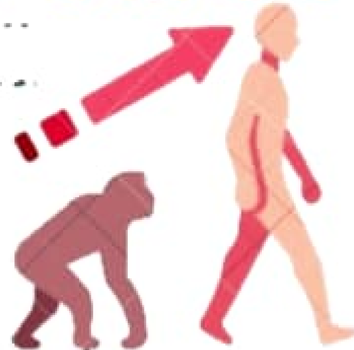
Krishnagar Academy

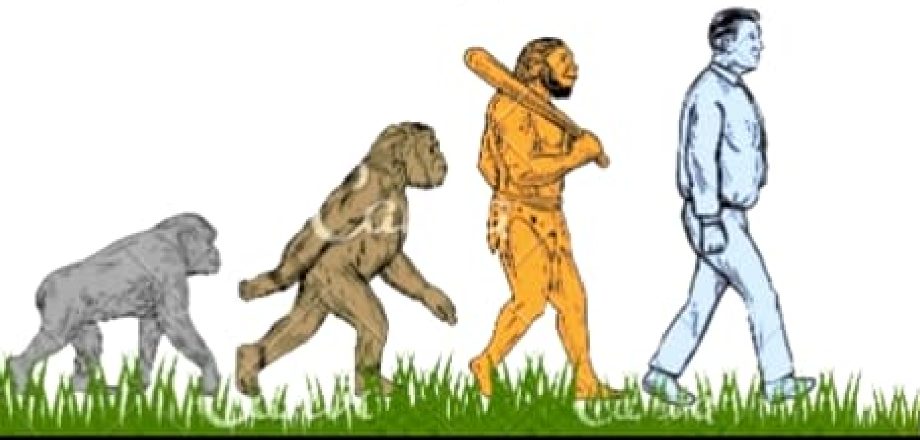
Evolution



chapter-7

BIOLOGY

CLASS 12



Life is the power that an organism possesses to maintain and reproduce itself. The origin of life is considered a unique event in the history of universe.The origin of life has been the most puzzling problem for biologists since the ages. They have tried to answer the question that in which form the life originated on this earth? There are several diverse views regarding the origin of the earth, and indeed the universe.

UNIVERSE AND ORIGIN OF SOLAR SYSTEM

It is believed that the **Cosmos**, which comprises all the material of reality, originated 10-20 billion years ago. The prevalent view is that Cosmos originated with a massive explosion of tightly condensed matter billions of years ago—the **big bang** theory. It talks of a singular huge explosion unimaginable in physical terms. The universe expanded and hence, the temperature came down. Hydrogen and helium formed sometime later. The gases condensed under gravitation and form the galaxies of the present day universe. Huge clusters of galaxies comprise the universe. Galaxies contain stars and **clouds of gas and dust**.

Cosmologists have estimated that there are approximately 100,000 million galaxies. All galaxies are moving away from one another at a great speed, approaching the speed of light. Our galaxy, the **Milky Way**, is just one of these galaxies (*Fig. 1*). All stars that we can see with the naked eye belong to our galaxy. The Sun is a medium-sized star lying about two-thirds of the way from the centre of the Milky Way. The Sun and its planetary satellites make up the **solar system** (*Fig. 1*). In the solar system of the Milky Way galaxy, earth was supposed to have been formed about 4.5 billion years back.

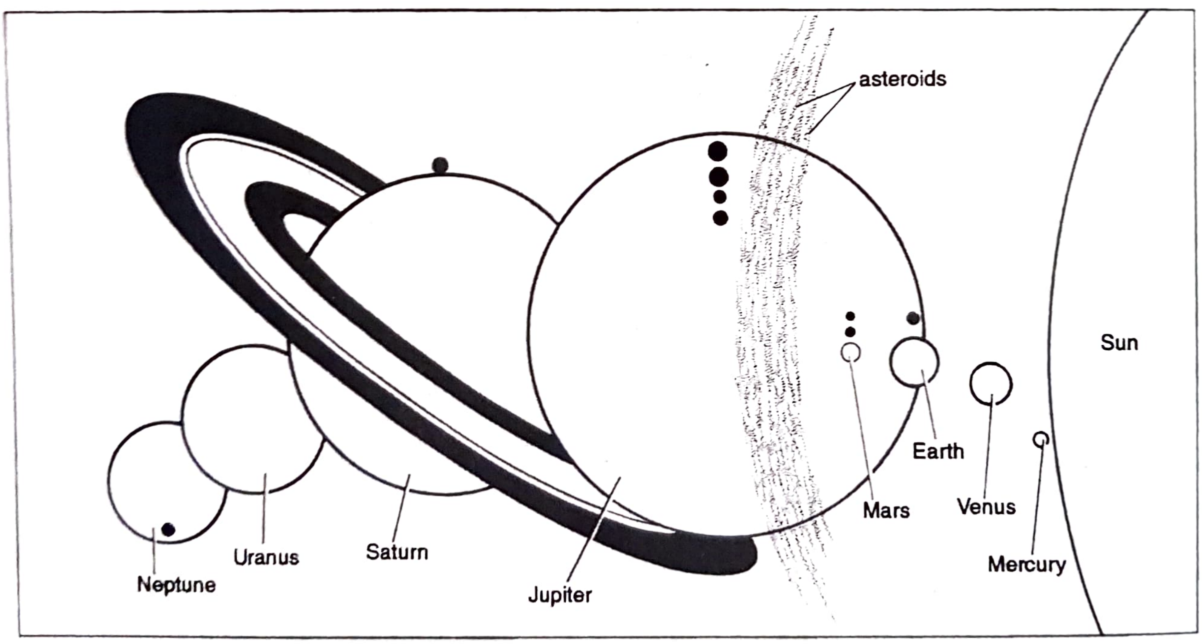


Fig. 1. Planets of solar system.

Our solar system probably arose as a swirling cloud of gases (called **nebula**) that eventually condensed into the Sun and the planets. The early earth also arose as a mass of gases but shortly afterward a core of heavy metals like nickel, copper, iron and lead formed. Overlying this core is a relatively thick **mantle** (shell) covered with a thin **crust** forming the surface of the earth. One of the theories regarding the origin of earth upholds that it was originally a cold mass that heated up under forces of compression in the settling and synthesis of core materials. Radioactivity also produced a great deal of heat. After about 750 million years the earth cooled and the present crust forming the surface developed. Today we are living on a relatively cool earth.

Of all the planets of the solar system, the earth is the only planet on which life as we know has evolved. What makes the earth so special a place in the solar system or perhaps in the whole universe? The earth has a special relationship with the Sun. Life on the earth would not have survived, but for the Sun. The Sun is steady source of energy for all basic processes that sustain life. The planet Mercury is close to the Sun and therefore exposed to the brunt of its burning nearness. Even on the Venus that lies between the Mercury and Earth, the heat is so intense as to completely evaporate all water that might have been present. Moreover, high levels of carbon dioxide in turn lead to further heating of the planet owing to greenhouse effect. Indeed, Venus is too hot to support even primitive forms of life. Earth, on the other hand, is just at the right distance from the Sun to retain water. This water absorbs the excess carbon dioxide and returns it to the earth in the form of carbonate rocks. The presence of water on the earth helped primitive marine forms of life to emerge and survive. These organisms further cleansed the earth's atmosphere of excess CO_2 through photosynthesis. This in turn lead to the rise of oxygen level in our atmosphere and evolution of higher forms of life. In our solar system, Mars has also provided evidence of possibility of life, since it had earlier a moderate climate and enough surface water. But being a small planet, with a smaller gravitational field, it could not hold on to its CO_2. The solar energy which is trapped by the gas could, therefore, no longer be retained.

ORIGIN OF LIFE ON EARTH

Life is the most complex and ordered state of organization that matter has achieved in our universe. The origin of life is a fascinating and perhaps an unique event in the history of universe. How did life originate on the earth? In order to explain it a number of views have been expressed from time to time. Most of these views are quite bizarre with only a historical significance. The major theories accounting for the origin of life on the earth are as follows.

THEORY OF SPECIAL CREATION

According to the theory of special creation, life originated on the earth due to supernatural event, an event which can not be described. All plants and animals appeared on the earth in the form they exist today. A supernatural power — The **God**, created all living beings on the earth. According to the first chapter of Genesis in the Bible, world was created within **six** natural days and on the sixth day human beings were created, first man called **Adam**, and then woman, **Eve**, from the 12th rib of the man. According to Hindu mythology, the **God Brahma** created the world.

This theory is upheld by most of world's major religions and civilisations and based purely on faith. Since the process of special creation occurred, it cannot be observed. This is sufficient to put the concept of special creation outside the framework of scientific investigation. Science concerns itself only with observable phenomena and as such will never be able to prove or disprove special creation.

THEORY OF SPONTANEOUS GENERATION (ABIOGENESIS OR AUTOGENESIS THEORY)

This theory was prevalent in ancient Chinese, Babylonian and Egyptian civilisations as an alternative to the theory of special creation, with which it coexisted. According to this theory, life has originated from non-living organic matter **abiogenetically**, *i.e.*, without the intervention of living things. Greek philosopher **Anaximander** (611-547 B.C.) maintained that plants and animals were formed from inorganic substances. **Epicurus** (342-271 B.C.) advocated the origin of worms and several other animals from the soil or manure by the action of warmth of the Sun and air. **Aristotle** (384-322 B.C.), often hailed as the founder of biology, believed that life arose spontaneously. **Van Helmont** (1577-1644) was of the opinion that human sweat and wheat bran when kept together for three weeks can form mice.

THEORY OF BIOGENESIS

In 1668, the Italian physician **Francesco Redi** (1626-1698) was the first to discard spontaneous generation of life. He cooked some fish so that no organisms were left alive and placed them in three jars; one of these jars was left uncovered, the second was covered with fine muslin cloth and the third was covered with parchment paper *(Fig. 2 A-C)*. After a few days, maggots appeared only in the first jar but not in the other two. He thus concluded that flies arise from the eggs laid down by the parent flies in the uncovered jar. He thus disproved spontaneous generation of maggots.

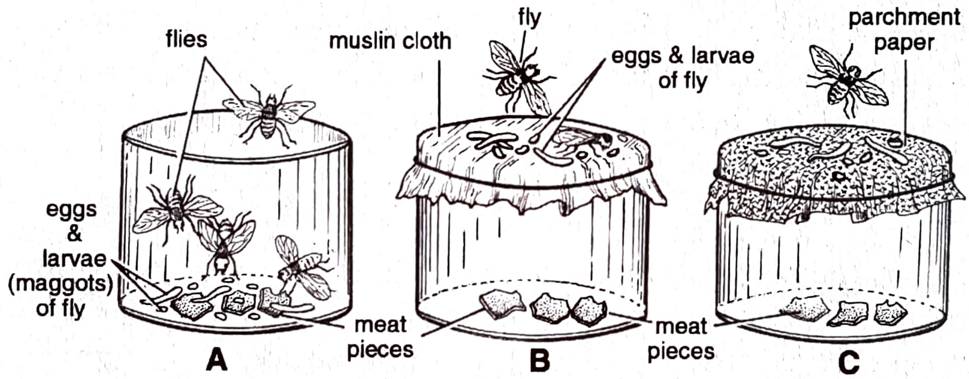


Fig. 2 A-C. Experiment of Francesco Redi to disprove the theory of spontaneous generation: **A.** jar uncovered; **B.** jar covered with muslin cloth; **C.** jar covered with parchment paper.

In 1767, an Italian scientist, **Abbe Lazzaro Spallanzani** (1729-1799) prepared a nutritive broth of vegetables and meat and placed it in flasks and sealed their necks so that air could not enter inside. He then boiled the broth for four hours and left it in the flasks for several days. He observed that no organisms appeared in the flasks (*Fig. 3 A*) and, therefore, concluded that microorganisms are not formed spontaneously, but from those already present in the air. In 1748, **John T. Needham** criticized Spallanzani's experiment, maintaining that overheating of the broth rendered it unfit for spontaneous generation. Infuriated by this statement, **Spallanzani** broke the neck of his sealed flask and as air got into it the broth boomed with rich bacterial growth within a few days (*Fig. 3B*).

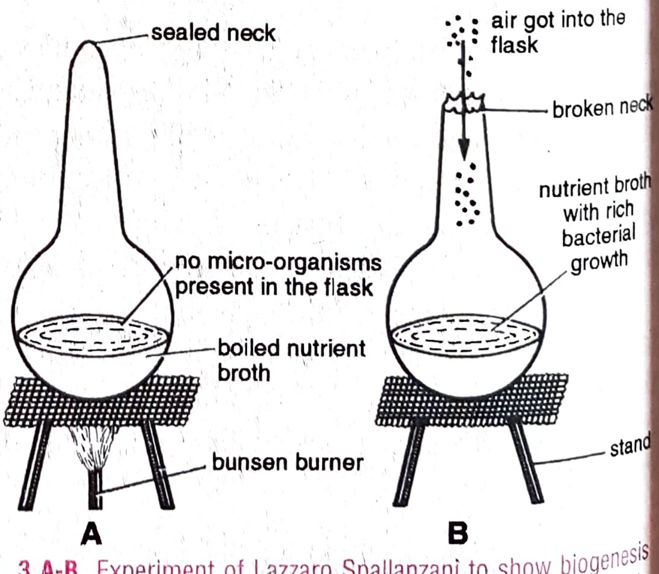


Fig. 3 A-B. Experiment of Lazzaro Spallanzani to show biogenesis of life: **A.** nutrient broth in a sealed flask; **B.** neck broken flask. Note that the broth boomed with rich bacterial growth.

In 1861, a French biochemist, **Louis Pasteur** (1822-1895) finally refuted the concept of spontaneous generation. He took a flask and half filled it with sugar and yeast syrup. He then softened the neck of the flask with flame and drew it into a S-shaped structure (swan-necked flask). The contents of the flask were boiled till steam passed out from the tube and then they were cooled. He did not find any change in the contents even after several days. There was no growth of organisms. This was due to the fact that when the air entered the flask, all air-borne particles got stuck at the bend of the tube and only pure air reached the syrup which remained sterile. After he broke the neck of the flask there was direct contact of the contents with the air and a thick growth of micro-organisms appeared in the flask (*Fig. 4 A-C*). This simple experiment conclusively disproved the idea of spontaneous generation.

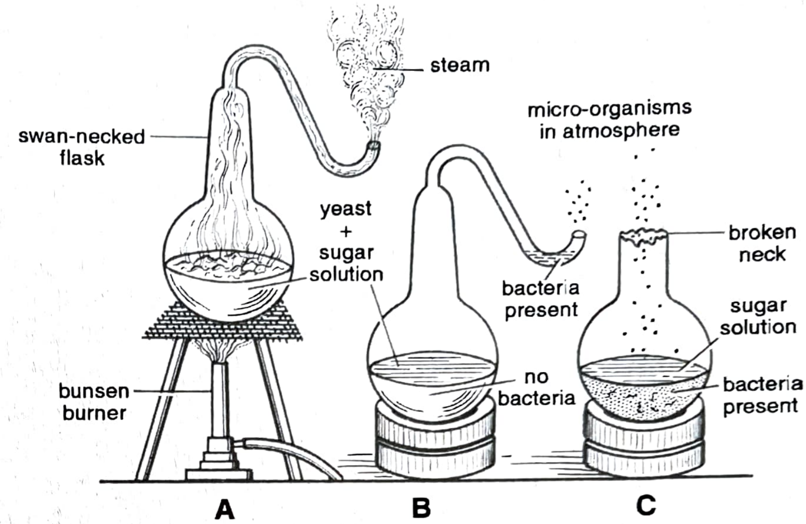


Fig. 4 A-C. Experiment of Louis Pasteur to refute the concept of spontaneous generation.

It is now clear that a living organism was required in order to produce another living organism. Where did the first living organism come from? The steady-state hypothesis has an answer to it but all the other theories imply a transition from non-living to living at some stage in the history of life.

BIOCHEMICAL ORIGIN OF LIFE (OPARIN-HALDANE THEORY OR MODERN THEORY)

Modern biologists agree that the origin of life was a gradual process. Life did not come into existence suddenly but was a result of a long series of physico-chemical changes. These changes brought about a gradual evolution of first inorganic and then organic compounds in accordance with the everchanging environmental conditions. The first scientific account of the origin of life was given by a Russian biochemist, **Aleksander I. Oparin**, in 1924 and subsequently by an English biologist, **J.B.S. Haldane**, in 1929. It is also known as **Abiogenic theory**.

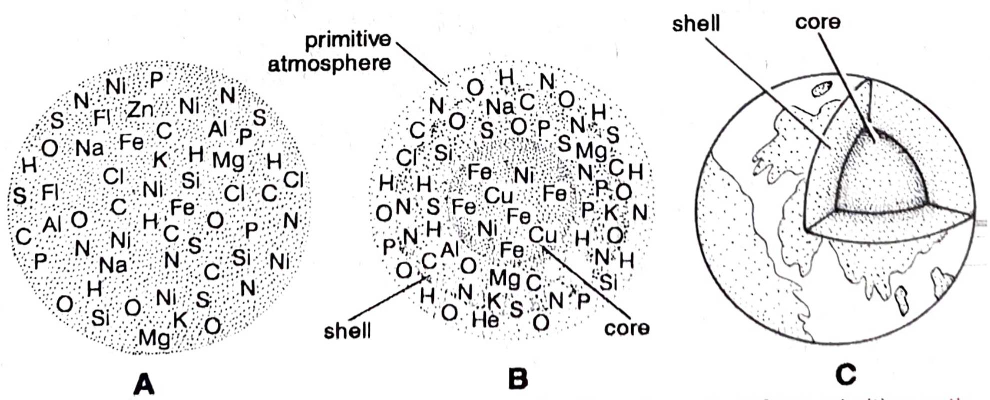


Fig. 5 A-C. Condensation of hot gases and vapours of various elements to form primitive earth.

Later, in 1936, **Oparin** published his views in his book, *The Origin of Life*. The whole series of events, as envisaged by **Oparin** and **Haldane**, can be divided into the following eight steps.

1. **First step : Origin of earth and its primitive atmosphere.** The earth is supposed to have originated about 5–6 billion years ago from a part broken off from the Sun or the cosmic dust gradually condensed and presumably formed the entire solar system.

There was no atmosphere on early earth. In the beginning, the earth was a fiery spinning ball of hot gases and vapours of various elements (*Fig. 5A*). Gradually, through hundreds of millions years, the gases condensed into a molten core and different elements become stratified according to their densities. The heaviest metallic atoms like those of iron, nickel, copper, etc., collected in the centre and formed the solid core of the earth. Medium-weight atoms like those of sodium, potassium, silicon, aluminium, magnesium, sulphur, etc., formed a shell (future lithosphere) around the core, and the atoms of helium, hydrogen, oxygen, argon, carbon and nitrogen, being light, flowed to the surface and formed the primitive atmosphere (*Fig.* 5 *B*, *C*).

2. **Second step : Origin of molecules and simple inorganic compounds.** Since, the original temperature of the earth was very high (5000°-6000°C), elements like hydrogen, oxygen, carbon, and nitrogen could not exist in free state. They combined among themselves or with metals forming oxides, carbides and nitrides. All these compounds were present in gaseous state, and water as superheated steam. These compounds formed the atmosphere of the primitive earth.

As the earth began to cool, its matter started condensing and solids, liquids as well as gases co-existed. Superheated steam condensed into water causing rain. The rain drops on approaching the superheated earth immediately evaporated and returned to the atmosphere. This cycle continued for millions of years thus cooling the earth's surface. About three billion years ago, the earth had a solid crust punctured by eruptions of molten rocks (volcanoes) and areas filled with hot boiling sea water which had dissolved ammonia, methane, minerals and salts.

Conditions on the primordial earth about 3600 million years ago were strikingly different than those which occur today. The earth's atmosphere was reducing at that time and not oxidising as today. Large quantities of hydrogen, nitrogen, carbon dioxide, methane, ammonia and water vapours were present on the primitive earth, but the atmosphere was devoid of free oxygen.

3. **Third step : Origin of organic compounds.** As the atmosphere cooled down to 1000°C, various saturated and unsaturated hydrocarbons were formed. These hydrocarbons later reacted with superheated steam and formed oxy- and hydroxy derivatives—aldehydes, ketones and acids. Due to the condensation and polymerisation of oxy- and hydroxy derivatives, several organic molecules like sugars, glycerol, fatty acids, amino acids and nitrogenous organic bases (purines and pyrimidines) were formed (*Fig. 6*). In the absence of free oxygen and bacteria, these complex organic

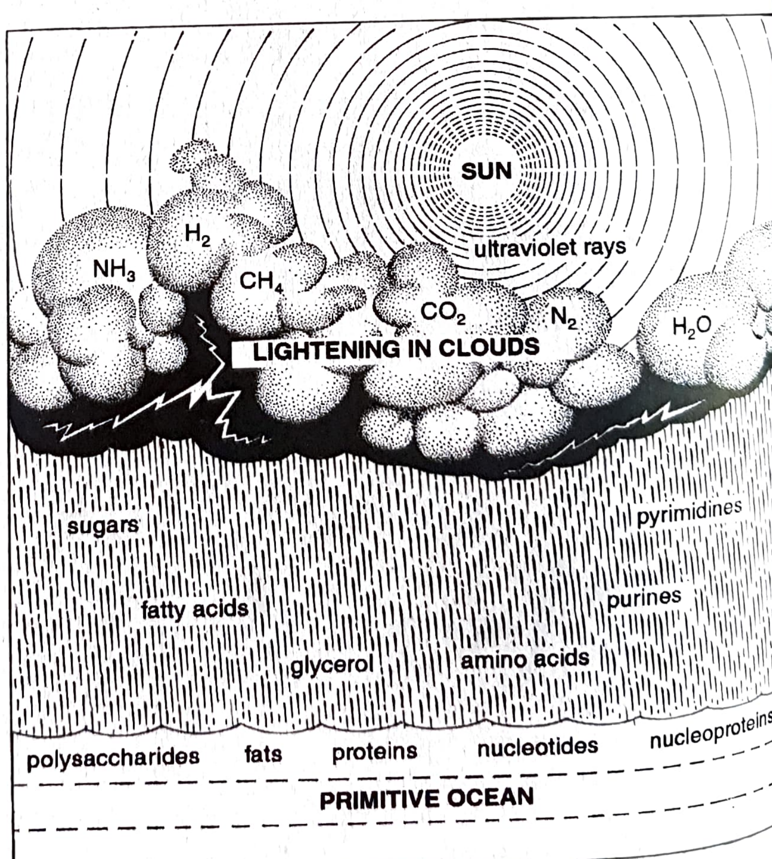


Fig. 6. Synthesis of complex organic molecules in the primitive ocean.

molecules were neither oxidised nor putrefied. But they progressively combined and reacted with each other, forming more and more complex molecules. Thus complex organic compounds—polysaccharides, fats, proteins, nucleosides and nucleotides were formed. The nucleotides linked together in different combinations and formed nucleic acids. The protein molecules and nucleic acids thus formed later aggregated and united into giant molecules of nucleoproteins. Some of the polypeptides acted as primitive enzymes which speeded up the rate of formation of specific molecules. Since these macromolecules (proteins, carbohydrates, fats, nucleic acids, etc.) are the main constituents of the **life substance** or **protoplasm**, their synthesis established the possibilities of **origin of life** in the primitive ocean.

The synthesis of carbohydrates, fats and amino acids and other complex organic compounds presumably took place in sea. J. B. S. Haldane described this mixture of sea water as hot dilute soup.

Miller-Urey's Experiment

The classical experiment of an American scientist **Stanley Miller** and **Harold C. Urey** (1953) on abiotic origin of biomolecules proved the Oparin-Haldane concept of the origin of life. They recreated the probable conditions on the primitive earth in the laboratory. They designed a **spark-discharge apparatus** as shown in figure 7. Two tungsten electrodes, connected to an electric source, were fitted to the larger flask to provide energy of electric discharge, simulating the effect of lightening of the primitive atmosphere. The larger flask was connected to a small U–tube by means of a straight tube passing through a condenser. An atmosphere containing hydrogen, ammonia, methane and water vapour was created in one chamber at 800°C and condensed liquids were allowed to accumulate in another chamber. Energy was supplied by heating the liquid-containing chamber as well as by electric sparks from electrodes in the gaseous chamber. With the help of this simple apparatus, they showed that amino acids like glycine, alanine, and aspartic acid and even more complex organic compounds can be formed *in vitro* when the mixture of water vapours, methane, ammonia and hydrogen gases in a closed chamber is subjected to electric discharge for a few days. This experiment thus confirmed the possibility of abiogenic synthesis of various organic compounds from the reducing mixture of simple gases.

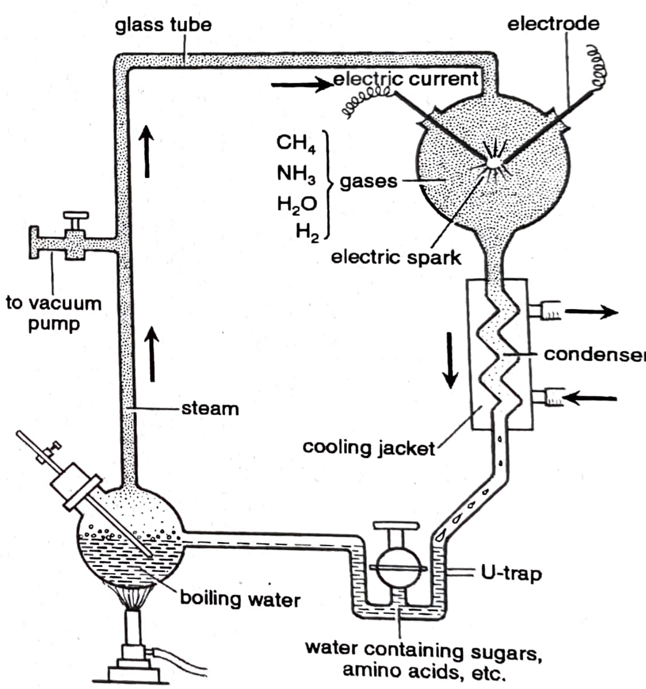


Fig. 7. The spark-discharge apparatus set up by Stanley Miller and Harold C. Urey to simulate conditions in the atmosphere of the primitive earth.

In similar experiments others observed, formation of sugars, nitrogen bases, pigment and fats. For instance, **M.Calvin** obtained amino acids and sugars by treating a mixture of hydrogen, water vapours, ammonia and methane. Similarly, **Bahadur** (1954) obtained all possible amino acids by subjecting a mixture of ammonia, ferric chloride and para formaldehyde to strong sunlight. Analysis of meteorite content also revealed similar compounds indicating that similar processes are occurring elsewhere in space. All these evidences indicated that chemical evolution has been taken place on this earth.

This experiment also indicated that a reducing atmosphere is essential for such abiotic synthesis and free oxygen would destroy most intermediate products in such synthesis. The presence of free oxygen and living organisms on the earth at present are considered to prevent the abiotic origin of life. This suggests that life originally arose from the inorganic molecules on the primitive earth, but on the today's earth life comes from the pre-existing life only.

4. **Fourth step : Origin of colloids, coacervates and individuality.** The organic macromolecules due to intermolecular attraction aggregated into various combinations and then they precipitated out in the aqueous medium in the form of large colloidal particles known as **coacervates**. Coacervates have more than one types of proteins, nucleoproteins and other organic and inorganic molecules in various combinations. Since protoplasm is also a colloid system, coacervates, as individual structures, have been looked upon as precursors of the first organisms, *i.e.*, **prebiotic structures** *(Fig. 8)*.

   Coacervates were later surrounded by a limiting membrane formed by the organized molecules of fatty acids like lecithin and cephalin. After the formation of limiting membrane, various substances accumulated inside the coacervate. Subsequently, coacervates also started absorbing organic substances from the oceanic soup. They thus became **anaerobic heterotrophs**, which grew in size, became variable in chemical composition, and multiplied by breaking down into smaller droplets after attaining an optimum growth depending on their viscosity.

5. **Fifth step : Origin of autocatalytic systems, genes, viruses and primordial life.** Nucleoproteins appeared in the primitive ocean as **self-duplicating** (= autocatalytic) systems. Hence, the nucleoproteins once formed, must have steadily increased in the oceanic soup. By virtue of their self-duplicating property, these are capable of performing **hereditary function**. The **first sign of self-perpetuating life** was thus displayed by the nucleic acids. The nucleotide monomers of the nucleic acids presumably first formed only small chains, comparable to the present day **genes**. A number of such genes might have later aggregated into a large unit called **protovirus**, comparable to the present day virus. Protoviruses had access to all necessary substances for their duplication in the oceanic water itself. These were probably the first **most primitive** or **primordial organisms**.

   Life was thus presumably originated in the ocean, about 3.7 billion years ago, in the Precambrian era, and the **first organisms were heterotrophic, anaerobic and virus-like nucleoprotein structures**.

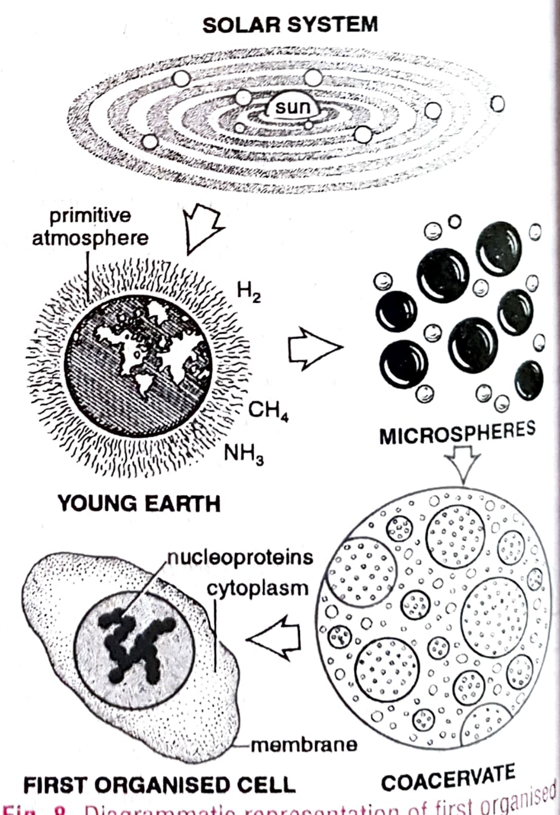


Fig. 8. Diagrammatic representation of first organised cell from coacervate.

6. **Sixth step : Origin of primordial cellular forms of life (prokaryotes).** Following the formation of self-duplicating systems in the form of nucleoproteins, conditions suitable for evolution of cell-like organisms existed in the primitive ocean. According to **Oparin**, the coacervates with nucleoproteins became the first cellular organisms. These primordial cellular forms were comparable with the bacteria of today.

7. **Seventh step : Origin of autotrophism.** Being anaerobic heterotrophs, the early bacteria-like prokaryotes gradually consumed all abiotically synthesized organic nutrients of the **oceanic soup** and struggled for existence. During the course of this struggle, some early prokaryotes acquired **enzymes** which would catalyse synthesis of simple carbohydrate molecules from inorganic substances of the oceanic water. This was thus the beginning of **autotrophism.** Since, energy used in the synthesis of organic molecules was obtained from anaerobic breakdown, the early autotrophism is said to be **chemoautotrophism**. Natural selection favoured the establishment of these anaerobic autotrophs in the conditions existing at that time. These anaerobic autotrophs could be compared with certain **deep sea sulphur bacteria** of today.

Later, certain autotrophic bacteria-like primitive organisms synthesized chlorophyll-like green pigments (bacteriochlorophylls) from magnesium porphyrin of the oceanic water. These pigments could absorb sunlight that provided solar energy for synthesis of carbohydrates. Some marine **planktonic sulphur bacteria** found today show such a photosynthetic autotrophism.

Subsequently, bacteriochlorophylls underwent certain changes in their molecular structure, forming the true chlorophyll which became organised into lamellar units together with the enzymes of the photosynthetic system. This change enabled the early prokaryotes to synthesize carbohydrates by using water in place of sulphides, or other inorganic molecules. Such chlorophyll–bearing prokaryotes of the primitive ocean can be compared with the present–day **blue-green algae**.

SOME IMPORTANT TERMS RELATED TO ORIGIN OF LIFE

Abiogenesis : origin of life from non-living organic matter, *i.e.* without the intervention of living things.

Biogeny : the process by which living organisms develop from other living organisms with the formation of nucleic acids and the surface membrane, the coacervates changed into first living system called **protobionts**. The first cell probably arose from these protobionts and acted as ancestor to present day prokaryotes and eukaryotes.

Chemogeny : chemical evolution; increase in the complexity of chemicals over time that could have led to the first cells. First, the primitive inorganic molecules interacted and combined to form simple organic compounds like alcohols, fatty acids, amino acids, sugars and nitrogenous bases. Thereafter, these simple organic molecules underwent condensation and polymerisation forming complex organic macromolecules such as polysaccharides, fats, proteins, nucleotides.

Coacervates : clusters or aggregates of large complex organic molecules capable of growth and replication; these are supposed to have given rise to the first cell like structure.

Cognogeny : evolution of mechanism of perfection, expression and communication; involves diversification and evolution of the prokaryotic and eukaryotic cells into **chemoheterotrophs**, **chemoautotrophs** and **photoautotrophs**. The first oxygenic and aerobic photoautotrophs were cyanobacteria. Thereafter, division of labour and cell differentiation in unicellular organisms led to the evolution of multicellular organisms.

Liposomes : a spherical vesicle (tiny bubble) formed by a lipid bilayer enclosing an aqueous compartment.

Protobiont : systems that are considered to have possibly been the precursors to first cells; the first living forms which originated in the primitive ocean; an aggregate of abiotically produced organic molecules surrounded by a membrane or a membrane-like structure; exhibits some of the properties associated with life including signs of reproduction, metabolism and excitability as well as the maintenance of an internal chemical environment different from their surroundings.

8. **Eighth step : Origin of eukaryotic cells.** Liberation of free oxygen (O_2) into the primitive atmosphere by blue-green alga-like prokaryotes was a revolutionary change in the early history of the earth. The free oxygen oxidised methane and ammonia forming carbon dioxide, nitrogen, and water and the reducing environment thus became oxidising. Hence, the composition of the primitive atmosphere changed to that of the present atmosphere. With the change in the composition of the atmosphere, it is unlikely that the conditions can return in

which life can originate. The free oxygen formed a layer of ozone above the sunlight blocking the U-V light and making it possible for the organisms to migrate on the land from the water.

EFFECTS OF OXYGEN ON EVOLUTION

- With the increase in the number of photosynthesising organisms, oxygen was liberated, in the atmosphere and the reducing atmosphere of primitive earth changed into an oxidising atmosphere. Organisms capable of utilising oxygen for their energy needs were able to survive. Moreover, free oxygen started reacting with methane and ammonia and oxidised them into carbon dioxide and nitrogen respectively. Gradually, the earth's atmosphere changed from the primitive reducing atmosphere into the oxidising atmosphere.
- An ozonosphere (formation of ozone layer) was developed by the reaction of oxygen under the influence of UV-radiations. Formation of ozone layer in the atmosphere protected the earth and life from UV-radiations. This makes possible for the organisms to migrate on the land from the water.
- The formation of oxidising atmosphere resulted in **oxygen revolution.** Ultimately, it results an end to abiotic synthesis and the evolution of new forms.
- Free oxygen in the atmosphere finally led to the evolution of **aerobic mode of respiration**. As a result, more energy is produced by the oxidation of food. Ultimately, the autotrophs became the source of food for heterotrophs.

With the liberation of free oxygen in the atmosphere, conditions suitable for **aerobic respiration** established upon the earth, presumably about 27 billion years ago. The prokaryotes gradually developed a true nucleus, mitochondria and other specialized organelles, and thus free-living eukaryotic cell-like organisms originated in the primitive ocean, about 15 billion years ago.

NOTE

Lederberg summarized the entire process of origin of life and evolution in three major steps :

(1) **Chemogeny :** Chemical evolution took place, resulting in the formation of simple chemicals.
(2) **Biogeny :** Origin of first living cells.
(3) **Cognogeny :** Development of complexities in form and functions of the living organisms.

EVOLUTION

Evolutionary Biology is the study of history of life forms on earth. With the change in the conditions on the earth, more and more complex life forms evolved (*Fig. 9*). The variety and complexity of life require organising principles to help understand so diverse a subject area. Evolution is a concept that provides coherence for understanding life in its totality. It presents a narrative that places living things in a historical perspective and explains their diversity in the present. It also throws light on the nature of interaction of organisms with each other and with the external environment. Evolution is the key for understanding the dynamic nature of an unfolding world of living organisms. It is continuously substantiated theory that all living things have descended by modification from ancestral organisms in a long process of adaptive changes. These changes have produced organisms that have become extinct as well as the diverse forms of life that exist today.

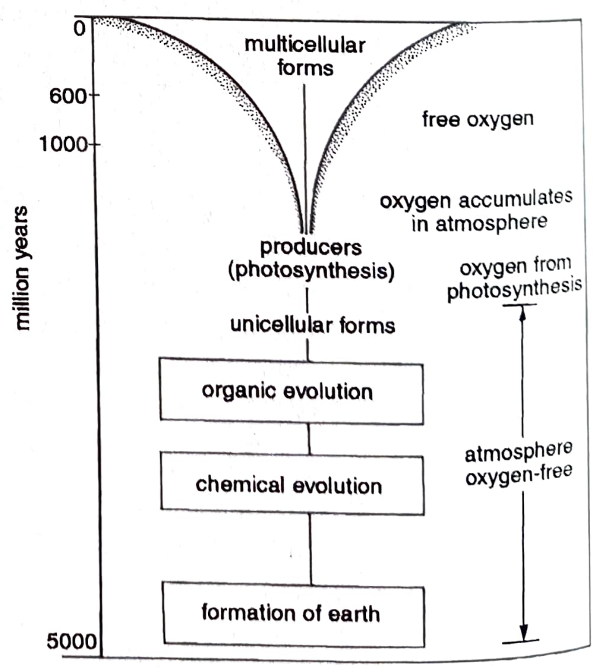


Fig. 9. Major events in the history of life on earth.

Evolution is a naturally occurring process. It is a slow, continuous and irreversible process of change. Complex forms of life have emerged from simpler forms over millions of years. Evolution occurs through variations arising from changes in genetic material and from natural selection. We can presume that biological evolution began with the formation of the first true cells. These must have been forms that did not require free oxygen and lived at the expense of organic molecules available in the waters that surrounded them. Eventually, as nutrients were depleted, the first cells capable of using carbon dioxide and energy from light to make their own food through photosynthesis must have arisen. Today, the diversity of plant and animal forms ranges from simple single celled organisms to many kinds of plants on one side and animals including man on the other. We have millions of species or living forms on our planet. There is evidence that all the life forms are inter-related and also that the higher forms have evolved from the lower ones.

Questions.

1. What are protobionts?
2. What are coacervates?
3. Enumerate some important effects of oxygen on evolution.
4. What is the big bang theory? List one evidence in support of this theory.
5. What was the role of anaerobic chemohetero-trophs, anaerobic chemoautotrophs, anaerobic photoautotrophs, aerobic photoautotrophs in evolution of life in primordial soup?
6. What are the unique features of water that make it most suitable medium for the origin of life?
7. What was the composition of the primitive atmosphere that favoured abiotic origin of life on the earth?
8. Give an account of the Miller & Urey experiment on the origin of life.
9. Describe in brief the Oparin - Haldane theory of origin of life. How does meteorite favour this hypothesis?