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Biochemisty of Living Organisms: The Genesis

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ABSTRACT

Biochemistry, a discipline which studies the chemistry of life is of interest to scientist as it describes the chemical constituents of living organisms and explains the processes involved in their functioning thereby pacifying the understanding of other health and physical sciences related field for the improvement of humanity. Thus, it becomes important to understand how this discipline emerged and how its evolution paved the way for new disciplines to foster development and mans wellbeing. However, this notion of its origin and evolution which is important to enhance its understanding is usually not given considerable attention. Hence, the centrality of this chapter is to give an overview of how this discipline emerged starting from the origin of life and the evolution of biomolecules to form living organisms, highlighting on the major constituents and macromolecules which govern life processes.

INTRODUCTION

Life is the greatest gift of mankind. Who knows what the world would have been without the existence of living things? Though this question may be very difficult to answer or may not even have an answer, we enjoy every second we spend in this world without even try to know how life originated and how it has evolved. Since biochemistry is a discipline that studies the chemistry of life, or in other words, studies the constituents of living things and the associated functions and activities, it may be of interest to know how this discipline came into existence in order to understand the evolution of living things and the constituents that have defined its activities. Thus this chapter will provide an overview of how life originated, narrowing the concepts to the scientific point of view and suggesting various postulates that tried to support this claim. The evolution of the first chemical molecules that may likely be the basis to life with experimental setup to support this claim and also how this molecule evolve to cells and eventually to animals is also another aspect of consideration. In trying to identify this first molecules, biochemistry emerged, hence the evolution of biochemistry, the basic disciplines of its emergence and the emerging disciplines stemming from biochemistry is another aspect of concern. Finally, because living things are made up of various constituents, it was of interest to have an overview of these constituents; the inorganic, organic (carbohydrates, nucleic acid, proteins and lipids), stating their building blocks and importance and also a briefing on the properties of water that makes it ultimate for life.

ORIGIN OF LIFE

Life, even though may be vast in definition, can basically be defined as the ability of something to live. Hence living things therefore posses certain characteristics which are fundamental for their existence. This includes though not exclusive, the ability to grow and reproduce, are sensitive to stimuli, have the ability to regulate their activities and maintain relatively constant internal conditions etc.

Understanding the meaning of life has questioned its origin. The origin of life remains a debatable and complex issue which is being addressed almost every second of our existence. The place where life started, the time of origin and the initial constituents are also part of the questionable origin. Being a complex question to answer, various postulates have been proposed to define its existence. This includes the supernatural, extraterrestrial and spontaneous postulates.

From a biblical point of view, it is believed life originated from a supernatural or divine force. This theory identifies a divine or Supreme Being (God) to be the creator of life and it's the central believe of most religions. This postulate is the oldest hypothesis about life's origin and also the most widely accepted.

Another postulate is the extraterrestrial origin whereby it is believe life originated from other planets and the earth was infected. The panspermia theory proposes that cosmic dust from other planets may have carried substantial amounts of complex organic molecules to earth, initiating life. Hundreds of thousands extraterrestrial materials are known to have fallen into the early earth. More so, recent findings suggest that some of these comets may contain organic materials as well as life in other planets by astronauts.

The third postulate known as the spontaneous origin, suggest life originated from inanimate matter where simple molecules in the earth's atmosphere combined to form more complex molecules by chemical reactions which is suggested to may have come from lightning and forms of geothermal energy (Figure 1). Further association between these molecules as time changes, gave rise to more complex molecules which culminate to evolve into cells. This last postulate is the most probable as agreed by scientist and also known as the scientific origin since it is scientifically tested. Hence, emphasis on the origin of life will focus on this last postulate.

Figure 1: The origin of life is suggested to be due to chemical reaction between simple molecules in the earth to form complex molecules aided by lightning and other geothermal forms of energy.

SCIENTIFIC ORIGIN

Scientific evidence has identified fossils of simple living things, particularly bacteria to be found in rocks and was dated to about 3.5 billion years old. This suggests life may have originated over 3.5 billion of years ago. However, how this happen is of our interest in this chapter. Though so many postulates have been laid in regards to where life originated, the most popular opinion suggest life to have originated from the ocean edge where water got in contact with the atmosphere. This early continent contained mainly carbon dioxide (CO_2) and nitrogen gas (N_2), along with substantial amounts of water vapor (H_2O). More so, it is suggested that hydrogen gas (H_2) was also present, bonding with other elements such as Sulfur **(S)**, N_2, and Carbon **(C)** giving rise to hydrogen sulfide (H_2S), ammonia (NH_3), and methane (CH_4) which further reacted to produce amino acids and nucleic acids. Because of the ample availability of hydrogen which are been reduced to other substances, this atmosphere is referred to as reducing atmosphere. Also, since in nature amino acids and sugars are readily being oxidized to CO_2 and water (H_2O) in the presence of oxygen (O_2), this postulate assumes there was little or no O_2 present in the atmosphere. It is believed that oxidative reactions emerged after only when simpler organisms had evolved to higher organisms that carry out photosynthesis releasing O_2 in the atmosphere. This was responsible for the change from a pre-biotic reducing atmosphere to an oxidative one which presently contains about 21% of O_2.

MULLER –UREY EXPERIMENT

In an attempt to proof this pre-biotic environment on early earth, Stanley L. Miller and Harold C. Urey in 1953 carried out an experiment with conditions of the ocean edge and reducing atmosphere. In this experiment, an apparatus consisted of a closed tube connecting two chambers; an upper and a lower chamber connected by tubes to circulated water and other materials was designed. An upper chamber on the right was filled with air highly rich in H_2 but excluding O_2 to resemble the reducing atmosphere. On the other hand, the lower chamber located by the left was filled with H_2O representing the ocean's edge. The chambers were maintained at a temperature somewhat below 100°C; and electrodes discharged sparks through the mixture of gases in the upper chamber, simulating lightning. Condensers then cooled the gases, causing water droplets to form, which passed into the lower chamber containing water. Following this reactions, samples were withdrawn from second heated chamber, (the lower chamber) for analysis (Figure 2). Within a week of the experiment, 15% of CH_4 initially formed had been converted into other simple carbon compounds such as formaldehyde (CH_2O) and hydrogen cyanide (HCN). Further reaction of this simple carbon compounds combined to form formic acid (HCOOH) and urea (NH_2CONH_2), and more complex molecules containing carbon-carbon bonds, including the amino acids (glycine and alanine) which are the building block of protein.

After this experiment, other scientist performed similar experiments in which so many different carbon compounds were identified including, the amino acids glycine, alanine, glutamic acid, valine, proline, and aspartic acid etc and other important molecules such as HCN which contributed to the production of adenine, a nitrogenous base found in DNA and RNA.

Putting together all the molecules formed in the Muller-Urey experiment and others suggest these simpler molecules formed in the pre-biotic environment could be the basis of the origin of life.

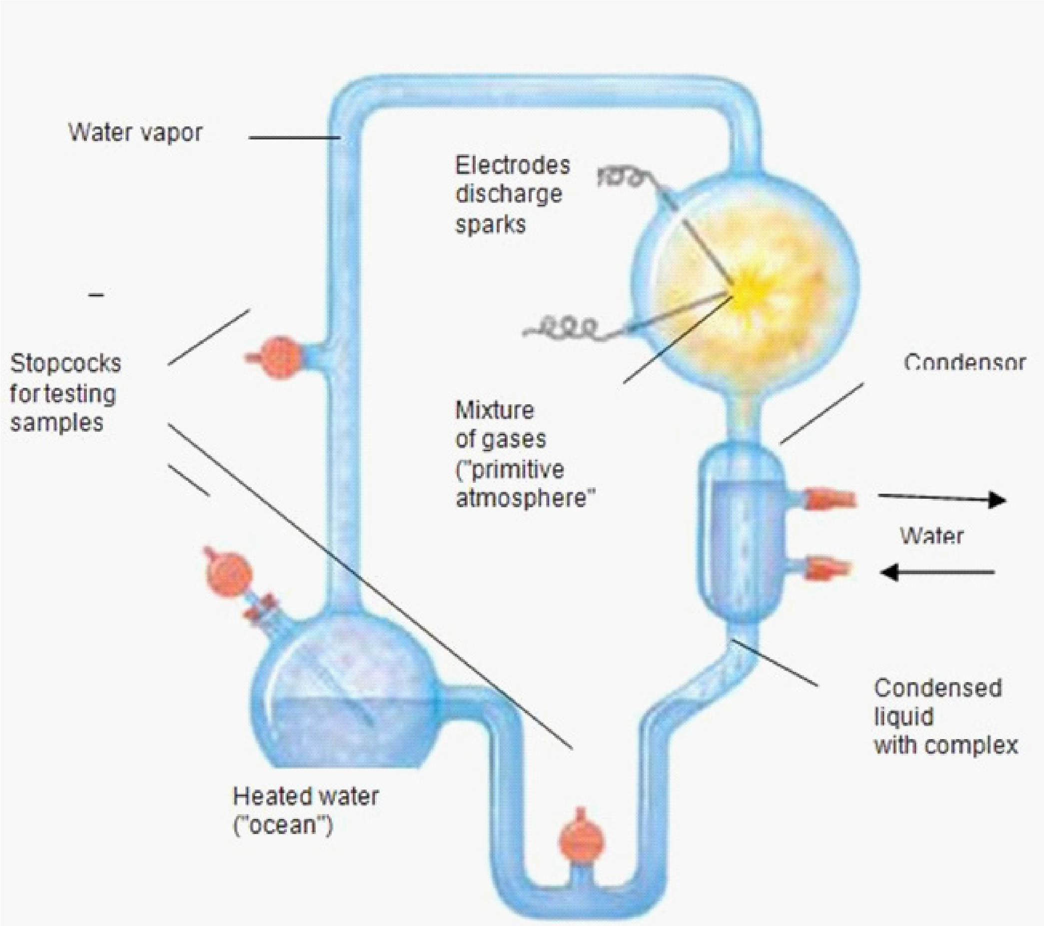

Figure 2: The Miller-Urey experiment trying to replicate the prebiotic soup of the origin of the life.

EVOLUTION OF ORGANIC MOLECULE

Even though it has been difficult to predict which organic molecule that emerged first, the findings of the Muller-Urey experiment and others tried to explain the origin of life raising arguments between RNA and proteins. Some scientists argue for protein, other for RNA while another group suggests both protein and RNA emerge simultaneously.

The "protein-first" group argument is center on the fact that enzymes are protein in nature suggesting that without enzymes life process such as replication would not have occurred. More so, they believe nucleotides, the central component of RNA and DNA are too large and complex to have been form spontaneously without the involvement of enzymatic reactions.

For the proponents of the RNA-first group, they believe that a genetic material is responsible for the synthesis of proteins through translation and also for reproduction. Hence, without a genetic or hereditary material, other molecules would not have been formed. This proposition was further supported when ribozymes, RNA molecules that can behave as enzymes by catalyzing their own assembly was discovered by Thomas Cech at the University of Colorado. More so, recent findings have shown RNA contained in ribosomes catalyze the synthesis of polypeptide linking amino acids together. This group stands on the argument that if RNA has the dual role to function as a hereditary material as well as an enzyme, then was there any need for proteins?

A Peptide-Nucleic Acid World is another group which does not see any of the organic molecules; protein or nucleic acid to precede the other. This position suggests both nucleic acid and protein emerged simultaneously with reasons that RNA is so complex and unstable, such that there was need for proteins to interaction with RNA to permit life processes.

ORIGIN OF CELLS

After the formation of macromolecules, it is obvious that these molecules had to become cells which are the basic unit of life. However, it remains unclear how this happened. Knowing the nature of cells which resemble little bags filled with fluid, so many scientists has proposed various postulates of which the bubble theory seems to be the most accepted.

The idea of the bubbles theory which is believed to be formed at ocean’s edge is based on the fact that if watched the flash of water along the bank of the shore will find foaming froth formed due to the agitation of water. Also, the fact that molecules with hydrophobic regions will form bubbles supported this theory since cell contains a cell membrane which is hydrophobic in nature. Owing to this, it is suggested that cells emerged from the edge of primitive oceans which were more likely to froth when in contact with atmospheric air such as methane and other simple organic molecules and upon bombardment by ionizing and ultraviolet radiations led to the formation of bubbles. This bubble hypothesis was further elaborated by Louis Lerman in 1986, geophysicist who proposed that the chemical processes leading to the evolution of life took place within bubbles on the ocean’s surface as shown in figure 3. His proposal was such that;

1. Volcanoes erupted under the sea, releasing gases enclosed in bubbles
2. The gases, concentrated inside the bubbles, reacted to produce simple organic molecules.
3. When the bubbles persisted long enough to rise to the surface, they popped, releasing their contents to the air.
4. Bombarded by the sun’s ultraviolet radiation, lightning, and other energy sources, the simple organic molecules released from the bubbles reacted to form more complex organic molecules
5. The more complex organic molecules fell back into the sea in raindrops. There, they could again be enclosed in bubbles and begin the process again.

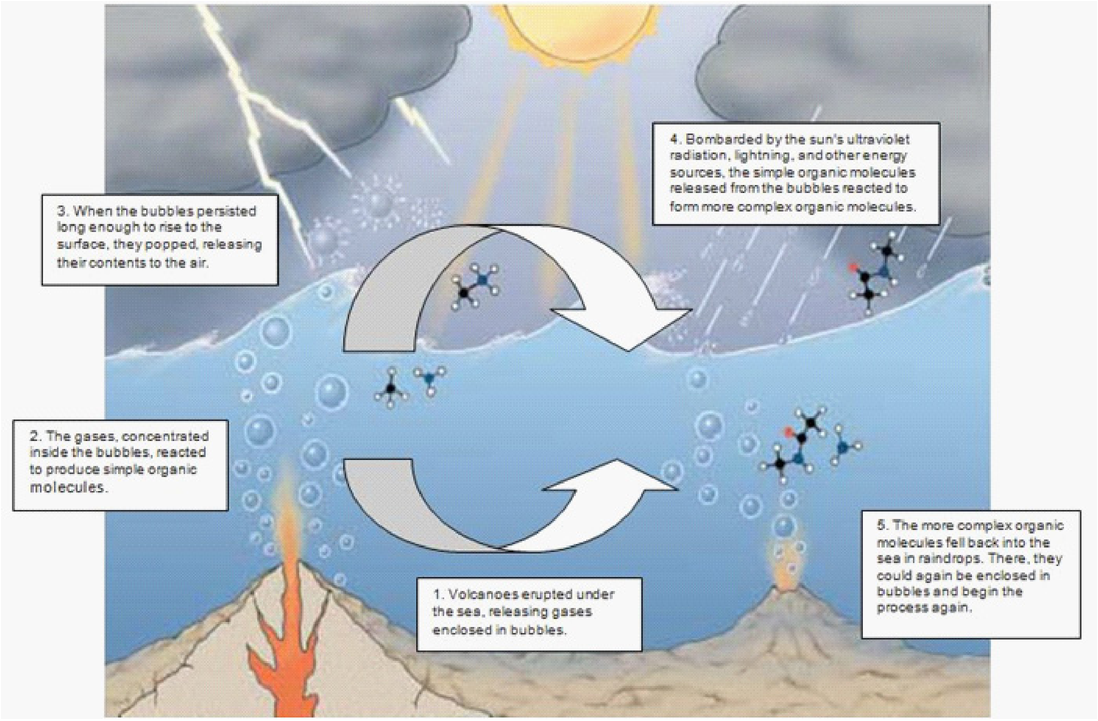

Figure 3: Bubble hypothesis for the evolution of life by chemical processes at the ocean edge.

Various versions of the bubble theories have been proposed by different scientists depending on the composition whether the bubbles are lipid or protein based and how there as synthesized. As explained above, the most accepted bubble proposal is the lipid based bubbles called coacervates. In this proposal, lipid bubbles form an outer boundary with bilayers that resembles a biological membrane of cell. These bubbles grow by accumulating more lipid subunit molecules from the surrounding medium enough to form budlike projections which subsequently divide by splitting into two just like bacteria. These bubbles can further accumulate amino acids and use them to facilitate various acid-base and enzymatic reactions which laid the bass of cellular processes.

EVOLUTION OF CELLS

Since cells do have a life span after which they die, it becomes very difficult to actually ascertain the cell that emerged first. However, one of the most probable ways to identify the first cell is through dating of fossils. This was done by determining the degree of spontaneous decay of radioactive isotopes locked within rock when it is formed. The profile of cells identified in fossil through radioactive isotopes is shown below in table 1.

Table 1: Historical timeline of microorganism identified by radioisotope dating of fossil.

PRECAMBRIAN	PHANEROZOIC	Geological evidence	Millions of years ago	Life forms
		Oldest multicellular fossils	570 600	Appearance of first multicellular organisms
	PROTEROZOIC		1500	Appearance of first eukaryotes
		Oldest compartmentalized fossil cells		Appearance of aerobic (oxygen-using) respiration
CAMBRIAN	ARCHEAN	Disappearance of iron from oceans and formation of iron oxides	2500	Appearance of oxygen-forming photosynthesis (cyanobacteria)
		Oldest definite fossils	3500	Appearance of chemoautotrophs (sulfate respiration)
		Oldest dated rocks	4500	Appearance of life (prokaryotes): anaerobic (methane-producing) bacteria and anaerobic (hydrogen sulfide–forming) photosynthesis Formation of the earth

Prokaryotes

Base on such procedure, William J. Schopf of University of California Los Angeles, discovered an ancient bacterial fossil in a 3.5-billion-year-old rock in Western Australia considered as the oldest cell and the earliest evidence of life (Figure 4). This fossilized form of microscopic life was about 1 to 2 µm in diameter, single celled, lacked external appendages with little evidence of internal structure comparable to bacteria although some other ancient forms cannot exactly match bacteria. More so, these ancient fossils lacked a defined nucleus, characteristic of prokaryotes. Thus, it is suggested that prokaryotic cell emerged before eukaryotes which have defined nucleus.

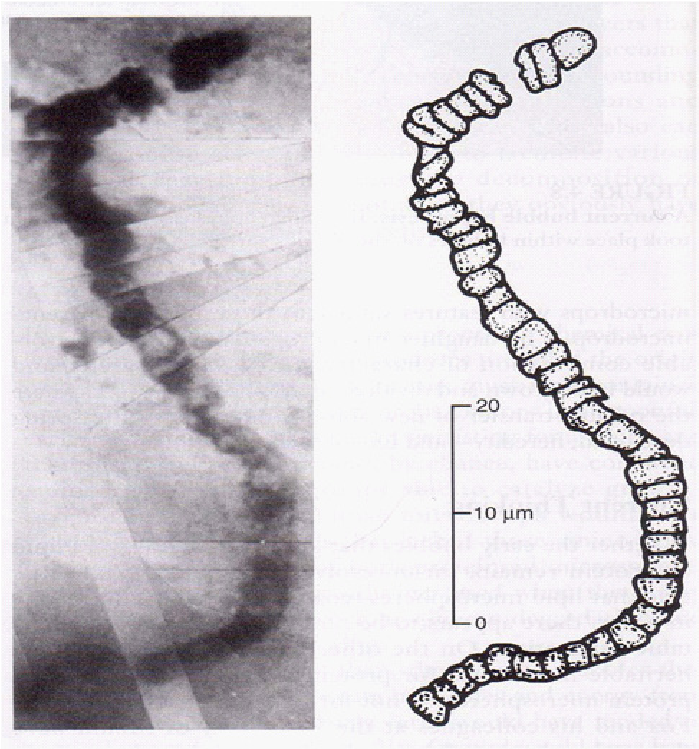

Figure 4: Oldest microfossil identified to be a prokaryote.

Another class of living cells to emerge after the simple bacteria is the archaebacteria. After full sequencing of the genome of *Methanococcus*, an archaebacteria in 1996 and comparing the gene sequences with other bacteria suggest archaebacteria to have emerged from other bacteria over 3 billion years ago. Archaebacteria are usually some of those bacteria that live in very salty environments like the Dead Sea (halophiles) or very hot environments like hydrothermal volcanic vents (thermophiles).

The third category of bacteria to emerge is the eubacteria. This class of bacteria is more advanced in their structure, properties and activities. These bacteria are capable to capture light energy from the environment and transform it into chemical energy through the process of photosynthesis just like plants and algae. Among this category, the cyanobacteria are one of the most advanced, closest to plants and algae and sometimes called the blue-green algae. These bacteria, believed to have appeared at least 3 billion years ago have the same kind of chlorophyll pigment present in most plants and algae, as well as the blue or red pigments and produce O_2 as a result of their photosynthetic activities just like plants.

Eukaryotes

Certain fossil identified in rocks which were dated to be about 1.5 billion years old showed some noticeably difference in appearance from the earlier fossil previously identified (Figure 5).

These fossils were much larger than the earlier ones with more elaborate, defined and thicker internal membranes and having a size above 10 µm in diameter. Also, some other fossils dated about 1.4 billion years old were much larger in size, close to about 60 µm in diameter with more defined nucleus containing a nuclear membrane. Hence, were named eukaryotes, from Greek words meaning “true” and “nucleus,” because they possess an internal structure called nucleus. About 600 million years ago, more advanced eukaryotic cells emerge having multiple cells (multicellular) together forming an organism. It is from this period forward that more specialized eukaryotic organisms with diverse activities emerged. This includes; fungi, plants and animals. Fungi are mostly multicellular eukaryotes, although yeasts are unicellular.

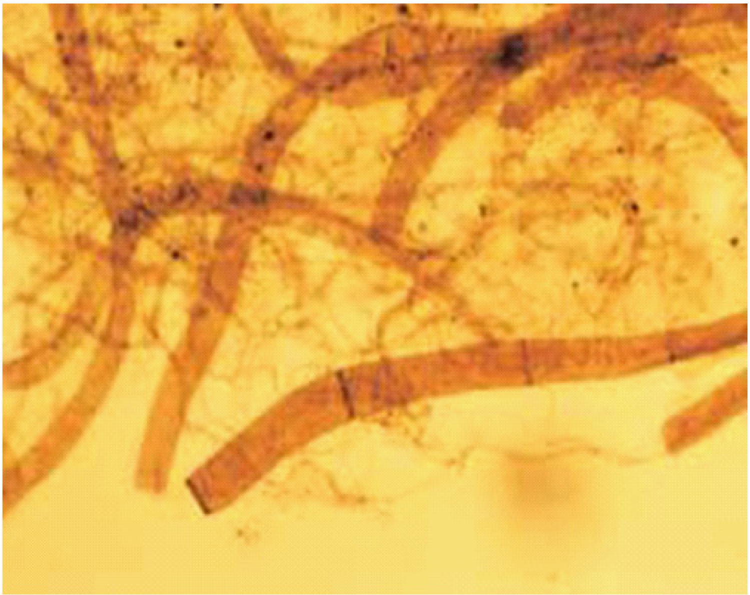

Figure 5: First eukaryotic cell by radioisotope dating of microfossil.

They are heterotrophic and usually non-motile organisms, with cell walls of chitin, such as mushrooms. Plants are generally multicellular, non-motile, usually terrestrial and photosynthetic organisms, such as trees, grasses, and mosses. Thirdly, animals are also multicellular eukaryotes which are generally motile and heterotrophic such as sponges, spiders, newts, penguins, and humans.

CHARACTERISTICS OF LIVING ORGANISMS

After having structured the evolution of living organisms, it is important to outline those properties or characteristics of these organisms that make them worth living. Living organisms are usually recognized by the power of growth, sense of irritability, respiratory activity, power of reproduction, and capacity of movement. However, movement may not necessarily be a distinguishing characteristic of all living things. Hence, the distinguishing characteristics of living things include the following.

1. Living organisms are *highly organized and complex structures* with a very large number of different organic molecules. The cell of an organism contain specialized organelles, nucleus, cell wall or membrane, numerous proteins, nucleic acids, organic compounds which are specific for various cellular processes.

2. Each component unit of a living organism is destined for a *specific purpose or function* whether microscopic structures such as cellular organelles like ribosome, nucleus, endoplasmic reticulum or macromolecules such as carbohydrates, proteins, lipids or macroscopic structures such as the heart, liver, lungs, brain etc.

3. All living organisms are capable *to extract, transform and use energy* from their environment. This could either be from radiant energy of sunlight to synthesize carbohydrates in the case of autotrophic organisms such as plants or from organic nutrients through digestion or catabolic metabolic processes or cellular respiration to release energy.

4. Self- replication is a paramount attribute to all living organisms. All living organisms are capable to replicate on their own from the sub-cellular level of DNA replication to cellular level of cell division. Growth is an aspect of self-replication since processes of growth requires cell division.

5. Reproduction is inevitable for all living organisms. Whether asexual or sexual, living organisms are capable to reproduce daughter cells or off springs.

Axioms of Living Organisms

The living objects are endowed with certain remarkable attributes which are in common. These characteristics are due to the typical nature, function and the kinds of molecules and interactions of the biomolecules present in living organisms. These characteristics, described as *axioms* or principles of living things was established by Albert L. Lehninger in 1984. These include;

1. There is a basic simplicity in the structure of biological molecules.

2. All living organisms constitute the same kinds of building block molecules and thus may have a common ancestry.

3. The identity of each species or organism is preserved by its possession of distinctive sets of macromolecules.

4. All biomolecules have specific structures for specific functions in cells.

5. Living organisms create complex organic molecules at the expense of free energy from their environment and also return this energy in less useful forms.

6. Living cells are chemical bodies that function at specific and constant temperature range.

7. The energy needs of all organisms are provided, directly or indirectly, by solar energy.

8. The plant and animal worlds – indeed, all living organisms – are dependent on each other through exchanges of energy and matter *via* the environment.
9. Living cells are self-regulating chemical engines, tuned to operate on the principle of maximum economy.
10. Genetic information is encoded in units that are submolecular in dimensions; these units are the four kinds of nucleotides, of which DNA is composed.
11. A living cell is self-assembling, self-adjusting, self-perpetuating isothermal system of organic molecules which extracts free energy and raw materials from its environment.
12. It carries out many consecutive organic reactions promoted by organic catalysts, which it produces itself.
13. It maintains itself in a dynamic steady state, far from equilibrium with its surroundings. It functions on the principle of maximum economy of parts and processes.
14. Its nearly precise self-replication through many generations is ensured by a self-repairing linear coding system.

HISTORY OF BIOCHEMISTRY

So many scientists actually study biochemistry and even making it their specialization without know its origin and trend of evolution. More so, this aspect of the origin is mostly not introduced in majority of biochemistry textbooks. This becomes the interest of young scientist or biochemist to understand the evolution of this discipline and how other specialties and disciplines shaped the emergence of biochemistry.

As far back in the BCs, wine was produced by fermentation from fruit juices and bread baked using yeast. These are some of the first products of man which were highly consumed and enjoyed without necessarily understanding the scientific basis of these processes. The first initiative of understanding biological processes was from the aspect of good health, whereby plants were used in the treatment of various illnesses and diseases. Even though medicine had basically commenced, understanding the processes of treatment was glaring until a Swedish alchemist and physician, Philippus Aureolus Paracelsus (Lifetime or LT, 1493–1541), laid the foundation of chemotherapy as a method for treating diseases. He applied the knowledge of chemistry which he first acquired to the field of medicine since he believed life processes where driven by chemical substances. Hence, such natural chemical substance can be used in the treatment of diseases. Subsequently, a new specialty in chemistry called medical chemistry amalgamating the science of chemistry with medicine by Jan Baptist van Helmont (LT, 1577–1644) was introduced. Owing this concept that life processes are chemical in nature, certain scientists exploited it to know the chemical composition of living things as well as drugs. One of such scientist was Karl Wilhelm Scheele (LT, 1742–1786), a Swedish pharmacist who discovered the chemical composition of some plant and animal materials as well as various drugs. He laid the foundation of descriptive biochemistry as he isolated a number of substances in living things such as lactic acid from sour milk, citric acid from lime juice, malic acid from apple and uric acid from urine. Another scientist whose contribution was immense in the evolution of biochemistry was a French chemist, Antoine Lavoisier (LT, 1743–1794). He characterize the chemical composition of air, studied the process of oxidation and the nature of animal respiration in which he concluded to be similar to combustion but at a slower rate. Lavoisier is often considered as father of modern biochemistry. From this moment onward, a lot of biological molecules such as urea were isolated, identified, characterized and chemically synthesized

By the nineteenth century, the foundation of structural biochemistry was laid as the composition of fats (glycerol and fatty acids) was discovered through the process of saponification by Michel Chevreul (LT, 1786–1889). Structural biochemistry was fully established by Hermann Emil Fisher (LT, 1852–1919), a German biochemist who did extensive work characterizing carbohydrates, amino acids and fats, establishing some of their composition. Subsequently, around 1869, nucleic acids was discovered by Friedrich Miescher (LT, 1844–1895) in the nuclei of pus cells, obtained from discarded surgical bandages. After the characterizing carbohydrates, protein and fats, digestion was a process which needed more emphasis to be laid. As such, Claude Bernard (LT, 1813–1878) of Paris discovered liver glycogen and showed its relation to blood sugar in health and disease as well as evaluated the digestive properties of pancreatic juice.

Physical chemistry was also another field which made substantial contribution in the evolution of biochemistry. Aspects of electrolytic dissociation and osmotic pressure were attributed to biological processes. This led to the development of the concept of pH by a Danish chemist Soren Sörensen (LT, 1868–1939). Principles of physical chemistry was applied to study biological processes which led to the development of apparatus such as the ultracentrifuge by Theodore Svedberg (LT, 1884-1971), the electrophoresis apparatus by Arne W.K. Tiselius and chromatography.

Though fermentation was a process which was highly exploited for various products, the biological process became fully established in 1857 after French microbiologist Louis Pasteur (LT, 1822–1895) who showed evidence of the process involving microorganism. He identified several organisms that carried out various fermentations, including that leading to butyric acid, a process performed by organisms that function without oxygen. He defined fermentation as “*la vie sans l’air*” (life without air). Pasteur, thus, introduced the concept of aerobic and anaerobic organisms and their associated fermentations. Understanding the processes of fermentation laid the basis for enzymology and metabolism as specialties in biochemistry by the twentieth century. In this regard, Leonor Michaelis placed the concept of chemical compound formation between enzyme and substrate on an experimental basis after the discovery of enzymes and cofactors involved in cellular oxidation. Further work on cell-free fermentation of sugars led to the establishment of metabolic pathways. The pathway for metabolism of glucose or glycolysis was laid by Embden and Meyerhof, with later named as the Embden-Meyerhof-Parnas pathway. In studying metabolic processes, Fritz Albert Lipmann (LT, 1899– 1986) and Kurt Henseleit showed the terminal pyrophosphate linkages of ATP as an energy storage reservoir in the body. Subsequently, upon studies on the fate of pyruvate during aerobic oxidation, Albert Szent-Györgyi and Hans Adolf Krebs (LT, 1900–1981) of England developed a sequence of reactions which they named Krebs cycle or citric acid cycle. It was later established that fatty acids and amino acids were also metabolized to yield intermediate metabolites that are identical with those in the Krebs cycle. This came to a conclusion that the kreb cycle was at the center of metabolism of all foodstuff to release energy.

Further work on characterization of macromolecules led to the identification of amino acid by Frederick Sanger who later established the complete amino acid sequence of insulin, a protein hormone. This paved the way to knowing the structure of proteins as the alpha-helix secondary structure was establish by Linus Carl Pauling (LT, 1901–1994) and Robert Corey (LT, 1897–1971). Subsequently in 1953, the double-stranded DNA molecule structure was proposed by James Dewey Watson and Francis Harry Compton Crick and confirmed by Erwin Chargaff. Following this discovery, DNA was enzymatically synthesized by Arthur Kornberg, which possessed properties that suit the Watson-Crick hypothesis. Further characterization of nucleic acids led to the identification of transfer, messenger and ribosomal RNA molecules and their involvement in protein synthesis. Holley, Medison, and Zachan outlined the base sequence of transfer RNA molecules specific for different amino acids while Marshall Nirenberg established the accurate list of the base sequences in messenger RNA that code for each of the amino acids by using synthetic nucleotides as messenger molecules to confirm the genetic code for each of the amino acids.

Even though enzymes had been discovered and many of them had been isolated, purified and kinetics established, the chemical nature of these enzymes remained unfolded. This was overcome around 1926, when James B. Sumner (LT, 1887–1955) at Cornell University known to be the ‘father of modern enzymology’, for the first time, was able to crystallize urease from the extracts of Jack bean and demonstrated its protein structure. Subsequently, other enzymes like pancreatic and gastric enzymes were also crystallized and structure established by John H. Northrop and Kunitz.

Owing to the understanding of metabolic pathways and enzyme involvement, it became of interest to understand the mechanisms for the regulation of the synthesis of cellular compounds. This led to the understanding of feedback inhibition of enzyme activity by the end product and enzyme induction and repression; genetic processes of the accelerating or inhibiting of synthesis of an enzyme respectively. Genetic regulation was proposed in 1961 by two Frenchmen, Francois Jacob and Jacques Monod, suggesting that the DNA molecules consist of areas in which genes are maintained in an inactive state (by repressors) until their products are needed and activated for the production of messenger RNA molecules. Molecular biology emerged after the structures of nucleic acids was established using more sophisticated apparatus such as Electron Microscopy **(EM)**, mass spectrometer, X-ray diffraction, Nuclear Magnetic Resonance **(NMR)** and other spectroscopic and separation techniques . After the advent of recombinant DNA technology, more other specialized fields such as genetic engineering and biotechnology have more emerged.

The word biochemistry was coined by German chemist Ernst Hoppe–Seyler around 1890s who established a journal and evoked the recognition of a new discipline called biochemistry. Since then, biochemistry which has evolved from organic, medicinal, physical chemistry and cell biology has also become a discipline that has paved the way for new disciplines. It has become very difficult to clearly find the boundaries of biochemistry with these disciplines as they are interwoven. Certain branches of chemistry, such as biological chemistry which studies the structural basis of living things overlaps with biochemistry. From a biochemist perspective, the interest in biological chemistry is to identify the structure of living organisms and relating them to their functions while a chemist will go further in synthesizing these biomolecules to understand the chemical properties. However, the boundaries cannot be fully established. Also biochemistry and molecular biology are also interwoven with similar objectives. However, they may be distinguished by their approaches to solving problems. From a molecular biologist perspective, the focus is to study the flow of biological information transfer by genetic material (RNA and DNA) which can be approached by recombinant DNA technology and molecular genetics while biochemists is interested on the structure and function of all biomolecules and energy relationships among them. Even though biochemistry exploits tools designed for chemical and physical measurements, certain biochemistry questions have required molecular biology techniques to answer them.

Today, biochemistry has developed to various specialties such as biological chemistry or chemical biology, structural or descriptive biochemistry, enzymology, bioenergetics, metabolism, clinical biochemistry, molecular biochemistry, endocrinology, medicinal biochemistry, agricultural biochemistry, pharmacological biochemistry, analytic biochemistry, comparative biochemistry etc.

CONSTITUENTS OF LIVING ORGANISMS

From the evolution of life which suggested living organisms to be made up of chemical substances, it has been confirmed after a lot of structural biochemistry research that all living organisms, from microbes to animals, are composed of chemical substances which are both inorganic and organic in nature. Of all the natural existing elements (over 100 of them), only about 31(28%) occur in living organisms. Among those present, carbon, hydrogen, oxygen and nitrogen make up 96.3% of the total weight of living cells which in addition with phosphorus and sulfur make up more than 99% (Table 2).

Table 2: Constituents of the Human Body.

Elements	Relative abundance (%)
Hydrogen	60
Oxygen	22.5
Carbon	10.5
Nitrogen	2.4
Calcium	0.22
Phosphorous	0.13
Sulphur	0.13
Potassium	0.03
Sodium	0.03
Magnesium	0.03

Hydrogen, oxygen, nitrogen, carbon, sulfur and phosphorous when in different combinations form various building blocks of macromolecules; carbohydrates, proteins, lipids and nucleic acids which are organic in nature (Figure 6).

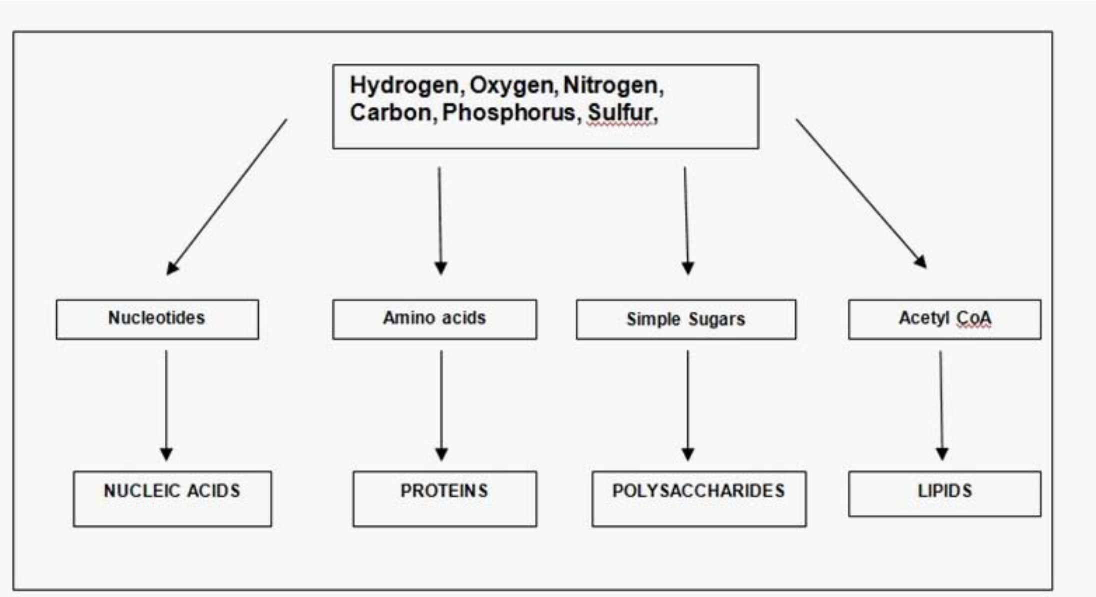

Figure 6: Formation of Macromolecules within Cells.

The remaining 1% constitutes minor elements which are inorganic in nature with various functions. The first category of them is metal such as sodium, potassium ions essential for the transmission of nerve impulses, and calcium is required for muscle contraction. Calcium and phosphorous are metals essential for teeth and bone formation. These metals when combined with other compounds can become acids, base or salts. Acids and bases are very important in the control of the acidity (pH) of the body, especially weak acids and weak base which serve as buffer to maintain the body's pH within very strict limits close to the neutral pH of 7. Various buffers in the body include protein, blood, haemoglobin, phosphate and carbonic buffers etc. Salts such as sodium chloride (NaCl) and Potassium Chloride **(KCl)** make up the main ionic constituents of the fluids bulk outside and inside cells and control the movement of water and other substance into the cell. The other category of the metals is the trace elements such as iron, iodine, copper, zinc etc. which are required in very small amounts (less than 0.01%). Most of these trace metals serve as cofactors for enzymes and are required for their activation and catalytic activity

In living organisms, there are general four classes of macromolecules; nucleic acids, proteins, polysaccharides, and lipids which are created through polymerization of building blocks (micromolecules) including nucleotide bases, amino acids, simple sugar and acetylcoA respectively. These macromolecules exist in various types in different cell types and tissue base on the functions. In cells, about 30% of the solid mass are macromolecules of proteins having the highest relative abundance with 15%, followed by nucleic acid (7%), carbohydrate (3%) and lipids (2%) while the remaining wet mass constitute about 70% of water (Table 3).

Table 3: Major chemical components of the cells.

Components	Percent (w/w)
Water	70
Proteins	15
Nucleic acids	7
Sugars	3
Lipids	2
Intermediates	2
Inorganic ions	1

On the other hand, the human body constitutes about 40% macromolecules of the dry mass while 60% is water. Lipids are about 20%, proteins 15%, nucleic acid (3%) and carbohydrates (2%). Although proteins are the most abundant and diverse macromolecules, DNA is the largest biomolecule in the cell. Details of the macromolecules and their relative abundance are summarized in Table 4.

Table 4: Chemical Composition of a normal Cell with reference to *Esherichia coli*.

Material	%Total Wet Wt.	Different Kinds of Molecules/Cell
Water	70	1
Nucleic acids		
DNA	1	1
RNA	6	
Ribosomal		3
Transfer		40
Messenger		1000
Nucleotides and metabolites	0.8	200
Proteins	15	2000-3000
Amino acids and metabolites	0.8	100
Polysaccharides	3	200
(Carbohydrates and metabolites)		
Lipids and metabolites	2	50
Inorganic ions	1	20
(Major minerals and trace elements)		
Others	0.4	200
		100

Data from Watson JD: Molecular Biology of the Gene, 2nd ed., Philadelphia, PA: Saunders, 1972.

OVERVIEW OF MACROMOLECULES

Nucleic Acids

The word nucleic acids originated from the Greek word poly, meaning “several”, and mer, meaning “unit”). Hence nucleic acids are nucleotide polymers that store and transmit genetic information. Nucleic acids contain mainly 5 different nucleotides bases which serve as their building block for biosynthesis. This includes Adenine **(A)**, Thymine **(T)**, Cytosine **(C)** and Guanine **(G)** for DNA while Uracyl **(U)** replace thymine in RNA molecules. These nucleotide bases in DNA in the cell exist as chromosomes. Within the chromosomes are genes which carry specific genetic information which can be expressed to direct chemical processes in the cell. The total number of genes in any given mammalian cell may total several thousand with humans having the highest number of genes to be over 23 thousands. Before cell division, chromosomes unfold leaving DNA in a straight and free state permitting the double helix structure to unwind for self replication producing identical copies of DNA molecules. This process permits the transfer and conservation of hereditary material to descent. The goal of the genetic information carried on DNA in genes is to provide instructions for the assembly of protein molecule within the cell. The flow of information is first from DNA to RNA through the process of transcription and RNA directs the synthesis of protein by the process of translation. The RNA are of three types; messenger ribonucleic acid (mRNA), the first of all to carry the information, secondly the transfer RNA (tRNA) to transport incoming amino acids to the ribosomes and thirdly ribosomal RNA (rRNA) to direct the recruitment of the amino acids for the synthesis of the polypeptide chain or protein.

Proteins

Genetic information from DNA needs to be implemented. Proteins are polymers of amino acids carrying these information or instructions contained within the genetic code for implementation. Proteins are synthesised in ribosome in the cytoplasm through the process of translation whereby mRNA, tRNA, and rRNA transfer genetic information from the genetic code to recruit amino acids. Proteins are organic compounds containing the elements Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur. Protein exists in so many diverse forms and types. The reason for this diversity as a result of the different types of amino acids which are recruited based of the different genetic information transfer. There exist twenty conventional amino acids used to synthesize proteins of which about half are synthesized in body while the other half are not and must be provided through our diets, hence referred to as “essential” amino acids. Based on the genetic information transferred, each protein formed in the body is unique in structure and specific in function. Hence, thousands of different proteins can be contained in a single cell, each having a specific function. Proteins can serve as enzymes that have the catalytic ability to speed up chemical reactions. Some proteins are hormones which act as chemical messenger carrying information for specific activities or neurotransmitter to transport nerve impulses. Certain proteins serve as membrane transporters, transporting various compounds and molecules across the cell membranes. Others transport molecules from one location to the other in the body through blood. For example, transferrin transports iron, lipoproteins transports lipids, while haemoglobin carries oxygen. Some protein have structural function (e.g., collagen and elastin), others serves in muscle contraction (e.g., the actin, myosin, tropomycin and troponin in skeletal muscle fibers). Proteins also serve as one of the major defence system in the body. This constitutes the white blood cells which are the major constituents of the innate immune system as well as produce immunoglobulins for adaptive immune response. Certain protein factors and platelets participate in blood clotting after injuries.

Carbohdrates

Carbohydrates, also known as polysaccharides are molecules formed from the polymers of monosaccharides or simple sugars. The name polysaccharide was derived from the Greek word sakchar, meaning “sugar or sweetness” hence, saccharide. They consist of carbon, oxygen and hydrogen only, with a ratio of hydrogen to oxygen of about 2:1. The simplest forms of carbohydrates are termed sugars. These simple sugars are either monosaccharides with just a single sugar units or disaccharides which are formed from two monosaccharides. Larger carbohydrates with several monosaccharide units are called polysaccharides. Certain polysaccharides contain only one kind of sugar and are called homogeneous polymers. For example, glycogen and starch are polymers of only glucose. Most homogenous polysaccharides usually serve as storage (starch) and structural purposes. Heterogenous polyssacharides are those that contain different types of sugar units. Some polysaccharides can serve as functional and structural components of cells (e.g., glycoproteins and glycolipids). The 8-10 monosaccharides that become the building blocks for heterogenous polysaccharides can be synthesized from glucose, or formed from other metabolic intermediates. Carbohydrates are the primary source of energy in the body. Glucose which is the central molecule for storage polysaccharides is oxidised to liberate about 16.7 kJ (4 kcal) per gram of glucose.

Lipids

The name lipid was derived from the Greek word lipos, meaning "fat". Lipids are another category of naturally occurring macromolecules which are nonpolar substances and mostly insoluble in water except for short-chain volatile fatty acids and ketone bodies. They are generally soluble in non-polar solvents such as chloroform and ether. The simplest type of lipids is called the triacylglycerols or triglycerides. They are formed from fatty acids and glycerol. Lipids could be saturated based on the presence of only single bond or unsaturated based on the presence of double or triple bond. At room temperature, saturated lipids are solids while unsaturated are liquids. Some lipids are conjugated to proteins known as lipoproteins for their transportation in the body. This includes Chylomicrons **(CMs)**, Very Low Density **(VLDL)**, Low Density **(LDL)**, Intermediate Density **(IDL)**, and High Density Lipoproteins **(HDL)**. Other types of lipids include glycolipids and phospholipids, steroids (progesterone, cholesterol, etc.), and eicosanoids (thromboxanes, prostaglandins and leukotrienes). The central building block of lipids is acetyl-CoA, which can also be generated from amino acids, carbohydrates, ketone bodies, short-chain volatile fatty acids (e.g., acetate), and fatty acids. Simple lipids can be described as simple if they are esters of fatty acids and an alcohol only (e.g., mono-, di- and triglycerides) and are considered compound lipids if they contain other additional substances to the alcohol and fatty acid (e.g., phosphoacylglycerols, sphingomyelins, and cerebrosides). Derived lipids are those that cannot clearly be classified into either of the above categories (e.g., steroids, eicosanoids, and the fat-soluble vitamins). Lipids have various functions in the body. They are the second energy source of the body after carbohydrates particularly triglycerides. Cholesterol, glycolipids and phospholipids serve as membrane components, they are precursors for the synthesis of other important biomolecules such as vitamins (A, D, E and K), steroid hormones etc. They also serve as protective coatings to prevent infection and excessive loss of water as well as insulation barriers for heat loss.

Inorganic Substances

Although most of the human body or cell is organic in nature containing carbohydrates, protein, lipids and nucleic acids, a small portion of it is inorganic. This inorganic elements based on their functions are subdivided into three categories; the macrominerals, trace elements, and ultra trace elements. Most macrominerals such as potassium, calcium, sodium etc. are "essential" for the body and therefore must be supplied in the diet just like certain unsaturated fatty acids and amino acids. In the cells, these inorganic elements are basically present in their ionic forms, existing either as free ions or complexed with organic molecules. Also, the trace elements such as zinc, ion, and copper are essential for the body. They function as cofactors for enzymes, structural components of non-enzymatic macromolecules,

WATER AND IMPORTANCE IN LIVING ORGANISMS

Water is the most abundant molecule present in living organisms. In the cell it amounts to about 70% while in the body it constitutes about 60%. This implies in a 70 kg human, about 42 liters (L) is water of which about 28 L (approximately 40% of body weight) is present within cells (intracellular fluid), while about 14 L (approximately 20% of body weight) is extracellular fluid constituting about 10.5 L interstitial fluid and the 3.5 L blood plasma . Water molecule is made up of two hydrogen and one oxygen atoms (H_2O). The hydrogen and oxygen atoms share electrons by covalent bonding, but these electrons are not shared equally. Because of this uneven pattern of charge, water is a polar molecule. Thus, water serves as a good solvent for other polar molecules such as sugars, salts and proteins. Also, the ability of substances to dissolve in water and dissociates into ions makes water a good medium for biological reactions. More so, because water is polar in nature and water molecules are attracted to the negative region of another water molecule by hydrogen bonding causes water molecules to be attracted to one another or stick together. This property makes water acts as a lubricant, preventing solid structures from rubbing against each other and causing damage. This helps to cushions the brain within the solid skull, preventing damage which could occur due to sudden movements of the head banging. Also, because the hydrogen bonds are weak bonds that can be easily be broken, thus permits water molecules to react with other substances and promote so many chemical reactions. Water molecules may not only reaction with each other through hydrogen bonding. The hydrogen can bond with nitrogen atoms exerting a significant attractive force; cohesion causing water to cling to itself and adhesion, to other surfaces. Cohesion and adhesion together enable water molecules to possess capillarity action, the ability of water to move upwards through narrow tubes against the force of gravity. Water has a high heat capacity which helps to stabilize the temperature of our environment and maintaining homeostasis balance. Above all, water serves in transporting molecule within the body through plasma and also in and out of the cell.

CONCLUSION

Even though it may be very difficult to conclude with certainty on the origin of life and the first molecules that emerged to eventually evolve to living organisms, biochemistry has tried to throw in more light into the evolution of life and identify the constituents that define living things. More so, biochemistry has been able to structurally characterise this constituents and clearly explain their functions and how they are implicated in the existence of living organisms. It is our hope that biochemistry will continue to evolve to more sophisticated techniques and focused specialties to provide solutions to issues pertaining to living organisms.

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