Biology for Engineers and other Non-Biologists
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Lecture Number 02
Origin of Life

Hello and welcome to this course called "Biology for Engineers and other Non-Biologists". My name is Madhulika Dixit and I am a faculty at Department of Biotechnology, and I am taking this course along with my colleague, Professor G K Suraishkumar. Now when this idea of taking this course for engineers and non-biologists was brought up to me, the idea was to essentially bring in biology, teaching biology at a level which will be easily taken up by the non-biologists. So for those students who have already taken some sort of a course in biology, a lot of things will sound very fundamental. However, the whole idea of this course is to essentially highlight the basic features of biological life.

Now, most of the times when I have taken these kind of courses with engineering students, I have always noticed an apprehension in terms of trying to learn a biological course, and the reasons that I have gone to more often from them is that it's a subject which requires a lot of memorizing. I would like to bring out to the students here that indeed there are lot of terms which seems very difficult, but I would also like you to understand that biology is at a very infant stage, in (term), in comparison to, for example physics or chemistry, where the logics of chemistry and physics are very well defined. For biology, we are still trying to understand those logics.

Hence, in this course, we'll try to understand the logics of how a biological life is governed, and what is it in terms of reactions, in terms of physical entities, which help a life to survive and sustain. So let me start this course with my first lecture or the first set of slides on origin of life. Now, life, or origin of life is a very intriguing topic because for a very long time, we still haven't been able to answer the question as to how life really evolved. But before I get into the actual topic of today, which is origin of life, it's important to understand what are the features of life. What is it that you call 'life' and how is it sets itself apart from non-living things.

Well, anything that you see around yourself which is living, you will notice that there are certain features which are fundamentally common across living world, whether you start from a bacteria, you go to a plant, you go to a fungal organism or you go all the way to human beings, you find that there are certain features of life which remain constant, and the most important of them all is the ability to replicate and reproduce. Now this is one critical feature which sets the living world separate from the non-living world. But in order to do that, in order to sustain it's survival, in order to pass on it's characters to it's progeny or it's off-springs as we call it, an, an organism goes through a whole lot of processes, and these include it's ability to utilize food, it's ability to synthesize food if the need be, it's ability to digest the food, it's ability to throw out the waste material and keep the machine going.

So in other words, life or any biological system is a very highly dynamic system, and it has it's all purpose of surviving and reproducing. So, this is one character of life which is very unique, and we are still puzzled and we still don't have a complete answer as to life (re), how a life really evolved on this earth. But, lot of studies done by geologists, by archaeologists, by molecular biologists, have noticed that there are enough proofs as of today, which, with which we can confidently say or atleast speculate that the present form of life has evolved from non-living things. In other words, we have essentially evolved from chemical reactions.

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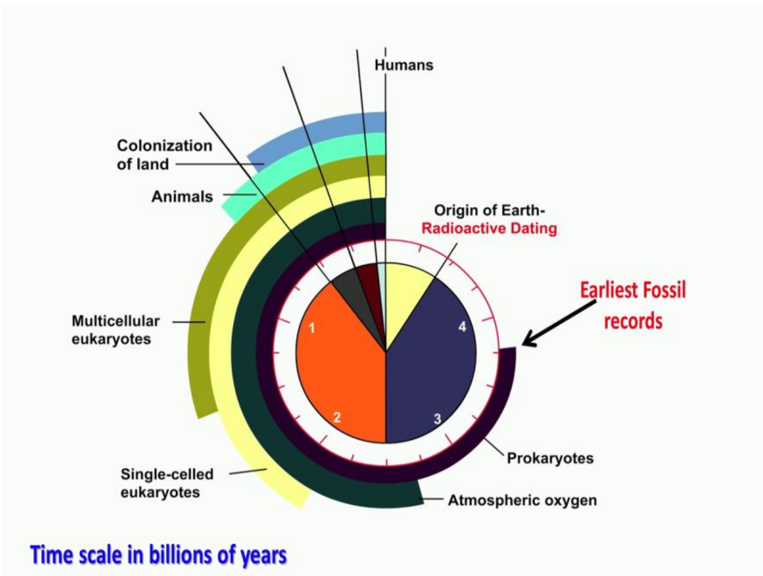

So, let's get to how the history of earth is, and how life really evolved during this history of earth. Now if you notice in the slide, if you were to look at the life of earth as a whole, and here I've drawn a clock and the time scale or in terms of billions of years, what you'll notice is that the radio active dating estimates that the origin of earth happened somewhere close to four point eight billion years ago, and, the earliest fossil records which suggest existence of life forms is about a billion years later. So, it is kind of, , possible to say, it is possible for us to speculate and now you have enough proofs through fossil records that the life must have originated within seven hundred to eight million years of earth's existence.

So, how did the life evolved is something that we'll talk in this class today, but I want you to understand that a lot of this was initially a set of chemical reactions, and these set of chemical reactions were actually possible because the earth's atmosphere was highly conducive for such reactions to happen. And mind you, at that point of time in the early life of earth, the atmosphere of the earth was very different from what we see of today, which is essentially full of atmospheric oxygen. So in other words, the initial phase of earth's history had a highly reducing environment. And I'll come back to this when we talk about experiments which actually go on to prove how the initial biological molecules actually got synthesized.

So, the earth seems to be about four point six to four point eight eight billion years old, the earliest fossil records are somewhere about three point six to three point eight billion years old, and somewhere in between the life really evolved. And what we also observe is one of the earliest forms of lives are something which we even see them today and those are the bacterial forms. So it's interesting that something which evolved or which came into existence more than three million years ago, has sustained it's survival for the last three and a half to four billion years.

And in the process, the Prokaryotes have also evolved and has given rise, is what we think as of today to different forms of life. So we'll come back to this and see it in a step by step fashion.

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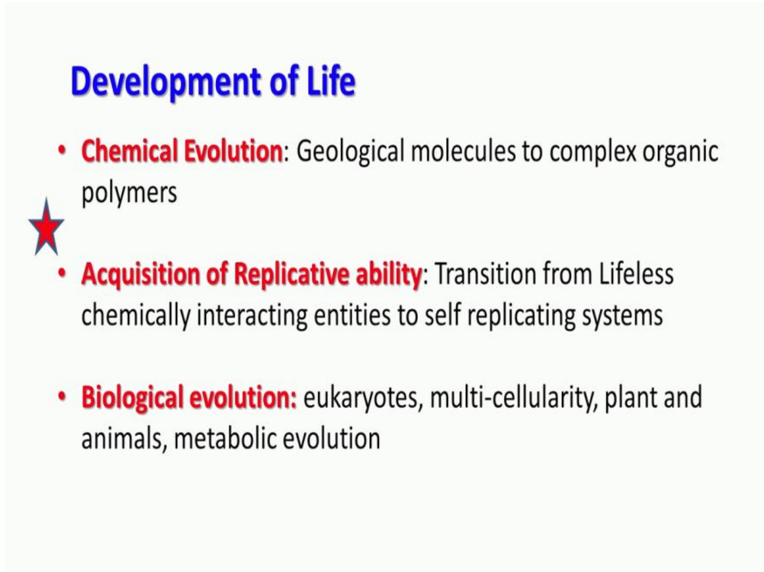

So, for simplicity, what (I) we understand today or rather, based on the various evidences that we have from geological excavations, from chemical reactions, from molecular biology techniques, for simplicity sake the biologists believe and have divided this very process of life and it's existence or origin into three different phases. The very first phase is of chemical evolution. Now this must be the phase which must have evolved during the very early stage of earth's life, when the earth's crust was very hot, the material has still not cooled down, the oceans, the springs, the hot pools were still boiling, the atmosphere was highly reducing.

And, it is during this phase that probably some sort of geological complexes or molecules would have interacted to form the initial and the early very building blocks of organic molecules. We'll come to this. Then came the most important feature which kind of sets apart life from chemistry, and that is the ability of these molecules, somewhere during the course of history, to develop into a property where it can replicate itself.

Now this is one of the most critical features, I would say, in terms of the origin of life, because this must have been one of the most, what I would say, the most critical phases of the origin of life, because it is at this stage you would find, that probably the system changed from just a set of chemical entities into developing a property where they could self-replicate.

And then, comes the last phase which would probably correspond to the rest of the phase all the way from here till what we see present today, is the evolution. And, what do we mean by evolution; it was just initially a set of chemical entities, all sitting together, these set of chemical molecules must have evolved an ability to self-replicate, and then sooner or later, these entities would have enclosed themselves into organism-like entities, which were the initial prokaryotes, and then the prokaryotes would have evolved into much more complex forms of life, which is what you call as the eukaryotes, a single-celled organism to a multi-cellular organism to plants, to animals, and then, to the present day human beings.

So, in that sense, for simplicity, we king of divide this development of life into three phases, chemical evolution, acquisition of the replicative ability by life, and the evolution of these early forms of life into what we see today as complex organisms and complex plants.

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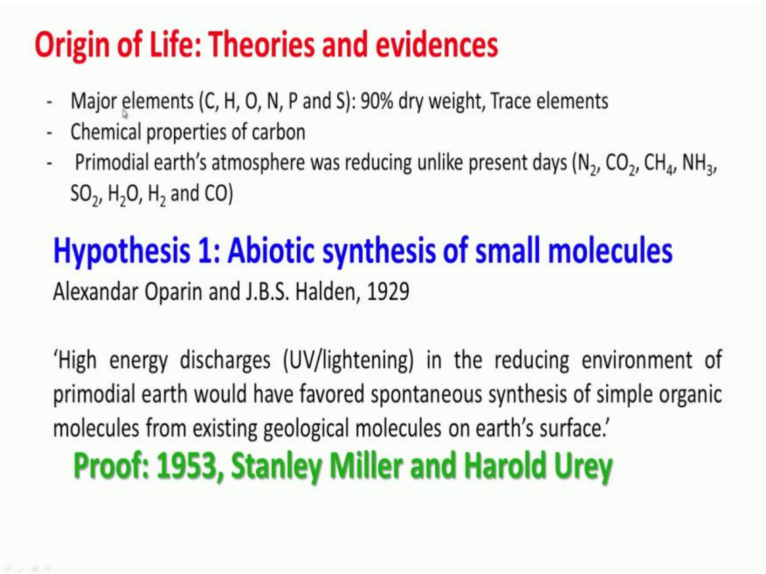

So let's go to what are the various theories and evidences for origin of life. But before I get into the theories and evidences of life, I want to highlight certain things, which are very important to understand how these theories were built up. If you were to look at any living organism as of today, we all know that our seventy percent of our body weight is made up of water.

But if would have just account for the dry weight, you'll find that the ninety percent of a dry weight of any living being essentially consists of these major elements – the most abundant being the carbon, hydrogen, oxygen, nitrogen, phosphorous and sulphur. In addition to these, you do have some trace elements like iron, copper, zinc; but in terms of bulk quantity, the bulkiest, or the one which is available in most quantity is the carbon, and that should not be a surprise looking at the chemical properties of carbon, because carbon has a versatile ability to form covalent bonds, not just with itself, and thus lead to a infinite long chain of organic molecules, it can also form covalent bonds with other elements, like hydrogen and so on.

So in that sense, carbon seems to be a very nice molecule, oh sorry, a very nice element. And, it should also be noted that when geologists went on analyzing the chemical composition of the early rocks of earth and the meteorites, which continue to keep hitting us, we have found to be very rich in carbonaceous compounds. So clearly, the earliest building blocks were formed because of carbon. The other important thing to note is that the initial earth's atmosphere, which is what we call as the primordial earth's atmosphere, was highly reducing. As I mentioned earlier, it is in, in the initial seven hundred to eight hundred million years, you would find that the earth's atmosphere was highly reducing because of presence of nitrogen, ammonia, methane, carbon dioxide, and it actually did not have any atmospheric oxygen.

So, what was the first hypothesis? With this background in mind, the first hypothesis was put forth by Alexander Oparin and J.B.S Halden in 1929, and they said, that the very first molecules, or biological molecules would have arosen, because of the abiotic synthesis of small molecules. So the first set of sugars or amino acids would have been formed by a mere abiotic synthesis of these molecules. And how it would have been possible? According to them, in that initial reducing environment of the earth, any high energy discharge, either in the form of ultra-violet lights, or in the form of lightning would have favoured spontaneous synthesis of simple molecules from existing geological molecules on earth's surface.

Now this was just a hypothesis way back in nineteen twenty-nine and it took almost twenty-four years, and later, twenty-four years later, in 1953, it was actually demonstrated to be true by Stanley Miller and Harold Urey.

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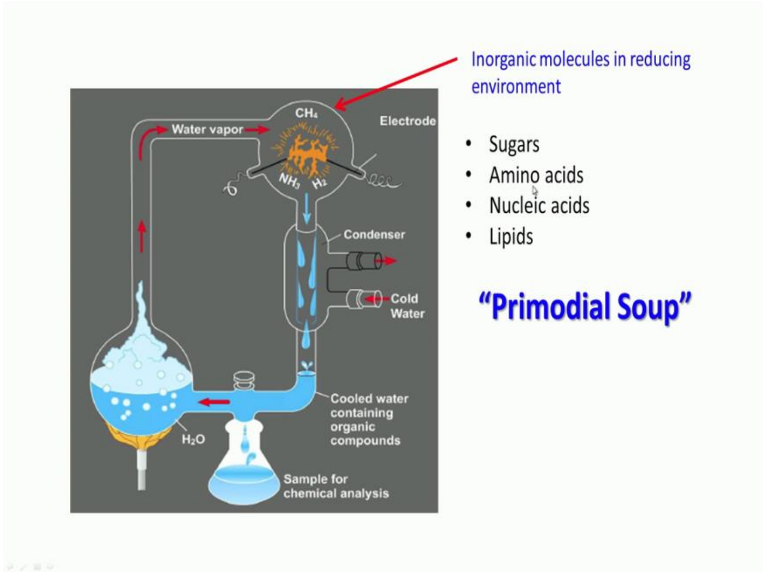

So what did Stanley Miller and Urey did is that they tried to create this kind of a primordial earth atmosphere, or the primordial soup, in this case I mean the early forms of oceans on earth which must have been at a very high boiling temperatures, and created that in a laboratory setup. So they had a primordial soup kind and they had an ocean kind of environment at a very high temperature, which is the boiling water.

They collected the water vapour under a very reduced environment consisting of methane, ammonia and hydrogen. Now in this reduced environment, when the energy was supplied, and, in in the form of (())(15:36) ultra-violet radiations or lightnings through electrodes, whatever was being spontaneously generated was then eventually condensed by the means of a condenser, and then collected at the collecting pole, or the connecting conical flask. And when they analyze the composition of this cooled water, they found to their amazement that it consisted of a lot of amino-acids that we even see today, such as alinine and glycine, sugars, nucleic acid, and nucleic acid bases like alinine and lipids. So this was one of the earliest proofs to the hypothesis which was put forth in nineteen twenty-nine, that the early forms of biological molecules must have had an abiotic synthesis.

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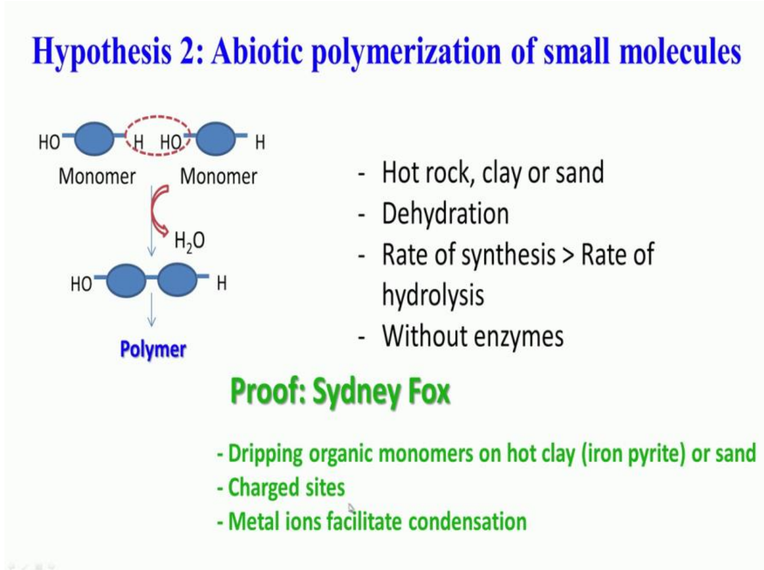

But then, just having small molecules is not enough, because if we were to look at the present day life, you find that you have macromolecules, and not just smaller molecules. For example, if you look at the plant cell, the outer covering of the plant cell or the (cell), as you call as the cell wall, and we'll come to it when we're talking about cell structure and cell function is actually a polymer of glucose, which is is made up of, which is what you call as cellulose, and these are huge polymeric molecules.

So how is it that these abiotic molecules eventually went on to polymerize and form higher order molecules? So the second hypothesis is that during the early phase of earth, when the earth's crust was still very hot, you find that there were hot rocks, clay or sand, and under such hot conditions, it was very easy for one monomer to interact with another monomer, through the process of dehydration. And since there were sufficient carbonaceous material available in the earth's crust, the rate of synthesis was much much higher than the rate of hydrolysis. So the postulation is that after the abiotic synthesis of monomeric units, there must have been spontaneous polymerization due to very high rate of dehydration and that is simply because of the presence of hot rock, clay or sand which will promote this chemical reaction.

And the proof of this was then supplied by Sydney Fox where he went about dripping (actual) organic monomers onto a hot clay. To be specific, on iron pyrite or on sand, which do have these charged sites, and he found that these monomeric molecules would eventually join together to form polymeric molecules, and in the process it is the metal ions which are helping or facilitating the process of condensation. So, we do know, or we do now believe that yes, the initial set of biological molecules were from abiotic synthesis, then you ended up having polymerization of these molecules, and then the question is, 'When did the replicative ability begin'? Because all this while, we are just talking about chemical reactions which are happening in a primordial earth, which has got a highly reducing environment, still doesn't have atmospheric oxygen, and it still has a very hot surface.

But, as I told you in the initial part of my presentation, what sets apart life from the non-living things is the ability to replicate. At this time, we don't really have the clear proof as to how this change happened from a non-replicative to the replicative form and life, but, if then to be, one way to look at which set of molecules would have been the ideal initiator of this process, we now have sufficient proof or suggestions which suggest that the earliest genetic material must have been RNA.

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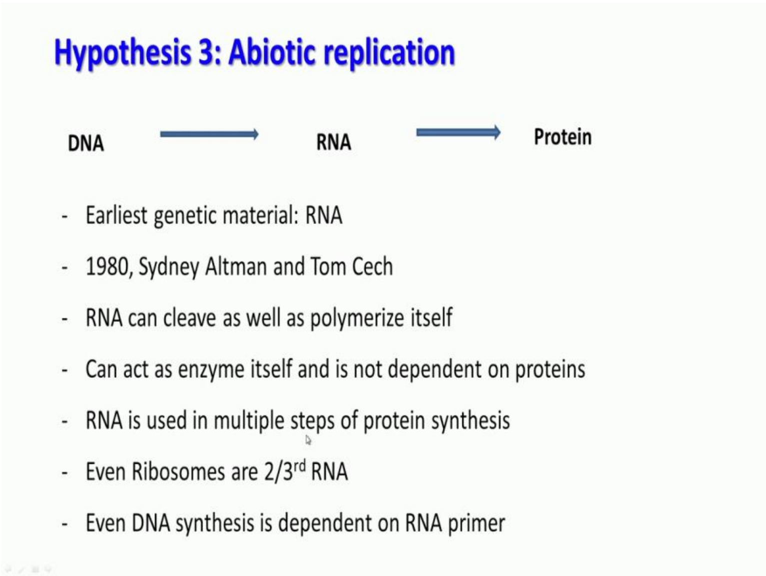

Now before I get to why we think it would have been RNA, it's important to understand the flow of information in a living world. And we all know, and that in our system, any organism for that matter, most of the information is encoded into what you call as the DNA, as of today. And this DNA is then transcribed and this process is called as transcription into RNA, followed by the actual work horses of your body or a cell, which is the protein. But, it's one way to look at RNA.

so we will discuss DNA to RNA, the process of transcription, RNA to protein, the process of translation, in subsequent videos.

But for today, we’ll focus our attention on RNA. So, there are enough proofs which suggest that RNA might have been the earliest genetic material, and this was also supported by the recent findings in nineteen eighties, where Sydney Altman and team, that RNA can not only polymerize, it is also has the ability to cleave itself. So, it not only acts as a molecule which can polymerize itself, it also can act as an enzyme, and this catalytic activity of RNA is not dependent on proteins.

So it's a very versatile nucleic acid molecule in that sense, that it not only can polymerize itself if the need be, it can cleave, and if the need be, it can also act as an enzyme. What is even more interesting and intriguing is to note that as we go into the details of protein synthesis, multiple steps in protein synthesis are dependent on RNA. For example, the actual machinery which puts this entire chain of amino acids into a protein which you call as the ribosomes, is chemically made up of RNA. Two third of ribosomes is made up of RNA. And not just that, even in today’s world, where DNA, the so-called our genetic material which has the entire coded information.

The DNA needs to replicate, it does depend on RNA, and I’ll talk about this, when we talk about the process of DNA replication. So we still don’t have concrete proof, but all these properties of RNA make it a very interesting molecule for it to be probably the earliest molecule capable of acquiring the ability to replicate.

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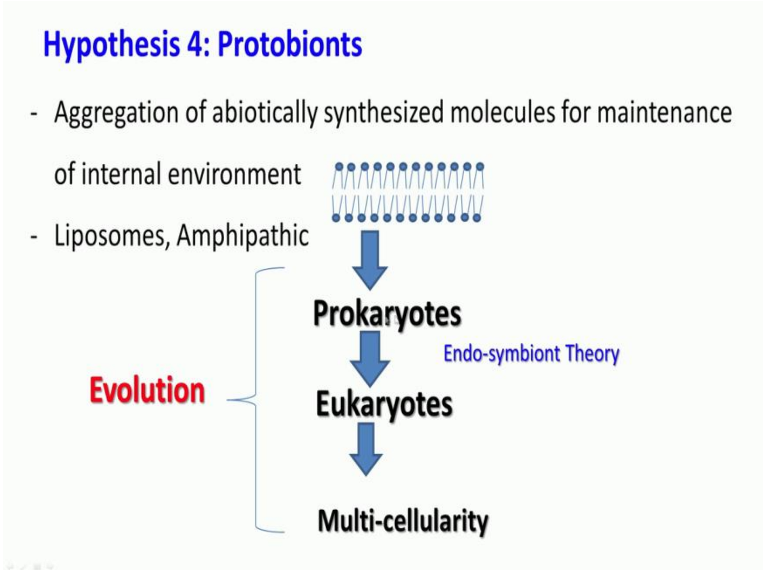

Then the fourth theory is, 'how did cells come into existence'? I mean all this while we are only talking about chemical synthesis of monomers, their polymerization to larger forms, hopefully acquisition of replicative ability. But then, how do you get to cells? And, this is where we have to consider that slowly, as the time went past, chances are the bigger sources became skewed, lesser and lesser.

There was far more entity for these cluster of molecules to kind of guard and maintain their properties, and in the process what would have happened is that lipid molecules would have assembled like liposomes. These are amphiphatic, in the sense that they do have a polar head, and a non-polar tail, and these, it's like you take a soap solution and when you drop it in water, the (endophine), these lipid molecules will end up forming bubbles. So these initial lipid liposomes would have somehow enclosed these abiotically synthesized self-replicating biological molecules to form the worst and the most earliest form of life, which is what you call as the protobionts.

And somewhere down the line, the protobionts would have then evolved into prokaryotes. But mind you, this time scale of change from abiotic synthesis all the way to prokaryotes has not happened overnight, it has happened over millions of years, and then, the earliest form of prokaryotes would have evolved into what we know eukaryotes, we'll talk about this when we talk about the cell biology, and would have finally evolved into what we see today as multi-cellular highly evolved organisms. So this journey, all the way from protobionts to the present day organisms, we'll cover them in the, in the topic of evolution.

But for now, so you find that there have been four hypotheses, abiotic synthesis of small molecules, polymerization of small molecules, ability of the small molecules to replicate, and then, the enclosure of these biological soups, or these biological molecules by means of lipid molecules, and probably the earliest forms of plasma membrane. But then, it has been a very important and one of the most crucial turn of events in history of earth, and that has been the oxygen revolution.

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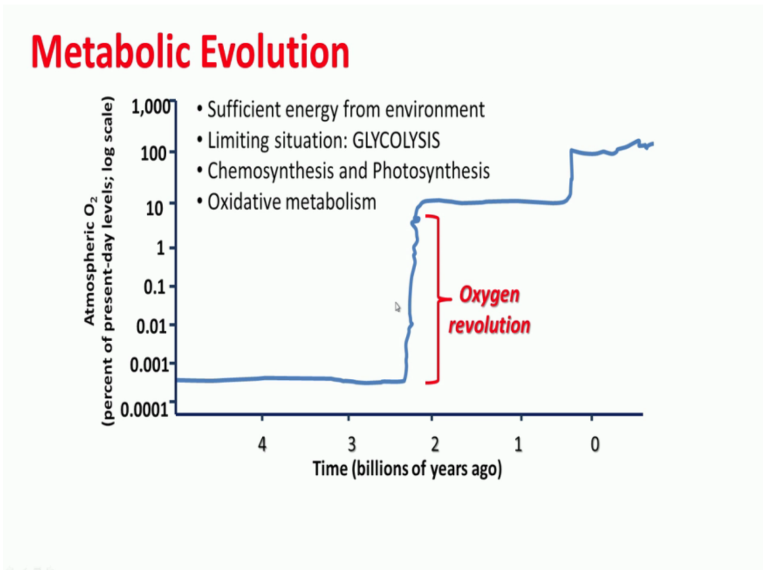

So if you see this curve where I have plotted atmospheric oxygen at the present day, right? You find that the earlier earth had very low oxygen. Almost for the first two and a half billion years, you find that there was hardly any oxygen in the atmosphere.

Something must have happened at this turn, which would have led to the sudden burst, and if you noticed, within a few million years, from hardly any oxygen to reach a point where the atmosphere becomes highly oxidized. And it's at this stage, we believe in earth's life that the plants or the photosynthetic organisms must have evolved. And the reason must have been pretty evident, the reason being that by this time, by the time of two and a half billion years, resources must have become lesser, it would have compelled the organisms to survive as I said, one property of life is to survive.

So if the resources are getting lower and lower, or that pool of carbonaceous inner compounds, energy rich phosphates, if they are getting exhausted, the organism, since it needs to survive, has to find alternate means of obtaining this energy, and one possible way by which it would have done that would have been to use the reducing power which it did, (clears throat) excuse me, as per our understanding in the initial phases using hydrogen sulphide. But then even hydrogen sulphide would have got exhausted and then, the organism must have developed a much smarter strategy of actually utilizing the unlimited pool of energy from solar energy or from the sun and hence the process of photosynthesis evolved.

And in the process of this, oxygen became a by-product and as a result the atmosphere becomes highly oxidized. Now, if the atmosphere has become highly oxidized, there are still ways by which the organism has to derive energy by breaking down it's larger molecules into smaller entities. Earlier it was fairly easy. But now in this oxidized environment, there have to be a specialized structure possible to efficiently do breakdown of these polymers.

The release of energy, and that is where it is postulated that the mechanism of what you call today as respiration must have evolved. So in other words, we started the initial life on earth in a highly reducing environment, and somewhere around I would say close to about two point six billion years ago, the transition must have happened where the organisms became smarter, started utilizing the solar energy, and the chemical energy from other reducing compounds like hydrogen sulphide, and in the process, they started generating oxygen as a by-product, because of which now the atmosphere became highly oxidized.

So the new set of chemical reactions had to evolve which under these conditions, oxidizing conditions could still breakdown polymers into monomers for release of energy, and that is somewhere here probably, that the evolution of mitochondria might have happened.

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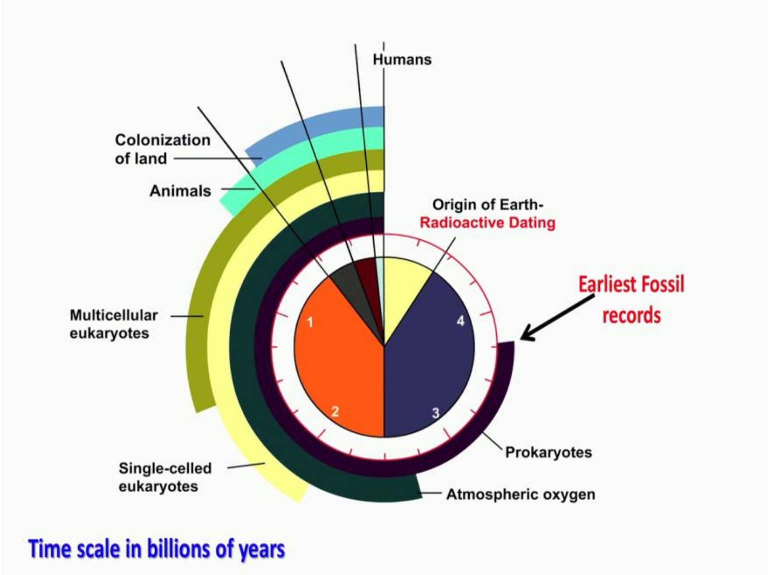

So let's come back to the slide which I was talking about. So this is where we think the origin of earth happened. This was the phase, I would say all the way upto here, you find that the earth's atmosphere must have been highly reducing, and then, you have evidences of early life, somewhere here, which says about seven hundred million years after the earth's origin, the earliest protobionts must have evolved somewhere here, later transitioned into what you call as the prokaryotes and then due to lack of sufficient high-energy compounds available and the resources become lesser and lesser, a point in evolution would have happened where the organisms would have developed a property of synthesizing their own food, using solar energy and in the process, went on generating oxygen as a by-product.

So it is at this point somewhere in earth's life that the earth's atmosphere became highly oxidate. And as a process evolved, the prokaryotes ended up becoming well formed, which is what we call today as eukaryotes, we'll talk about this, and then somewhere, as it's life became more and more complex, these single-cell eukaryotes went on to become multi-cellular eukaryotes, plants, animals, and then finally, the humans.

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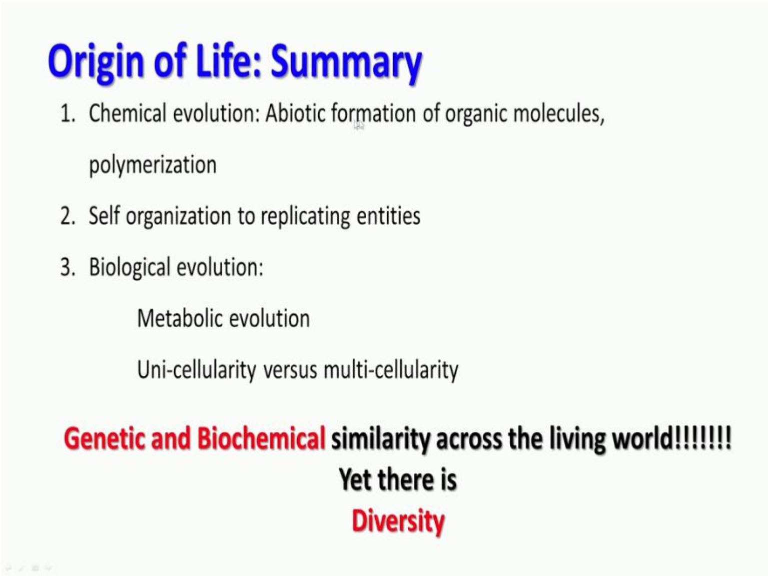

So, to summarize, what we understand today, is that the origin of life essentially is divided into three stages; the first stage is the stage of chemical evolution, which is abiotic formation of organic molecules and it's polymerization; the second is the self-organization, and the ability of these polymers to somewhere developed the property of replication and formed the early protobionts.

And then came the actual process from where the life went on evolving again over billions of years, and these evolutions were in terms of evolutions in metabolic reactions, what I mean by metabolic reactions are the chemical reactions which happen inside a living organism, is how we call as metabolism. These metabolic reactions to allow an organism to now synthesize food, and having synthesized food, also have the ability to break down the food if it needs to have some energy, and eventually transition from a single-celled organism to a multi-cellular organism.

One point which still puzzles, and is still very intriguing in life, and study of life is, that despite the varied forms of life that we see today, what we really find interesting is that when we look at some of the fundamental chemical reactions in biology, what you call as metabolic reactions, or the way the information is coded in our DNA, genetic information, you find that right from prokaryotes all the way till humans, a lot of these informations and the processes are conserved.

In other words, the codes by which the messages are stored in DNA, the information is stored in DNA, you find that that language which is used for coding, or information has remained more or less uniform all across life, starting from bacteria all the way from human beings, and yet, yet, they are highly diverse when you look at our forms and our phenotypes; phenotypes are our physical appearances, and we'll try to answer some of these questions in our next class which is on evolution.

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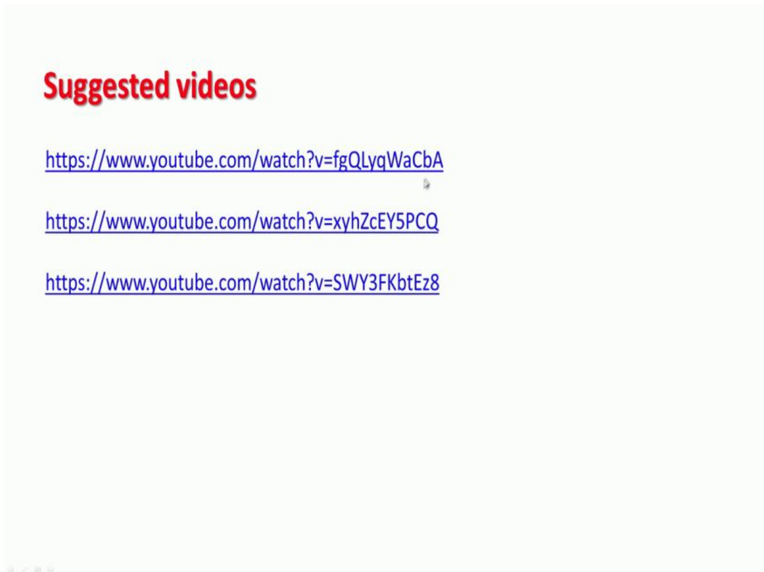

So with that, we'll end origin of life, I would urge you to go through some of the very informative videos, which very (explicitively) explicitly and beautifully through animation also try to explain you how life must have evolved on earth. Thank you.