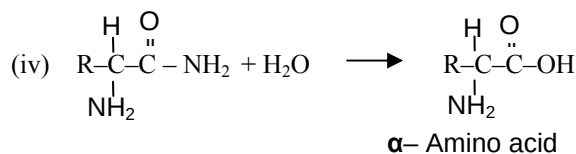
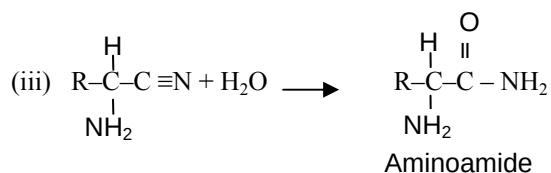
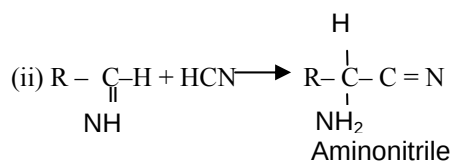
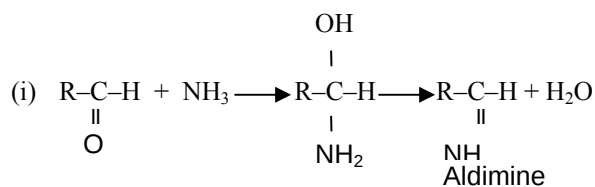
- b) Formation of Carbohydrates. Glucose, ribose and deoxyribose for, example, can be formed by condensation of formaldehyde



- c) Formation of fatty acids and glycerol: Condensation and polymerization of aldehydes and ketones and their oxidation resulted in the formation of fatty acids. Such compounds had lesser percentage of oxygen and long straight chains of carbon.



- d) Formation of amino acids: Steps of Amino Acid Synthesis



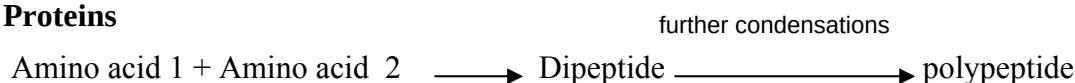
Thus we see that many of the basic organic molecules used in living organisms may have been or can be formed from relatively easy reactions.

Synthesis of carbohydrates, fatty acids, amino acids and other complex organic substances most probably occurred in the sea, which had been described by Haldane as the hot dilute soup containing molecules of these organic substances in abundance.

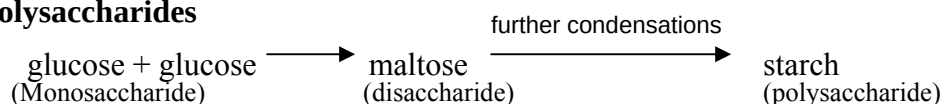
Step II: Formation of Macromolecules or complex organic molecules (polymerization)

In the hot organic soup the molecules of simple organic substances came together in increasing number, collided, reacted and aggregated forming new molecules of increasing size and complexity resulting in formation of more complex organic compounds like polysaccharides, fats, proteins, purines and pyrimidines etc.

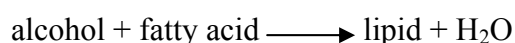
(a) Proteins



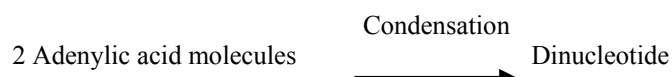
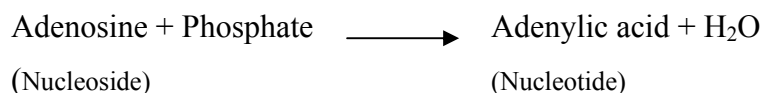
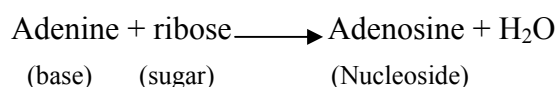
(b) Polysaccharides



(c) Lipids



(d) Nucleic acids



The compounds functioning as condensing agent has been identified in the primitive atmosphere. These include cyanamide, cyanogens, dicyanamide etc. Thus condensation of two amino acid into a dipeptide is coupled to the hydrolysis of cyanamide.

Under anhydrous conditions, heat can promote condensation and polymerization by causing the loss and evaporation of water molecules even in the absence of specific condensing agents.

Biological Evolution or Biogeny

Step III: Formation of primary organisms or Eubionts

Following events could have been responsible for the formation of first living cells:

- (i) Tendency of organic macromolecules to aggregate i.e. carbohydrate, fats, proteins and nucleic acids aggregated to develop into a precell. These precells resemble the virus of the present day.

These precells develop with following characteristic properties :

- 1) Properties of nutrition
- 2) Reproduction
- 3) Synthesis
- 4) Respiration
- 5) Control of all these activities
- 6) Adaptation to the existing environment

Oparin and Fox independently demonstrated the formation of aggregates of these polymers in the aqueous suspension. Oparin named them coacervates while Fox called them proteinoids or microspheres.

Step IV: Evolution of modes of nutrition:

- 1) Chemoheterotrophs : obtained their required energy by the formation of complex organic substances available i.e. the first mode of nutrition
- 2) Parasitism : some forms started living within the bodies of the other living cells and obtained energy for their sustenance from them.
- 3) Saprophytism: Obtained nutrition from the disintegration of molecular products from the dead and decaying bodies of the cells.
- 4) Chemoautotroph : Synthesize their own food, utilizing the chemical energy by the process of fermentation similar to the present day sulphur bacteria
- 5) Beginning of autotrophs
- 6) Anaerobic photoautotrophs : Use light energy predominantly in the visible range of solar spectrum to synthesize complex molecules using less complex and simple molecules. The first photosynthetic cell was anaerobic similar to the present day anaerobic bacteria and yeast cells.
- 7) Aerobic photoautotrophs: It is presumed that accumulation of CO₂ and formation of chlorophyll resulted in the evolution of the autotrophic forms. The first aerobic autotrophs were similar to the cyanobacteria

These aerobic photoautotrophs released free gaseous oxygen in the atmosphere.

Step V: Oxygen revolution and the present day atmosphere

With the increase in aerobic photoautotrophs, oxygen was liberated in the sea and then released and got concentrated in the atmosphere

Free oxygen reacted with methane and ammonia forming carbon dioxide and free nitrogen.

The oxygen molecules also reacted with each other to form ozone which formed a blanket around the developing atmosphere protecting Earth from harmful UV radiations

These events ultimately transformed the original reducing atmosphere into the modern oxidizing atmosphere with plenty of free oxygen accumulation in the atmosphere.

Free oxygen finally led to conversion of life forms into aerobic mode of respiration which yielded more energy on oxidation of food stuffs than through anaerobic mode of respiration or fermentation and eventually led to the evolution of the higher forms of life.

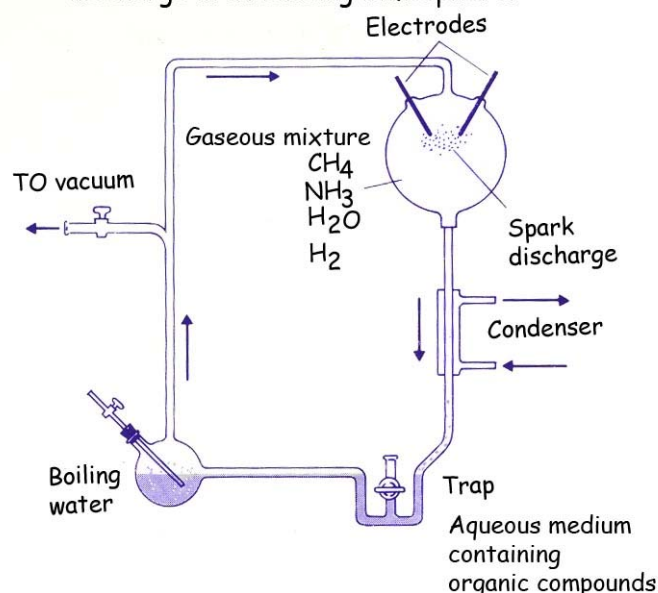
Experimental Evidence of Biochemical Origin of life

All evidences from the fields of cosmology, astronomy, chemistry, physics, and geology converge to indicate that the primordial crust of the planet Earth was formed between 4.6 and 4.5 billion years ago (4.6 to 4.5 Ga.).

According to this hypothesis, the primitive atmosphere of the earth was reducing and contained gases like ammonia, methane and carbon dioxide. The fact that such compounds can be observed in interstellar clouds in our galaxy and also in various carbonaceous meteorites that are believed to represent primordial material remaining in space from the original solar condensation 4.6 billion years ago lend support to this view. One such meteorite named Murchison which fell in Australia in 1969 contained more than 80 kg of carbonaceous material of which about one percent was the organic carbon. Upon analysis, this material included a greater concentration of amino acids that are normally used in proteins. The remarkable fact is that all the amino acids found in the meteorite are identical to the amino acids produced by sparking mixtures in laboratory experiments.

The first stage in the origin of life involves non-biological synthesis of simple biochemical "building blocks" (monomers), followed by the linkage of these units into more complex biochemical molecules called the polymers. Numerous experiments, involving interactions of water and gas mixtures analogous to those present in the early atmosphere with various energy forms such as electrical discharge, heat, ultra-violet radiation, etc suggest that a diverse array of monomers can be spontaneously formed as a result of reactions between elements and simple compounds that were present on the pre-biotic earth. These experiments, often called "Miller Experiments" in recognition of the pioneering work of Stanley Miller in 1953, produce varying mixtures of amino acids, urea, nucleotides, simple carbohydrates and fatty acids, and critical energy-rich molecules such as adenosine tri-phosphate (ATP) (fig 1). The fundamental basis of the energy metabolism of all living cells is the breakdown of ATP molecules. These experiments and others that followed indicate very strongly that the chemical environment that existed before the origin of life was probably not a chaos. Rather the earth possessed a significant portion of simple organic molecules that could participate in the formation of the living organisms.

FIG 1: Miller's experimental apparatus to demonstrate the synthesis of organic compound by electrical discharge in a reducing atmosphere.



According to the Step III of this hypothesis, the organic matters so formed by polymerization and condensation organize themselves under nonliving conditions that develop characteristics

of precells. Oparin prepared such droplet like structures resembling precells and called them as coacervates.

Coacervates

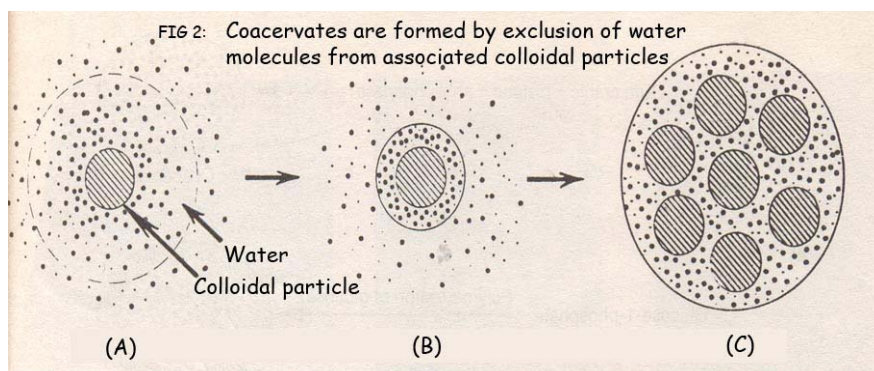
They are prepared artificially by mixing two oppositely charged colloids like gum arabic and gelatin. They develop into a droplet like structure because of special conditions of acidity and temperature (fig2). Therefore, it is believed that such drops must have got developed in the sea water. As there were no bacteria, molds and such living things which could bring about their decay, there was no free oxygen for oxidation. He claimed that these are the forerunners of the precells.

Characteristic Properties of Coacervates:

- 1) They possess simple but persistent organization.
- 2) They can float in the surrounding medium.
- 3) They can increase in their size
- 4) They could incorporate enzymes which would help to synthesize and hydrolyze starch i.e. they can assimilate.

Thus coacervates show some of the properties of the precells. However they lack:

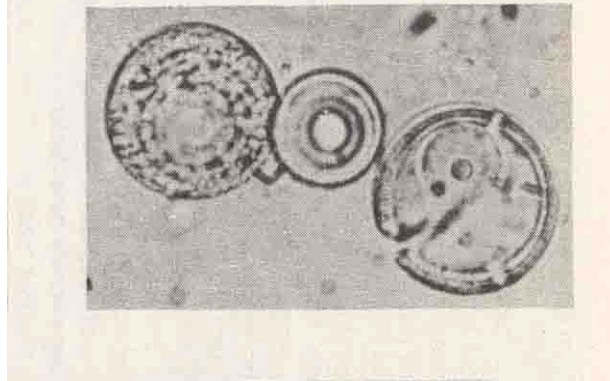
- (1) Membrane
- (2) Do not show selective absorption
- (3) They break off in solution if shaken vigorously
- (4) Smaller in size as compared to precells.



Microspheres

S.Fox heated a mixture of about 18 amino acids in anhydrous condition to about $160 - 200^{\circ}\text{C}$. On cooling the amino acids were observed to have linked together to form long chains which resembled to the polypeptide chains of proteins. When these were heated and cooled again they formed small cell like structure which he called proteinoids or microspheres (Fig 3).

FIG 3: Structure of microsphere



They show following characteristic properties:

- (1) Same size as bacteria
- (2) Stable
- (3) Divide by fission
- (4) They are bounded by double membrane as revealed by electron microscope
- (5) Show selective absorption
- (6) When Zinc is added to the solution of microsphere it splits ATP with the release of energy which means that microspheres release energy in the presence of metal catalyst.

However microspheres are neither precells nor living but they indicate the process that might have occurred in the ocean, resulting in the formation of precells and cells. This process of self assembly in coacervates and microspheres is also visible in the present day molecular structures such as T₄ phage and Tobacco Mosaic Virus (TMV).

Therefore life is believed to have originated from the organic soup

The direct fossil record for the origin and diversification of life are rare since rocks of this great age are rare and are confined to limited exposures in the interior of ancient continental shields. Much of the rock from this remote period is igneous in origin or has been subjected to such intense metamorphism that fossils that might have been present are either destroyed or altered beyond recognition. With the exception of layered columnar fossils called stromatolites, most of the fossils are microscopic cells about the size of modern bacteria, ranging from isolated cells to simple chains or filaments, and may be observed under microscope in the study of thin sections of promising rocks. The major challenge in studies of this type is differentiating actual microscopic fossils from inclusions or other small structures in the rock that might resemble simple cells. Interpretation of microscopic structures is essentially a matter of skill, imagination, experience and intuition on the part of a participating microscopist.

The earliest cellular remains recognized to date approximately 3.6 to 3.5 Ga, and include material from the North Pole, Dome area of Australia (3.56 Ga) and the Onverwacht Group of South Africa (3.54 Ga). All the microfossils from these deposits appear to be simple prokaryotic organisms with cells characterized by very small size, relatively simple structure and lacking an organized nucleus or other complex internal structure. In form, the fossils include isolated cells, small clumps or cellular aggregates, simple filaments, and laminated sheets of cells with each layer being one cell thick, accumulating in multiple layers resulting in the characteristic columnar fossils known as stromatolites. The fossils appear to document a diverse array of organisms including bacteria which obtain their energy from the

breakdown of organic molecules (heterotrophic metabolism) to photosynthetic cyanobacteria that utilize solar energy to synthesize complex organic molecules (autotrophic metabolism). The extent of diversity represented by the earliest known microfossil assemblages suggests that the actual origin of life occurred before 3.6 Ga.

Structurally and chemically, the simplest living cells are heterotrophic, bacteria-like cells that synthesize ATP (the universal energy "currency" of life) using energy obtained from the breakdown of carbohydrates and other organic polymers. The first cells probably functioned in this manner and utilized molecules from the surrounding "organic soup" as source of their food. Such breakdown reactions are inefficient, in the absence of oxygen in that the "food" molecules are only partially dismantled and the ATP yield is minimal. However the process does work. This simple reaction system, known as "glycolysis" or "anaerobic respiration", is still used by all living prokaryotic and eukaryotic cells as the preliminary step in cell respiration.

Limitations in the availability of "food" molecules might well have resulted in the eventual extinction of these first life forms but for the appearance of autotrophic prokaryotes that could use an outside energy source to synthesize energy-rich molecules. The most successful of these early autotrophs were the cyanobacteria, which used light (photosynthesis) as a source for their energy. The evolution of the cyanobacteria may well be linked to the intense U.V. levels near the ocean surface as a result of the lack of oxygen and an ozone shield. If cells were to survive in shallow water, one solution would be the internal shields to protect the cell from exposure to U.V. Chlorophyll is a pigment that absorbs blue and U.V. light and chlorophyll pigments, incorporated into membranes, should make an effective U.V. shield. Early cyanobacteria, with such shields, could survive in shallow sunlit waters. Chlorophyll, when excited by U.V. exposure, generates "high-energy" electrons. The development of very simple electron transport systems would allow some of this energy to be channeled into ATP synthesis. With ample supplies of ATP, synthesized from solar energy, cyanobacteria could essentially operate anaerobic respiration reactions "in reverse", producing energy rich molecules like sugars from simple molecules such as carbon dioxide. This very simple form of photosynthesis does not produce oxygen, and is essentially identical to a little-used form of photosynthesis (cyclic photo-phosphorylation) found in all plant-like cells. The early appearance of photosynthetic cyanobacteria represented the first stable balance between photosynthetic "producers" and heterotrophic "consumers" that has been the basis for the structure of ecosystem ever since that time.

The most successful cyanobacteria were the stromatolites and their photosynthetic activity provided the resource base for diversification of heterotrophic prokaryotes. Their photosynthesis did require sources of hydrogen, which initially would have been available directly from the atmosphere either as hydrogen gas or hydrogen sulfide. Hydrogen, the lightest of the known elements, was the gas most prone to leakage into space and, around 2.5 Ga., cyanobacteria did face a hydrogen crisis. The solution was to adapt itself to the use of a new hydrogen source – water. Elaboration of the light reactions of photosynthesis led to a new reaction (photolysis) that splits water into its gaseous components hydrogen and oxygen. The oxygen was an unnecessary (and toxic) byproduct that was released into the surrounding environment.

As a result of this new variant of photosynthesis, oxygen gradually began to accumulate in the atmosphere between 2.5 and 2.0 Ga., creating a serious biological crisis. Oxygen is a reactive gas that is toxic to cells and, as oxygen levels increased (essentially as an oxygen pollution of the atmosphere); all cells were increasingly at risk. The solution to this crisis was the evolution of new variations on respiratory metabolic pathways that stripped hydrogen from "food" molecules and linked them up to any oxygen molecules entering the cells. The

evolution of this new metabolic variant, known as aerobic respiration, had two consequences. The first was the protection of the cell from oxygen (the water produced when hydrogen was combined with oxygen was harmless) while the second was a huge increase in metabolic efficiency. Being able to strip hydrogen from complex molecules implied that food molecules such as sugar could be broken down completely to carbon dioxide and water with an ATP yield that was ten to fifteen times greater than what could be achieved with anaerobic metabolism. Aerobic cells that could metabolize oxygen were thus not only protected from its toxic effects, but also enjoyed a ten-fold increase in available energy from the same quantity of food intake.

The large increase in energy yields brought about by aerobic metabolism provided the necessary energy resources for rapid evolutionary innovation between 2.0 and 1.5 Ga., leading to the appearance of larger and more complex eukaryotic cells and, after 1 Ga., the evolution of complex multicellular life forms. In effect, photolysis created and maintained the earth's oxygen-rich atmosphere, a chemical anomaly with respect to all other atmospheres in our solar system. Aerobic respiration, a metabolic solution to the problem of increasing oxygen levels in the atmosphere, led to the evolution of complex, multicellular life forms.

Protein – first or RNA –first Hypothesis

Which came first, DNA, RNA or protein? Proteins were considered by many to be the only organic molecules in living matter that could function as catalysts. DNA carries the genetic information required for the synthesis of proteins. The replication and transcription of DNA require a complex set of enzymes and other proteins. How then could the first living cells with DNA-based molecular biology have originated by spontaneous chemical processes on the prebiotic Earth? Primordial DNA synthesis would have required the presence of specific enzymes, but how could these enzymes be synthesized without the genetic information in DNA and without RNA for translating that information into the amino acid sequence of the protein enzymes? In other words, proteins are required for DNA synthesis and DNA is required for protein synthesis. This classic "chicken-and-egg" problem made it immensely difficult to conceive of any plausible prebiotic chemical pathway to the molecular biological system. Lipmann and others have provided support in favour of protein as self replicating system by showing that at least two antibiotics produced by spore forming *Bacillus brevis* bacteria are formed exclusively by enzymes in the absence of mRNA while others suggested that RNA molecules might have formed the first self-replicating chemical systems on the primitive earth.

They carry genetic information and (unlike DNA) occur primarily as single-stranded molecules that can assume a great variety of tertiary structures, and might therefore be capable of catalysis, in a manner similar to that of proteins. The problem of which came first, RNA or proteins, would then be resolved.

Self-replicating RNA-based systems would have arisen first, and DNA and proteins would have been added later. But in the absence of any direct demonstration of RNA catalysis, this suggestion remained only an interesting possibility.

But in early 1980's, [Sidney Altman](#) and [Thomas Cech](#), discovered independently a kind of RNA that could edit out unnecessary parts of the message it carried before delivering it to the ribosome. Since RNA - ribonucleic acid - was acting like a type of protein known as an enzyme, Cech called his discovery a **ribozyme**.

The discovery that RNA molecules could act as catalyst rocked the world of molecular biology. RNA being able to cleave itself was all well and good, they argued, but what about

all the other chemical reactions that RNA would have to perform as the sole information molecule and enzyme?

Wilson found that ribozymes could carry out alkylations a hundred times faster than the protein which are normally found responsible for it in a series of experiments designed to mimic evolution.

Given the right materials, RNA molecules can make copies of themselves that are more or less identical. Surprisingly, it is the less-identical ones - those that have errors in them - that win over time. Subtle differences may make an RNA better able to put carbon and nitrogen together - or render it completely useless, which is what usually happens. By selecting the RNAs that could speed alkylation and then letting them reproduce, generation after generation, Wilson eventually wound up with a group of RNAs that were really good in sticking the atoms together.

Natural evolution takes much longer, centuries and millennia rather than weeks and months. But the process is essentially the same, and Wilson's experiments provided the kind of support that RNA controls other reactions and change them - like turning cancer genes off or growth hormone production on.

A second impetus to the RNA world hypothesis came from the cluster of technical innovations now known generally as ribozyme engineering. Naturally occurring RNA catalytic activities are actually restricted to a small set of highly specialized reactions, e.g., the processing of RNA transcripts primarily in eukaryotic cells. However, ribozyme engineering, made possible by techniques such as DNA sequencing, *in vitro* transcription and the polymerase chain reaction [PCR], allow molecular biologists to manipulate RNA to whatever extent the molecule allows. Thus, the catalytic repertoire of RNA can be expanded beyond the naturally occurring activities -- in the main, by two broad strategies of ribozyme engineering.

Judging from the progress in ribozyme engineering in recent years, it seems likely that new and improved types of RNA catalysts will be produced in the years to come ahead. Moreover, molecular biologists may discover additional catalytic roles for RNA in living cells.

Instead of nucleic acids **Cairns-Smith** suggested that the primitive self – replicating unit may have been composed of organic, **clay- like silicate crystals** or layered clay mixtures. These crystals are believed to possess some self replicatory activities. According to Cairns-Smith, nucleic acids such as RNA could have been incorporated into such an assembly, followed by the formation of peptides and the evolution of a protein synthesizing system. Therefore, some biologists have placed emphasis on the possibility that either protein themselves or protein-nucleic acid combinations were the first self replicating systems