Evolution - Origin of Life - Part 1

Objectives

After going through this lesson, the learners will be able to understand the following:

- Evolution of Universe and Our Solar System
- Origin of Earth and the primitive Earth
- Origin of life
- Evolution of Oxygen
- Role of water in origin of life

Content Outline

- Introduction
- Evolution of Universe and Solar System
- Origin of Earth
- Origin of Life
- Evolution of Oxygen
- Role of Water in Origin of Life

Introduction

The vast complex forms of diversity of life that we see on our planet is a product of a long journey of evolution. This variety of living organism is called *Biodiversity*. Though there are a lot of different forms of life yet there is so much in common. This raises many questions regarding our scientific explanation to the origin of life on earth “Where did all these life forms come from?”, “How living organisms developed from inanimate matter and how such a vast variety of life forms developed on earth? What were the ideal conditions in which simple organic molecules gave birth to the first forms of life? To find answers to these questions one needs to trace the origin of life in the backdrop of the evolution of the universe itself. In this unit we would try to understand the origin of the universe and our solar system, the origin of earth and what were the conditions on primitive earth , the various theories of origin of life , the experimental evidences for evolution of life , the first life forms , evolution of oxygen and its effect on evolution , and finally the role of water in origin of life .

The Universe and the Solar System

It seems clear now with the photographs taken from the Hubble space telescope and mathematical calculations that the age of the universe is around 13.8 billion years old. However, one of the most accepted theories about the origin of the universe suggests that the universe originated with a big bang (thermonuclear explosion) of an extremely dense entity (George Lemaitre's BIG – BANG THEORY, 1931). It talks of a singular huge explosion unimaginable in physical terms. The universe expanded and the nebula of gases arising from the explosion Hydrogen and Helium formed sometime later. The gases condensed under gravitation and formed the galaxies of the present day universe. Our universe is the vast empty space around us that consists of stars, the solar system, galaxies etc. The galaxies are a collection of stars and there are about 100,000 million galaxies. Our earth belongs to the galaxy called the Milky way or the Akash Ganga which contains about 100 billion other stars. Stars are glowing heavenly bodies and our sun is also a star that supplies a constant source of energy for us. According to the Nebular theory given by P.S Laplace in the year 1755 according to this theory the solar system arrived in its current form after collapsing form of molecular gas cloud of our solar nebula which gradually contracted to form cloudy mass of cosmic dust and gases the dense center of the nebula developed to form the sun and the material in the flattened region around the center developed onto planets and other heavenly bodies.

The Origin of Earth

Geological proofs show that Earth is about 4.6 billion years' old the earth was formed over a course of 100 million years where several pieces of cosmic debris attracted one another however there is a possibility of it being hit by very large pieces that led to melting of the earth, later the various elements rearranged themselves according to density. The densest elements formed the core and the radioactivity generated heat which melted which and converted the interior into molten rock, the moderately dense floated to the surface and the least dense elements including hydrogen and nitrogen formed the first atmosphere. The initial atmosphere was reductive and was very different from what we see today. The earth was still bombarded by meteorites and asteroids and it led to cosmic H_2O from the meteorites and from the crust of the earth . This gaseous H_2O rose and got mixed with other gases and formed an incredible dense cloud over the earth. The hydrogen already present in the primitive environment reacted with Nitrogen, Carbon and Oxygen to form compounds like CH_4, NH_3 and H_2O. Initially the lithosphere and atmosphere was formed, later the

Hydrosphere was formed. The surface temperature of the earth was 5000- 6000 degree Celsius and high energetic UV rays persisted during that time. However in the primitive atmosphere there was absence of free Oxygen. These radiations triggered Photochemical reactions and about 3.8 billion years ago earth's surface cooled enough to remain as a liquid.

The Origin of Life

The origin of life on earth from inanimate matter is known as biopoiesis (*bios*-life , *poiesis* – making) which occurred about 4000-4200 million years ago .
Several theories have been proposed in order to explain the origin of life.

Theory of Special Creation: It says that life was created by some supernatural power either once or at successive intervals. All religions commonly preach that life was created by God, the different forms of life were created by a supreme power, the God. This theory also claims that life is immutable and all living organisms are not interrelated to each other in any way. This theory is based on faith and has no scientific basis.

Cosmozoic Theory (Theory of Panspermia): It is also called inter planetary theory. Cosmozoic theory was proposed by Richter (1865) and supported by Arrhenius (1908) . Richter believed in immortality of life like steady state theory but not on stability of life forms. The theory states that life had reached the earth from some other heavenly body in the form of resistant spores of simple organisms (called cosmozoan/panspermia) in meteorites or in spaceships. For example, the discovery of liquid water under the surface of Jupiter's ice-shrouded moon Europa and suggestions of fossils in rocks from Mars lend some credence to this idea. The hypothesis that an early source of carbonaceous material is extraterrestrial is testable, although it has not yet been proven.

The Theory of Spontaneous Generation or Abiogenesis: Spontaneous generation is the hypothesis that some vital force contained in or given to organic matter can create living organisms from inanimate objects. This theory was proposed by Von Helmont. Many ancient Greek philosophers including Aristotle supported this theory. Spontaneous generation was a widely held belief during the middle ages till latter half of the 19th century. According to Aristotle, leaves falling from a tree transformed into fishes when they fell in a pond etc.
Another often-used example was the generation of maggots from meat that was left in the open. This theory was disapproved by Francesco Redi in 1668 with a classic experiment.

- **Redi's experiment-** Redi suspected that flies landing on the meat laid eggs that eventually grew into maggots. To test this idea, he devised an experiment. He first cooked flesh in order to kill all microscopic organisms that were alive. He divided the cooked flesh in three jars. One jar was covered with parchment, one with muslin cloth and the last jar was left open. The flesh in all the three jars was left to rot and the flies got equally attracted to all the three jars. However maggots grew only in the uncovered jar. The flies could enter the open jar and lay their eggs, the other covered jars were free from maggots. The maggots actually developed from the eggs and not directly from decaying flesh.

- **Spallazani's Experiment-** He conducted an experiment in 1768. He put broth into two flasks (glass containers) and sterilized them both by boiling the broth. He kept one of the flasks open to the air. The other flask was sealed up to keep out any organisms that might be floating in the air. He observes that microorganisms developed only in the uncovered flask. From this, Spallanzani concluded that the microorganisms did not come from the broth, but were in the air that entered the flask. Therefore, not even microorganisms came from nonliving things.

- **Pasteur's Experiment-** Louis Pasteur, however, allowed air to enter the flask of sterile broth. He performed the same type of experiment as Spallanzani, except both of his flasks allowed air to enter. He kept the neck of one of the flasks straight so that both air and microorganisms could enter. The other flask had an S-shape neck that would allow air to enter, but not microorganisms. The broth in the straight neck flask became contaminated with microorganisms. The broth in the flask with an S-shaped neck did not become contaminated. Therefore, Louis Pasteur showed that even though air could get in the flask, the broth did not produce microorganisms. Scientists finally were convinced that living things, no matter how small, do not come from nonliving things. Thus the theory of biogenesis states that living things come only from other living things. For example, mice come only from mice, and microorganisms such as bacteria can only come from other bacteria.

Chemosynthetic Theory of Origin of Life- This theory states that life originated on earth through a series of chemical reactions that took place around 4 billion years ago . The theory was proposed by A.I.Oparin and J.B.S Haldane in 1928 the theory believed that primitive life

originated in water bodies and non living organic molecules such as Nucleic Acids and Proteins underwent a series of reactions to form the first primitive forms of life .

Chemogeny (Chemical Evolution)

Initially due to extremely high temperature elements like H,O,C,N were not able to bond together, with gradual cooling of earth with time, these free atoms came together and formed simple compounds like nitrides, oxides, ammonia, methane, cyanide. These simple compounds later reacted under the influence of energy from UV light radiations, Volcanic eruptions, electrical energy produced during lightning helped in the formation of simple organic molecules .

The synthesis of carbohydrates, fats and amino acids and other complex organic compounds probably occurred in sea which had been described by Haldane as “The Hot Dilute Soup”.
It is in this hot organic soup the first molecules of simple organic substances came together in increasing numbers. These molecules collided and then reacted and aggregated in forming new molecules of increasing size and complexity. Simple sugar units combined to form large sugar or starch molecules. Fatty acids and glycerol united to form fats, sugar, nitrogenous bases and phosphates combined into nucleotides which polymerized into nucleic acids. Amino acid units joined to form polypeptides and proteins. Water and ammonia were probably the first compound molecules of primitive earth. First organic compound was methane. Later on hydrogen cyanide was formed. Formation of protein molecules is considered a landmark in the origin of life.

Oprain (1924) observed that if a mixture of a large protein and a polysaccharide is shaken, coacervates are formed. The coacervates contain mainly proteins, polysaccharides and some water. Oparin ‘s coacervates also show a simple form of metabolism. As these coacervates do not have lipid outer membranes hence they cannot reproduce. Thus they do not fulfill the requirement for probable precursor of life. When mixtures of artificially produced organic compounds are mixed with cool water, the microsphere is formed.

Sydney fox (1950) heated a mixture of 18 amino acids to temperature of 130 to 180^{o} C. He obtained stable, protein-like macromolecules which he named proteinoids. When the proteinoid material was cooled and examined under microscope, fox observed small spherical cell like units that had arisen from aggregation of proteinoids. These aggregates were called

the proteinoid microsphere. The first non-cellular forms of life could have originated 3 billion years back. They would have been giant molecules (RNA, Proteins , Polysaccharides etc.) Under electron microscope, concentric double layered boundaries around them have been observed through which diffusion of material occurs.

Experimental proof of Oparin and Haldane's theory

Oparin-Haldane's theory of chemical origin of life is accepted by majority because experiments have been performed that prove this theory. Most famous experiment is Stanley Miller and Harold C. Urey's Experiment.

Simple organic compounds could be formed in nature in the manner explained by Oparin-Haldane was demonstrated through a simulation experiment in 1953 by Stanley L.Miller, a biochemist, and Harold C. Urey, an astronomer. They designed a glass apparatus (named spark discharge apparatus) comprising a gas flask, a condenser and a liquid flask interconnected with tubes and fitted with sources of energy.

The apparatus simulated the conditions on the primitive earth, including a "reducing atmosphere" (gas flask) and an "ocean" (liquid flask). They circulated in the apparatus a mixture of methane (CH_4), ammonia (NH_3) and hydrogen (H_2) in the ratio of 2:1:2 and water vapour (H_2O) at 800^0 C which is believed to prevail in the ancient atmosphere. Energy for the interaction of the gases present in the mixture was provided by electric sparks of 75000 volts from electrodes in the gas flask. Here, energy was provided as heat with an electric heater (simulated lightning).

Then the gases were condensed in a narrow tube and passed through a liquid flask. Here, energy was provided as heat with an electric heater (simulated volcano).

They kept their experiment working continuously for 18 days. A mixture of small organic molecules was formed in the gas flask (atmosphere) and was carried by condensation (rain) to the liquid flask (ocean). Analysis of these products showed presence of amino acids such as glycine, alanine, aspartic acid , adenine and simple sugars such as ribose. Thus it proved the Oparin/Haldane assumption that the prevailing conditions on primitive earth simulated formation of simple organic compounds from inorganic compounds which eventually give rise to life.

Biological Evolution (Biogeny)

Biogeny (Formation of Primitive Life)

Initially scientists were puzzled whether proteins were formed first or the nucleic acids. In accordance with one of the hypotheses nucleic acid evolved first and later they controlled the formation of proteins .As proteins can be formed based on the information present in the nucleic acids so in one way we may believe that nucleic acid evolved first. But for cellular physiological processes like replication of nucleic acid enzymes are needed which is also a form of protein thus it was like the hen and the egg paradox. However this puzzle was later solved with the discovery of rRNA (Ribozyme) thus the genetic code was based on RNA that may catalyze reactions like formation of lipids that could later form plasma membrane and proteins. Thus RNA has been the first polymer and some form of reverse transcription may give rise to DNA. But still it is not clear how living organisms gained the ability to reproduce. Some chance association of proteins, purines, pyrimidines and other organic compounds might have given rise to a system that could reproduce.

A thin limiting membrane was developed around the cytoplasm by the folding of a monolayer of phospholipids to form a cell-membrane. It is thus possible that first cells arose in the same way as coacervates were formed in primitive water bodies. The first "cell-like" structures with division power were called "eobionts" or "Pre-cell". Such first cellular forms of life originated about 2,000 million years ago.

These were perhaps similar to Mycoplasma which gave rise to Monerans (cells without a well defined nucleus) and Protistans (cells with distinct nucleus). *Progenote* is the early one celled common ancestor of eubacteria, archaebacteria and eukaryotes

The Monerans later evolved into bacteria and cyanobacteria and the anaerobic chemoautotrophs . The chemoautotrophs obtain energy by fermentation of complex organic substances available to them from the sea broth. The chemoautotrophs synthesized organic material from inorganic raw material. A certain protocell turns photosynthetic and evolved to produce photoautotrophs "The first photosynthetic cells. Gradually with anaerobic photo autotrophs evolved to give rise to aerobic one . These organisms then released free oxygen in the atmosphere; these organisms appeared about 3.5 billion years ago. The free oxygen then reacted with the already present methane and ammonia present in the primitive atmosphere to release CO_2 and free N_2.

Effect of Oxygen on Life

With the presence of a lot of fossil evidence at our hand there is evidence that photosynthetic bacteria became common in shallow seas around 2.2 billion years ago; they were steadily producing oxygen as an outcome of the photosynthetic reaction . This oxygen then combined with the Iron in the ocean to form iron oxides which settled to form bands at the base of the ocean floor . Thus without iron the ocean changed its colour from brown to blue-green . Later the oxygen started to accumulate in the atmosphere and concentration of methane and hydrogen sulfide began to decrease as the ozone layer was formed .

Initially with the rise of oxygen in the atmosphere some of the organism got extinct however several other life forms evolved new more efficient metabolic pathways that used oxygen for respiration.

Summary

The origin of life on earth can be understood only against the background of the origin of the universe, especially earth. Most scientists believe chemical evolution, i.e., formation of biomolecules preceded the appearance of the first cellular forms of life. The subsequent events as to what happened to the first form of life is a conjectured story based on Darwinian ideas of organic evolution by natural selection.