# An Introduction to Evolutionary Biology

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**Week 11 Lecture 47**

## Origin of Life: Part 1

Hi, so over the last 10 weeks or so, we have been discussing the various forces that affect the evolution of populations. And all the concepts and everything that we discussed form the so-called modern synthesis. or its more modern cousin, the extended evolutionary synthesis. However, all these things that we discussed start with the assumption that life is there; you know it is a given. It has all these properties: variation, inheritance, and so on; and now, how things are changing. However, none of these discuss the core question in biology, so to speak, which is how exactly life originated and this, you know, is again one of the big questions in biology; this is what we are going to discuss today and in the next discussion. But before we do that, we first need to come up with some kind of definition of life. And as all of you are aware, that is a very, very hard task. Honestly, there is no consensus definition that everybody agrees on; therefore, you know, There was a 2011 study that actually analyzed some 123 different definitions of life and came up with, you know.

Life is a metabolizing material informational system with the ability of self-reproduction and evolutionary change. which requires energy and a suitable environment. You know, as you can see, it is a very clunky kind of definition; it does not give you, you know, insights straight away. And to be fair to the author Ian Trifonov, he did not really, you know, propose this as the definition of life. They simply said to look after looking at these 123 definitions and essentially taking out all the words that are composing those definitions, it looks like these are the major words you know. or major concepts that people think should be part of the definition of life. And if I combine these various concepts, this is one of the ways to do that; that is about it.

E.N. Trifonov does not really say that this is the best way to do it. But as I said, this definition does not really lead us anywhere. So, what we will do is use a much simpler and often quoted definition that you know is ascribed to NASA. Which says that life is a self-sustaining chemical system capable of Darwinian evolution. Now, what are the implications of this definition? We will see that in a few minutes, but before that, do you know what the various theories of the origin of life are? Of course, you have the supernatural theories of life that suggest some deity created living organisms and, hence, life.

Now, being a supernatural theory, we cannot really subject it to scientific investigation. However, note that we have already dealt with the various arguments against creationism. and since you know, creationism does not differentiate between the origin of life and the evolution of life, therefore, all the arguments that we made against creationism, all of that is also going to work over here. So, once we have that out of the way, let us look at the various natural theories of life. And the first, and perhaps the most ancient theory of how life originated, dates back to Aristotle who essentially said that life could arise from nonliving matter. And this, you know, by and large made sense because people all the time saw, you know, maggots coming out. You know from rotten fruits, or they saw, you know, insects and other things arising seemingly out of nowhere. And therefore, people took this very seriously, and this remained the dominant view until about the 16th century. And people did all kinds of things.

So, for example, there is this very famous Dutch chemist, Jan Baptist van Helmont. who actually ended up giving a recipe for how to create mice. So, he basically said to take some hay, put it in some dirty cloth, and keep it outside. And after about 21 days, you are going to get mice, you know, coming out of it. It looks like he also studied it; you know, when you look at his notes, it seems he tried doing this experiment.

However, all this was somehow very strongly challenged in the 17th century. and there were multiple experiments which were done to show that you know whether this works or not. The first and most famous of these was done by this person, Francesco Redi. So, Francesco Redi was an Italian scientist and poet, and he is referred to as the founder of experimental biology. As well as being the founder of modern parasitology, he has done a lot of work, but the most You know, perhaps what he is most remembered for, at least in the field of evolution, is related to his work on spontaneous generation.

So, what did he do? So, at that point in time, it was believed that maggots rose from dead meat spontaneously. But Redi thought that that was not really correct; they probably arose from other flies. So, what he did this, did over here was took pieces of meat and put them under three conditions. So, in the first condition, he put it in a jar and then sealed it. In the second condition, he put it in a jar but covered it with extremely fine cloth.

And in the third case, he put it in a jar but did not cover it; he just kept it that way. Now, why exactly did he you know do the second treatment? That will become clear in a moment. And then he left the meat to rot for several days and found as follows. So, when the meat was in a sealed jar, as in the first one on the left, no maggots arose, although the meat did rot. When the meat was kept in an open jar, then the you know maggots and then flies came out of that treatment.

Now, these two were the early experiments that Redi had conducted. And then people commented that, you know, in the sealed jar, there is also no air; airflow is blocked. So maybe life does arise spontaneously, but it requires air. In the absence of air, it will not happen. And that is where, in a subsequent experiment, which is what I am showing you, the third middle treatment came in where he put extremely fine cloth that did not allow the flies to go inside but allowed air to go in and out. And even in this particular case, he ended up seeing that there were no maggots coming out of the meat. Although there were some, you know, maggots—first very small maggots—that were seen on the top. So, based on this, Reddy came to the conclusion that, look, flies could access this area in the third one. Maggots arose in these two cases where flies could not access, which is why there were no maggots.

And therefore, he came to the conclusion that omnivum ex vivo, all life arises from pre-existing life. In other words, there is no spontaneous generation. Now, this was a pretty well-done conclusive kind of experiment. There were a few other experiments of this type, but in spite of all this, The scientific world did not really abandon the idea of spontaneous generation until this person did. So, this is Louis Pasteur, and as we know, he played a very important role in the development of modern microbiology.

So, for example, when you look at your milk packet in the morning, very often you will see that it is written "pasteurized." And that, you know, is the process by which you kill all the microorganisms in the milk. And you know that is how the milk stays fresh for a long time, and for that, we have this man to thank. Now, what Pasteur did you know around the time? He was obviously in the late 19th century. So, it's around the mid-19th century, 1850s or so, The French Academy launched a competition to validate or negate the theory of spontaneous generation.

And Pasteur took part in that competition. He designed his very famous experiment using these kinds of flasks, which are known as swan neck flasks. So, what Pasteur did was put some liquid that he knew was fermentable. meant that you knew microorganisms could grow in them, and then he boiled the liquid. And the structure of this flask was such that when you boiled, Then the vapor is going to be pushed through this, and you know it is going to escape through here, this part.

But once the vapor has escaped, in some of the treatments he sealed it, and in some of the treatments, he just kept it like that. But what happens is once the vapor has escaped, if there is air or anything coming from this side, Then that essentially gets blocked over here, or at least the things that are in the air. The particulate matter settles in this part of the neck, the swan neck, so to speak. And this is very, very crucial for this experiment, as I am going to show you in a minute. So, what Pasteur did was take these bottles, sorry, flasks, boil his fermentable liquid, and in the first treatment, You know he sealed them and then let the flask sit for a long time, and nothing really happened.

The liquid stayed as it was; it did not turn turbid, showing that there was no microbial activity happening there. Then, in the second case, he did not seal it; even in that case, there was no microbial activity here. In the third case what he did was he did the whole treatment, applied the heat, boiled the thing, got rid of the microbes, but then removed this neck and let it sit. Basically, let the liquid come into contact with the air outside. And when that happened, after some time, the solution turned turbid, indicating that there were bacteria.

And finally, this is the very interesting and important part of the experiment. What he did was take this flask and tilt it. Now, what is the point of tilting? So, remember whatever you know once the air has been expelled, Whatever air you know is coming from outside is kind of settling in this swan neck part, this part. So he could see those precipitates. Now, as long as the flask sat like this, there were no bacteria present.

But when it tilts like this, this liquid now comes in contact with whatever is over here. And then he tilts it back and lets it sit; then this turns turbid, suggesting that the bacteria are what is present over here. What is getting settled down in that swan neck part is what is responsible for turning this thing turbid. Just the air, you know, which is otherwise able to flow, is not causing the turbidity. So, this was a very, very conclusive experiment, and Pasteur actually ended up famously proclaiming That never will the doctrine of spontaneous generation recover from the mortal blow of this simple experiment.

And it turned out that he was right. After this, nobody really took spontaneous generation seriously any more. So, now that we are done with spontaneous generation, you know, this has led to the principle of what is known as biogenesis. That is, life only comes from pre-existing life. However, that leads to a logical problem. What is the problem? The problem is that if life only comes from pre-existing life, then at some point, you know life must have originated.

Where did the first life come from? And that is something that people then started thinking about. And one of the theories that at least some people put forward is I would not say that it was a very big theory; it was the theory of panspermia. What is it? So, people thought that life originated elsewhere in the universe and was transmitted to Earth via meteorites, comets, and Whatever asteroids or other celestial bodies that came near Earth and fell to the Earth transported life. Now, frankly speaking, this is not a very scientific theory because it is simply saying that it did not happen on Earth. It happened somewhere else; that is about it.

It does not really talk about how life arose to begin with, does it? And that is why nobody really took this theory seriously. And although there are some books that do mention this stuff, the scientific community has more or less ignored this theory. Now, here I need you to take a quick aside and tell you about something slightly different. which is very close to panspermia, but it is called pseudopanspermia. So, as I told you, panspermia is not even a scientific theory, but pseudopanspermia is a very different ball game.

What is pseudo-panspermia? It is a notion that different organic molecules—what do I mean by organic molecules? Molecules that contain carbon. So, different organic molecules were formed in space, and they arrived on Earth via meteorites. Now, this is actually supported very strongly by the fact that Organic molecules that look like they are of extraterrestrial origin have indeed been found inside meteorites. Now, this is thought; I mean, it is thought that all these molecules, organic molecules, They might have taken some part in the formation of life on Earth from non-living molecules. It simply says "might" because it is, you know, not possible for us to prove that conclusively, as we are going to see in a minute.

But at least we think that this happened. Why do we think this happened? Because if you look at the various meteorites that we find in different parts of the Earth, Many of them actually contain such molecules. And the most famous meteorite in this context is the so-called Murchison meteorite. It landed on Earth on 28th September 1969 in Australia.

Now, I mean, meteorites are nothing new, right? But the reason this one is important is that it arrived in recorded history. Scientists were able to get hold of it, you know, very soon after its arrival, extremely soon actually.

So, what they did was essentially, you know, this meteorite broke into many, many parts. So, it was collected from various parts of Australia, and I am showing you one piece of the meteorite. And this is one of the most well-studied meteorites on the planet, and people have found that The silicon carbide grains that you find on this meteorite are 1 to 5 billion years older than the Earth itself. So, their age is somewhere between 5.5 and 10 billion years, and the Earth originated about 4.5 billion years ago. indicating that this is the oldest material found on the surface of the Earth to date at least. However, more important than silicon carbide is the fact that If you know how to break open this meteor and take samples from the center of it. Now, why is that important? Because remember, this has come and fallen on the Earth, right? Therefore, anything that you get from the surface of the meteor can potentially be an earth contaminant. But if you are taking something from the very center of the meteor and you are obviously observing all precautions, then the chances of that being a contaminant are very, very low. There are other chemical signatures as well, which is why people are reasonably sure that whatever they have observed on this meteorite is indeed of extraterrestrial origin. And people have seen that there are amino acids such as glycine, alanine, and glutamic acid. And you know nucleobases, purines, pyrimidines, etc. And as I said, the chemical properties of these things suggest that they are most probably of extraterrestrial origin. A very important point to note is that, although this is the most famous example, it is absolutely not the only example.

There are many other meteorites from which people have been able to recover. You know what looks like organic molecules of extraterrestrial origin. So, unlike panspermia, pseudopanspermia is something for which we have very strong scientific evidence. Now, this brings us to the third and perhaps the most credible theory of the origin of life, which is known as abiogenesis. What is that? It is the natural process by which life can arise from nonliving matter.

Now, obviously, this leads to the question: if you are saying that you know life is arising from non-living matter, then, In what way is this different from spontaneous generation, which, as you know, we said has been thoroughly discredited? So, the major difference between abiogenesis and spontaneous generation is In spontaneous generation, there is no mechanism by which life could have originated. We simply say that you know maggots come from rotting meat; this animal comes from whatever soil. That animal comes from bark and so on, without any mention of a mechanism. And secondly, it assumes that life can and does originate repeatedly under normal circumstances. So, if you remember when we were talking about Lamarckism, Lamarck actually subscribed to this idea of the origin of life.

He essentially said that, look, continuously life is originating, and each lineage has traveled different, you know, lengths of time. On the other hand, what abiogenesis is saying is that life did arise from non-living chemical components. But that happened only on early Earth, and this is not something that is happening every day. It is a unique event, and it happened because certain very specific conditions were met in the early Earth. And what abiogenesis does, the theory of abiogenesis, is that it actually tries to provide the physicochemical mechanism.

Based on our knowledge of physics and chemistry, it is obvious how the origin of life happened. So, it is a very mechanistic theory as opposed to a simple observational hypothesis, like spontaneous generation. Now, what do we have here? Like many things in evolution, Darwin was one of the people who thought about abiogenesis. So, he was very acutely aware of the point that whatever he was talking about, Evolution through natural selection presupposes that life exists. And then essentially he was talking about what the various properties are or what are the various outcomes of different evolutionary forces acting on them? But he did realize that his theory was not talking about where life comes from. and he did not talk about it in his book, Origin of Species, But he did mention it in his correspondence, particularly with the famous scientist Joseph Dalton Hooker. So, I will just give you one sentence that Darwin wrote in, you know, an otherwise long letter. It is a very famous sentence, but it is a long one.

So, what I will do is break it up for you. so that you can see what the various thoughts are that are packed in that one simple sentence that Darwin wrote. So, he says that, but if—oh, what a big if. This is a very famous quote, but if—oh, what a big if! We could conceive of some warm little pond. So, the first thing he thinks is that this is happening: life is probably originating in water and not on dry land. With all sorts of ammonia and phosphoric salts, light, heat, and electricity present.

Now, why is he mentioning these things? Because nitrogenous compounds and phosphoric compounds, These are all known components of the biochemistry of living organisms. And you also need some kind of energy for these things to come together to form the various polymers that are present in our body. So, he is explicitly talking about the source or the potential sources and the fact that you need energy in that context. That a protein compound was chemically formed, ready to undergo even more complex changes. At the present, such matter would be instantly devoured or absorbed.

Why? Because right now what we have is an oxidizing atmosphere, we have a huge amount of oxygen around us; therefore, Any such early reaction that you know of, which is happening out there in the wild without being encased inside a cell membrane, etc. All that is going to be subject to the forces of oxidation, the chemical forces of oxidation. And that is why he says that at present such a reaction would not have happened. but which could not have happened had been the case before living creatures were formed.

So, just to let you know, read it all once more. But if, and oh, what a big if, we could conceive in some warm little pond. With all sorts of ammonia and phosphoric salts, light, heat, and electricity present. That a protein compound was chemically formed, ready to undergo even more complex changes. At present, such matters would be instantly devoured or absorbed. which would not have been the case before living creatures were formed.

So, Darwin did not really take this idea forward. But the people who took this idea forward were the very famous Russian biochemist Alexander Oparin and JBS Haldane. whom we have already met. So, together, to be fair, it was Alexander Oparin who proposed the theory in rather elaborate form in his book in 1924. However, JBS Haldane did not know about it, and he independently proposed a smaller version of that in 1929. When Haldane was asked about it, he was very clear that it is Oparin who gets precedence.

However, in the literature, this is known as the Oparin-Haldane hypothesis. Also, you know it facetiously as the primordial soup theory. Why is that? I will talk about it in a minute. So, what exactly did these two, you know, people propose? So, it is a lengthy thing, but I will just break it down into the salient points. So, the Operin and Haldane hypothesis says that the early Earth had a chemically reducing atmosphere.

Why do we need this? Because remember, as I told you, if you have oxygen, Then it was thought that many of the reactions that now happen inside the cell would not have happened. Because of oxidation in the atmosphere, you know, under natural conditions. So, the early Earth had a chemically reducing atmosphere. This atmosphere is exposed to energy in various forms. What are the sources of energy? Lightning, solar radiation, and volcanic heat produced simple organic compounds.

And what kind of compounds are you talking about? Monomers include amino acids, sugars, nucleotides, etc. These compounds accumulated to form a soup. So, again, the whole idea was that this most probably would have happened in water. That is where the chemistry will probably work. And you know, I think the soup thing comes from Haldane's imagination, and I think he was thinking about the warm little pond of Darwin.

So, he was the one who introduced the soup concept that you know all these various compounds will accumulate to form a soup. And that is not sufficient because then all these monomers are going to be very diluted. So, you need some way of concentrating that even if it is happening locally, it does not have to happen globally. So, the concentration could have happened at places like shorelines, mud flats, and oceanic vents, etc.

We will talk about all these points later. And once this concentration happened, then there were further transformations because of which More complex organic polymers were formed, and finally, all this somehow came together to form life in the soup. And this soup is what Haldane calls the primordial soup. Now, obviously, you know this was just a way of visualizing things, but Somehow, the primordial soup name stuck, and that is why this is also known as the primordial soup theory. Now, as you can see, it is making a bunch of, you know, claims, and these claims were not really made in thin air. So, Operin in particular had lots of reasons to believe whatever he was saying, and obviously some parts of it were hypothetical.

But some part of it came from his deep knowledge of biochemistry. So, this hypothesis, as you can see, gives a probable chain of events that ultimately leads to the formation of life on prebiotic Earth. So, obviously, the question is: does it really work that way? And over the last 100 years or so, Every single component of this proposed chain has been investigated intensely, both experimentally and theoretically. And although we obviously know this is happening billions of years ago, This is happening at a time when you know for which we do not even have fossil evidence. Therefore, we cannot really pinpoint the precise events that would have happened to lead to life as we know it today. However, right now we have excellent candidate mechanisms for every single stage that Openin and Halen have proposed.

Now, what are those mechanisms? How did we find them? What is the nature of the evidence and how sure are we about every step? All those things we are going to look at in our next discussion. See you then. Bye.