Cell and Molecular Biology
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Week 01
Origin of Life and Evolution
Lecture - 02
Origin of Life (Part 2)

Hello everybody, this is Dr. Vishal Trivedi from the Department of Biosciences and Bioengineering at IIT Guwahati, and what we are discussing is the origin of life on Earth. In this context, we have discussed the various theories, and we have also discussed the conditions of the Earth that made it possible for life to exist. We have talked about the structure of the Earth, and so on. So in the previous lecture, we emphasized the conditions and the way in which life originated on Earth, and in that context, we discussed many types of theories. We have discussed the theory of spontaneous generation, the theory of special creation, and the theory of abiogenesis, among others.

By discussing those theories, we have understood that they were mostly based on different types of assumptions, not on experiments; they were only based on assumptions. For example, in the theory of special creations, this is completely a religious theory in which people have discovered or believed that God is the creator of the earth and the different types of organisms, and different religions have their own ways of explaining this particular phenomenon. And then we discussed the theory of spontaneous generation, which states that non-living matter gives rise to different types of organisms. So, there were six major theories that we mentioned in the previous lecture that have been proposed.

Out of these six theories, five were discussed in our previous lectures, and all of these theories were mostly based on assumptions as well as not performing many of the conclusive experiments. So now, in today's lecture, we are going to start discussing the modern theory, or the chemical theory, of the origin of life, which explains how different chemical molecules give rise to the generation of organisms. And this theory is apart from the earlier five theories; it has completely depended on the different types of experiments that are being performed, and it is based on scientific evidence. So let's start discussing the modern theory, or the chemical theory, of the origin of life. So, what we have discussed includes the theory of special creation, the theory of spontaneous generation, the theory of catastrophism, the theory of cosmozoic, and the theory of the eternity of life.

Now in today's lecture, we discuss the modern theory. So, what is the modern theory? The modern theory, which is also known as the chemical theory or the theory of primary abiogenesis, is the focus of our discussion. So modern theory is very much linked to the theory of abiogenesis, except that what they have said is that it is not possible to have life on Earth under the current conditions. So we have to create the conditions that were present on primitive Earth. If you recall, in the previous lecture, we discussed what the conditions were on primitive Earth, right? The condition on primitive Earth was that it was reducing in nature because no molecular oxygen was present, and it was mostly hydrogen and hydrogen compounds, right? Whether it was water, hydrogen, methane, or ammonia, all these molecules were hydrogen derivatives.

So these molecules were making the environment more reducing, and we discussed in the previous lecture as well why the reducing environment is good and what supports the origin of life. Although life cannot continue without oxygen because it depends on various processes that require energy, that energy is released only by the oxidation process. But earlier in the primitive Earth conditions, there was no other energy because it was getting energy from solar energy, volcanic eruptions, lightning, and other kinds of sources, including radioactive decay, and so on. So the conditions on primitive Earth were different from present conditions, which did not permit abiogenesis. Therefore, people have been trying to achieve abiogenesis.

If you recall the classical experiments done by Redi, Spallanzani, or even Louis Pasteur, they disproved the theory of abiogenesis simply because the current conditions on Earth do not support life. It does not support the origin of life. It only supports life activities because it supports the generation of energy. It does not permit abiogenesis. The idea of the chemical theory was put forward by the two scientists, A.

I. Oparin and J.B.S. Haldane, and it makes the following assumptions. What are these assumptions? The spontaneous generation of life under the present environment is not possible, and that is the reason the abiogenesis theory was disproved or discarded because of the classical experiments conducted by Redi, Spallanzani, and Louis Pasteur.

The Earth's atmosphere approximately 1 billion years ago is very different from the current condition; it was not the same. It is very different because the current condition is more oxidizing, whereas at the time of the formation of the Earth 1 billion years ago, it was mostly reducing. So it has more hydrogen and hydrogen-related molecules. The primitive Earth's atmosphere was reducing in nature, which was very important; under these conditions, the chemical molecules, such as inorganic molecules like water, ammonia, or methane, reacted with each other through a series of reactions to form organic substances and other complex biomolecules. The solar energy and UV radiation provide the energy for the chemical reactions.

Now, when these two great scientists proposed the modern theory of origin, or the chemical theory of origin, they also said, "Okay, this is fine." But now how you say that this is actually be the case, right? So you have to perform the conclusive experiment. You have to show me that this is actually be the truth. And for that reason, the scientists have started doing the experiment to prove or to disprove the modern theory. So the first scientist who provided the experimental evidence to prove the modern theory did so because, initially, the hypothesis proposed by Haldane did not receive much scientific attention or support, as no experiments were conducted by scientists.

And then, to conclusively support the chemical theory, Stanley Miller and Urey conducted an experiment that mimicked the primitive Earth conditions. So how they have done that is by actually developing a scientific experimental setup that contains a glass flask, a condenser, and a liquid flask, all of which are interconnected with a tube and a source of electric spark to provide energy. So what they have done is take an experimental setup where they have the glass flask connected to the liquid flask, which is the flask where water can be boiled. And then they also have the glass flask where they have actually been able to produce an electric spark, and that electric spark is mimicking lightning. And that's how they were actually been providing the energy and then they can actually be able to allow the entry of the different types of gases into this so what they have done is they have taken the methane ammonia and hydrogen as a gas into this chamber.

And then they had the condenser so that it would actually cool down these gases so they would be present in liquid form, or the substances that were going to be formed. So then what they have done they have taken this apparatus and then he introduced a mixture of methane, ammonia and hydrogen in the ratio of 2 : 2 :1 and the water and water vapor at a temperature of 800 degree Celsius. If you recall, when we were discussing the Earth's formation, we said that the Earth was formed when the temperature was approximately 1,000 °C. So, they have maintained similar kinds of primitive Earth conditions, such as 800 °C. They have created a reducing environment by introducing hydrogen, as well as ammonia and methane.

So, there was no oxygen in their apparatus. Then they circulated this mixture into the apparatus. So, this is a closed apparatus, right? There is no way it can go out, right? So, because the oxide outside is oxygen, right? So if oxygen enters, it will actually destroy the chemical reaction, and that's why there will be no generation of organic molecules. Then they allow the mixture to circulate in this closed glass apparatus continuously for 18 days, so they have allowed it to be circulated. They have heated the water correctly.

So water is going this way, right? And while it is going, it is also taking in different gases, right? Different gases are entering this mixture, and then these gases are entering this bulb, right? And once they enter the bulb, they are actually putting in the electric shock; because of that, there will be an electric spark that mimics lightning, and that's how it provides heat or energy to the system. So, because of this energy, these gases are actually going to react with each other, and then they are going to form a new compound, and that's how they will be cooled down by a condenser, so they will form a liquid. And then these gases are actually going to, you know, condense; the liquid is going to be condensed in this particular trap, and after that, the gases will again enter this water. And once they enter this water, they are actually going to come out in the form of a kind of volcanic eruption or something, right? So they will come out of this water, and again they will travel. This continued for 18 days.

During these 18 days, they have taken out the sample. So they have a sample port, which you see here, right? They have a sample port. So whatever liquid condenses here, they can take out the sample, and then that sample can be tested for the synthesis of the new compound or not. So they provided the energy in the form of sparks by supplying electricity at 75,000 volts to the two electrodes. The electric sparks mimicked the lightning that occurred in the primitive Earth's atmosphere.

While passing, the mixture of gases was passed through a liquid flask to simulate the volcano; the mixture was collected from the stopcock and analyzed using chromatography as well as the calorimetric technique. So chromatography is a technique, or calorimetry is a technique; calorimetry is actually going to tell you what the energy level will be or what the free energy change of these compounds that are being formed is. Whereas chromatography is actually going to tell you the nature of that particular compound, it indicates whether glucose is formed, whether sugars are formed, or whether organic molecules are formed. So chromatography is a separation technique that not only separates the molecules but also tells you the nature of a particular compound. Chromatography can also be used to purify or characterize the molecules.

The analysis of the mixture indicates that the presence of amino acids such as glycine, alanine, aspartic acid, and the nitrogenous base adenine is observed in these particular experiments. So, this proves that you can synthesize new compounds by doing this experiment. The mixture collected from the stopcock was analyzed using chromatography and calorimetric methods. The mixture indicates the presence of amino acids such as glycine, alanine, and aspartic acid, as well as nitrogenous bases such as adenine, along with the simple sugar ribose. Thus, you know that adenine and the sugar can actually form the simple molecule called DNA or a nucleotide.

So, these two molecules can actually give you DNA as well as RNA, whereas all these molecules like glycine, alanine, and aspartic acid will probably be good for providing you with proteins. So that's how they have proved that by doing this simple experiment, they have not conducted the experiment for a very extensive period, like, you know, 18 days, which is a very short period to see whether the proteins are formed or not. So, 18 days is good enough to say that by using this method, you can synthesize the biomolecules. Once you synthesize the biomolecules, they can give rise to life. The chemical molecules and the chemical reactions that explain the synthesis of these compounds are as follows.

The formation of simpler organic molecules like formaldehyde or HCN occurs when carbon dioxide is dissociated into carbon monoxide and molecular oxygen, and then methane reacts with these two compounds to produce HCHO. This is a formaldehyde and then water is going to be released. Similarly the carbon monoxide which is going to be react with ammonia is actually going to give you the HCN. And if the methane is also going to react with the ammonia, it also can give you the HCN. Similarly, you can explain the formation of glycine.

Formaldehyde, ammonia, and HCN then react to form glycine. So, this is formaldehyde; it reacts with HCN, and then it reacts with ammonia, and that's how it actually gives rise to glycine. And then this NH_2CH_2CN is actually going to react with water, and that is how you will have a molecule of ammonia, and you will also have a molecule of glycine. So, the generation of glycine and the generation of the other biomolecules proved for the first time that it is possible to synthesize the biomolecule with the help of inorganic molecules. Before that, it was not possible, right? So, because the condition in which the people were trying to prove abiogenesis was not, you know, conclusive, like, for example, even if you take the rotten meat, it will not give rise to, you know, the molecules.

So, this classical experiment by Stanley Miller actually proved that the modern theory, or the chemical theory, is correct and that it can actually give us insight into how life originated on Earth. Then they move ahead and actually give the details of what the different steps could have been, probably through the synthesis of these biomolecules, and how these biomolecules could have given rise to the primitive cell, which could have evolved into more and more complex organisms. According to the chemical theory, what are the proposed events? Nobody knows how life originated on Earth, but based on these experiments, scientists have proposed multiple events. What you have is four major steps that have been proposed. So, according to the chemical theory of the origin of life, a series of chemical syntheses gives rise to life, right? You have seen how carbon dioxide, ammonia, and methane are actually reacting to give rise to formaldehyde, and then formaldehyde is reacting with these molecules to give rise to glycine.

So, the synthesis of glycine, which is the simplest amino acid, allows for multiple combinations once glycine is formed, and that's how you can achieve the synthesis of even more complex biomolecules. Considering this, these scientists have proposed the events that probably could have happened in the primitive Earth environment, and that is how they have stated that it is a four-major-step process. What is step one? Step one is the formation of inorganic molecules. The high temperature of primitive Earth did not allow the condensation of atoms to form inorganic molecules. As the temperature of the Earth goes down, the condensation of different atomic molecules gives rise to simpler molecules.

For example, in primitive Earth, there were hydrogen, carbon, nitrogen, and oxygen. But when the temperature goes down, these molecules come together, and that's how they synthesize simpler inorganic molecules like ammonia or acetic acid. So you can see that the molecular oxygen, which is associated with this molecule, is what has given rise to the two simpler molecules, which are ammonia and oxygen. Apart from that, you can also have methane and the elements; the most abundant elements are hydrogen, oxygen, nitrogen, and carbon. The reaction of these molecules gives rise to different gases such as hydrogen, nitrogen, ammonia, methane, carbon dioxide, and water vapor.

So, because these elements are present, you can have different types of gases: nitrogen, hydrogen, and ammonia, right? You can have the ammonia, you can have the carbon dioxide, and you can have the nitrogen, water, and water because the temperature is high; it is always going to be present in the form of vapor. So, water will actually be a medium through which these different gases react with each other. The energy of these reactions is provided by sunlight, lightning, or volcanic eruptions because, you know, if you want to do a chemical synthesis, you have to form the bonds. For example, you have two carbon molecules. Then, if they do not form a bond, they have to make a compound.

They are supposed to form a bond, whether it is a single bond, a double bond, or a triple bond. This bond formation requires energy, so that energy will be supplied externally by sunlight, lightning, or volcanic eruptions. So in step 1, you are going to have the formation of inorganic molecules, whether they are gases or liquids. Then in step 2, you are going to have the spontaneous formation of monomeric organic compounds. The simple molecules interact with each other to form simple monomeric organic compounds.

So, you can imagine that you have the primitive ocean where there are all sorts of gases like methane, ammonia, carbon dioxide, hydrogen, nitric oxide, and all those kinds of molecules. So when they do, and then you have the lightning, right? And you also have the UV light from the sun, and all these are when they are doing, they are actually forming simpler monomeric compounds like fats, proteins, nucleic acids, primitive water, and polysaccharides. So, these molecules are like sugars, fatty acids, glycerol, amino acids, and organic bases, such as purines or pyrimidines. The reactions between the inorganic compounds to give simpler organic compounds occur in a reducing environment inside the ocean. The inorganic molecules are condensed in the form of rain as the temperature of the Earth decreases.

Hence, both inorganic compounds and simpler organic compounds were present in the primordial ocean, which means that once the temperature went down, the water was condensing, right? So there was rain, right? And because of the rain, all these molecules that are present in the atmosphere are condensing and getting dissolved into the molecular ocean, and that is how they obtain a medium in which all these molecules react with one another. The energy they are getting from the lighting as well as the sunlight is how they are forming simpler sugars. They are forming simple fats and simple nucleic acid molecules like nucleotides, and all these molecules are present in the primordial oceans. Then, in step 3, the spontaneous formation of complex organic molecules occurs. Once you have generated the simpler organic molecules, these simpler organic molecules will actually react with one another.

So what we have generated are simpler carbohydrates, like simpler sugars, and these simpler sugars are then actually going to form more complex sugars. So the small, simpler organic compounds react to form complex organic compounds. Simple amino acids react to form polypeptides. Sugars react to form large sugar molecules. Fatty acids and glycerol combine to give you fat, and the heat of the sun is utilized to provide energy for these reactions.

So, what we have are the simplest organic molecules, which will react with each other to give larger, more complex molecules like glycerin, ribose, glucose, and even larger molecules. So, fat is also being developed once you have the glycerol and the fatty acids; the glycerol and fatty acids actually combine to give you fat. And you know that fat is a very important component of the plasma membrane. Right. So, that is actually going to give rise to the plasma membrane of the primitive cell.

That is what we are going to discuss. In step three, you are going to have the synthesis of complex organic compounds. Then, in step four, you will see the generation of smaller molecular sizes. Once you have generated the small molecules, they do not tend to clump together, but once you generate bigger biomolecules like proteins or nucleic acids, they tend to do so. They will actually react with each other, and that's how they will form the complex, right? So they will form a complex, and these complexes are known as coacervates, right? Therefore, they will be called coacervates. And you can see, right? So all these molecules, where you can probably find a protein that is actually going to form the outer layer, and then within this, you can have the DNA or lipids and all those kinds of things.

And that's how you are actually going to have ball-shaped coacervates, where the molecules come together and form the colloidal aggregates called coacervates. A layer of water molecules forms around the protein molecules present in coacervates. So, once the protein molecules are there, even if we discuss in the future that protein molecules are actually made up of amino acids, the amino acids will attract water. So, what will happen is that the water molecule is actually going to, you know, adsorb onto these molecules, and that's how you have coacervates; apart from the coacervates' weight, outside the coacervates' weight, you are going to have, you know, the layer of water. And because of this, this small area is actually going to be turned into a very concentrated area.

So it will actually concentrate the reactants, and that's how it is actually going to facilitate the chemical reaction at a faster rate. You know that chemical reactions are dependent on the concentration of the molecules, right? So if A is being converted into B, if you have 10 milligrams of A, it is actually going to be from 10 milligrams of B. But if you increase the amount, even if you keep the 10 milligrams and the concentration is 0.5 milligrams per ml, the reactions are actually going to give you the reactants in the same ratio. But if you take the 10 milligrams and make the concentration 10 milligrams per ml, then in a given time, what will you get? You will get the 10 milligrams of B, right? So, the rate of reaction has always been dependent on the concentration of the reactants, right? You can increase the rate of reaction simply by having a protein that covers these coacervates, and apart from the proteins, you can also have the water molecules.

So, that is why it is actually going to form a small vessel-like structure, and because of this, the local concentration of the molecules will increase. So the membrane that is present around the molecule protects the molecule, right? First of all, it is going to protect it. It is not going to be damaged. It is not going to disintegrate. So this is actually going to form the colloidal particles, which will not be dislodged, and at the same time, it will bring a high concentration of the reactants to enhance the chemical reaction.

So you can see, when we were talking about the previous lecture, it took a couple of billion years for these reactions to complete so that you could have the synthesis of these biomolecules. But if you increase the reaction concentration, the chemical reaction will enhance because remember that there is no enzyme, right? So there is no enzyme in this case, so the chemical reaction has to occur spontaneously on its own. The colloidal aggregates absorb proteins and other biomolecules from the ocean, resulting in the growth of coacervates as well as internal complexity as the coacervates divide into multiple smaller ones. So now what happened is these coacervates started, you know, collecting the protein.

As a result, the protein was present outside. And inside this structure, they will be trapping different types of biomolecules like nucleotides, DNA, and RNA; outside of this, there will be a water layer that is actually going to form membrane-like structures. And ultimately, these coacervates started taking up the molecules from the outside, and that is how they began growing. So they will start growing in size, and once they grow to a larger size, these coacervates break apart from the middle, and that's how they divide into multiple coacervates. This is what is happening: you have single coacervates around this; you have the protective membrane. This protective membrane is there, and then it actually grows in size.

If it grows to a large size, it divides and produces multiple coacervates. And you can imagine that all these multiple coacervates will again do the same, right? They will grow, and then they will actually divide, and that's how you will see a large number of coacervates. Into the primordial oceans, we then have the two steps. Okay, so the first step is from the coacervates.

You are actually going to have the deployment of the protocell. Once the coacervates started taking up the biomolecules from the ocean, they actually started developing primitive cells. So coacervates are the initial species present in the ocean that start the formation of primary cells. This process is accomplished in two steps. So step four has been further divided into two steps.

In step one, you have the formation of protocells. The coacervates have the ability to take up new molecules to replace the degraded molecules and maintain their size. So coacervates were the first species formed, and they had the ability to replace the molecules that were degraded. If there is an injury, they can repair that particular part, and thus the coacervates have the basic ability of a living system; they do not have complex molecules such as enzymes. The process of acquiring a new molecule was not regulated. Later, nucleic acids were entrapped within the coacervates, and the process of division became precise and controlled.

This form of coacervate with nucleic acid is known as protocells. Later on, the coacervates began trapping the biomolecules. So initially, all the reactions were, you know, very unregulated because they were governed simply by the mass balance; wherever the mass is, if the mass goes beyond a certain size, it actually gets weakened, and that is how it is going to break into multiple portions. For example, this is what you see, right? This is a coacervate. It was very big but at this point it got you know very high size of the biomolecule. So that is how this portion got you know constricted and that is how this portion is going to be and now form the new coacervates.

So same is happening here also. So, this coacervate does not have any regulation regarding where this could happen, but ultimately these coacervates have started taking up the nucleotides or the nucleic acids. So, once they have started taking the nucleic acid, it has, you know, been taken up because nucleic acid carries the information, whether it is RNA or DNA that contains the information, and they have started governing the activities within the coacervates. And that's how these coacervates, which had entrapped nucleotides or nucleic acids, are known as eobionts or protocells. So, these were the first forms of living organisms.

Later on, these protocells formed the first cells. Then, the protein molecules and the appearance of enzymes enhanced the synthesis of several biomolecules that are present in the protocells. The RNA and DNA developed in these molecules and took over protein synthesis. So initially, protein synthesis happened because of the spontaneous reactions between the inorganic biomolecules or the smaller biomolecules, right? Because the smaller biomolecules were synthesizing the amino acids, these amino acids bound to each other, and that's how the proteins were synthesized. But as soon as the RNA and DNA were trapped within the coacervates, they guided the synthesis of the biomolecule. Although there are many things that are not known in this particular process, how RNA and DNA govern the synthesis of biomolecules or protein molecules is still unclear.

These are some of the things that we still do not understand. The interaction of the lipid and the protein allowed for the formation of the biomembrane, which has provided selectivity in the primitive cell for intake or exclusion. So ultimately, what will happen is that the lipids form aggregates with the proteins, and that's how they form the plasma membrane. So now there was a plasma membrane outside, and then you had, you know, the nucleic acids in the middle, and that's how it actually formed the first cell, which was primitive. It still needs to develop many things, like the different types of organelles and so on.

That's how this primitive cell could be prokaryotic in nature. This prokaryotic cell could have given rise to eukaryotic cells. It allows for the appearance of the membrane-bound protocell and has eventually given rise to the first cell on Earth. So this is probably what happened, and these are the proposed events. Still, there is no experimental evidence to prove these points. These are the proposed events suggested by different scientists based on experimental evidence, but not the direct experimental evidence through which people understand, because we all still know that if you take the proteins and lipids and mix them, or if you provide energy to the system, they actually get rearranged to give you a plasma membrane.

So, these are some of the experiments, but nobody has actually done these steps individually so far to create a protocell or the first cell. The mutation in the DNA and the selection of the first growing cells give rise to the appearance of the first primordial cell. Ultimately, there could be some mutations in the DNA, and that's how they occur. The first cellular form was formed on Earth approximately 2 billion years ago.

That's how life originated on Earth. This is all about the origin of life on Earth. If we summarize what we have just discussed, we have talked about the multiple events required to form life on Earth. All of these are the proposed events based on the results obtained from Stanley Miller's and Urey's experiments. So what he says is that the proposed events are actually a four-step process. In step one, you will have the formation of the inorganic molecules, and then in step two, you will have the spontaneous formation of the simpler monomeric organic compounds.

So in that, you are going to form the monomers, such as amino acids, nucleotides, fatty acids, and glycerol. And once you form the fatty acid and glycerol, they actually clump together to form complex biomolecules in step three. And then these biomolecules will come together; they will aggregate, and that is how they are actually going to form the coacervates in step four. And once step four is reached, the coacervates are formed; these coacervates will actually start acquiring the biomolecules from the primordial oceans, and they will begin to grow in size, and that is how they will actually, you know, Apart from that, they will also have the ability to replace the biomolecules that are damaged, and once they grow to a certain size, these coacervates will actually divide, giving you the daughter coacervates. But ultimately, these coacervates also started trapping the nucleic acids that were present in the primordial oceans, and that's how they formed the first protocells, once they had the nucleic acids.

They have also directed protein synthesis; the lipid also came into the picture, and the lipid, along with the protein, has formed the plasma membrane, and that's how the plasma membrane-bound first cell was formed in the primordial oceans. So this is all about the origin of life and what we have discussed: we have discussed different theories. In the previous lecture, as well as in this lecture, we discussed the modern theory of the origin of life and the different experiments. So we have discussed in detail Stanley Miller's experiment and how Stanley Miller proved that smaller, simpler biomolecules, similar chemical molecules, can give rise to complex biomolecules. One interesting thing that is very important is that people are still trying to discover more and more molecules that Stanley Miller actually formed.

So Stanley Miller has collected the different fractions, and these fractions are still being preserved in his laboratory. Recently, the scientists have analyzed those reagent bottles or those fractions. What they could find is that because Stanley Miller did not have the very high-end technique at that particular time, he could not identify some of the biomolecules. But now, if you go and try to fractionate those molecules, what people have found is that even if they could see the different types of nucleotides and other kinds of biomolecules, which Stanley Miller could not report at that point, this is all about the origin of life. In our subsequent lecture, we are going to discuss the evolution and how the simple cells that were formed in the primordial ocean developed into the different types of organisms. So, with this, I would like to conclude my lecture here. Thank you.