Biology for Engineers and Other Non-Biologists
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Week- 02
Lecture - 10
Cell structure and function: Prokaryotes

So welcome back to these series of lectures on biology for engineers and non-biologists. In the last 2 videos we did talk about the origin of life and then the evolution different forms of life. Now since its inception, it is very clear that life has been an enigma and it continues to be an enigma for a lot of biologists as well as other researchers. Now what we donot understand are how is it that different cells behave differently or different forms of life behave differently.

And the reason is very simple because if you look around yourself in this world of life biology, you find huge amount of complexity. You have a simple, single organism, single celled organism like amoeba or you have a much I would say a much more complex organism like human beings. So there is a huge complexity and how do you try to understand this complexity, and most of the researchers use a very reductionist approach, wherein you try to study life in bits and pieces and try to identify the unifying features which can connect to this thread of life.

So with that background in the next 2 videos what we are going to talk about, are the very fundamental unit of life which is the cell. Now how do you define cell; as I just mentioned it is the most fundamental unit of life and it is this cell if you understand how this fundamental unit of life works you can kind of extrapolate a lot to the various organisms and their mechanisms of working.

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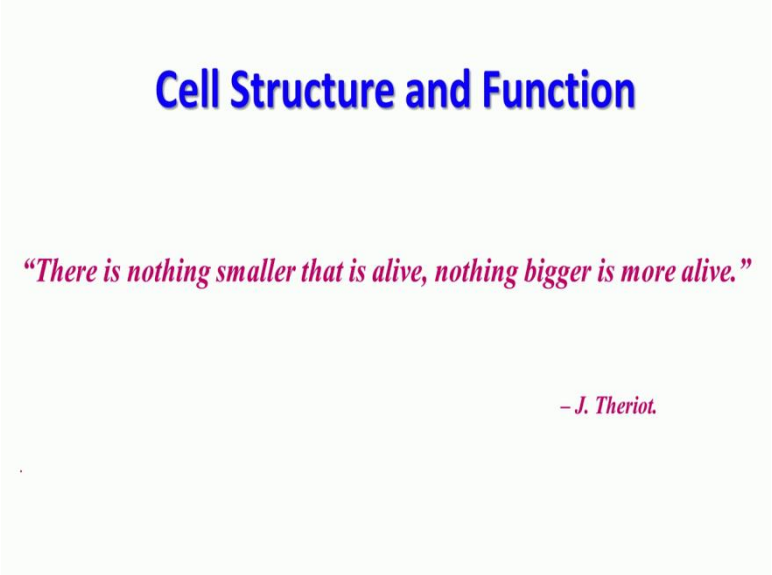

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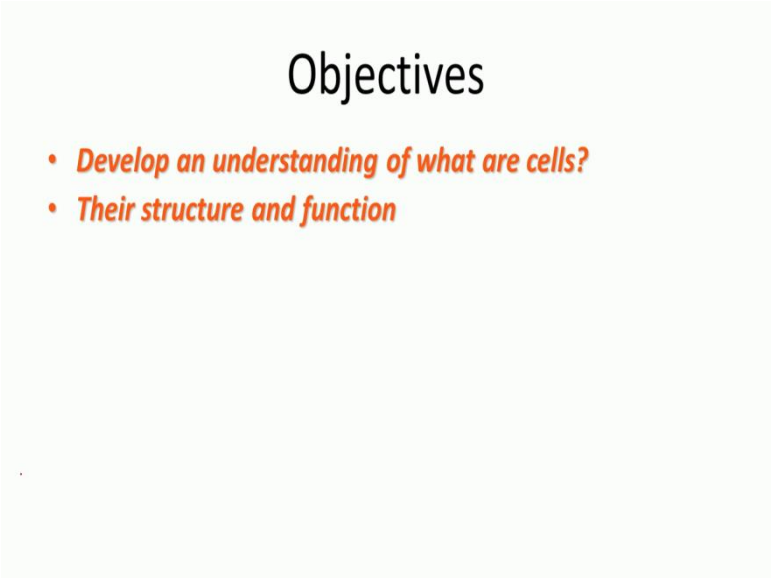

So in this video we are going to talk about cell structure and function and I would like to start this particular video in this series by quoting J. Theriot that "Nothing which is smaller is more alive and nothing bigger is more alive." So in other words it is the most fundamental unit and it is the unit of life. So what are the objectives of this video? The objectives of this video are to develop an understanding of what are cells and what is their structure and how this structure interconnects with the function of the cell.

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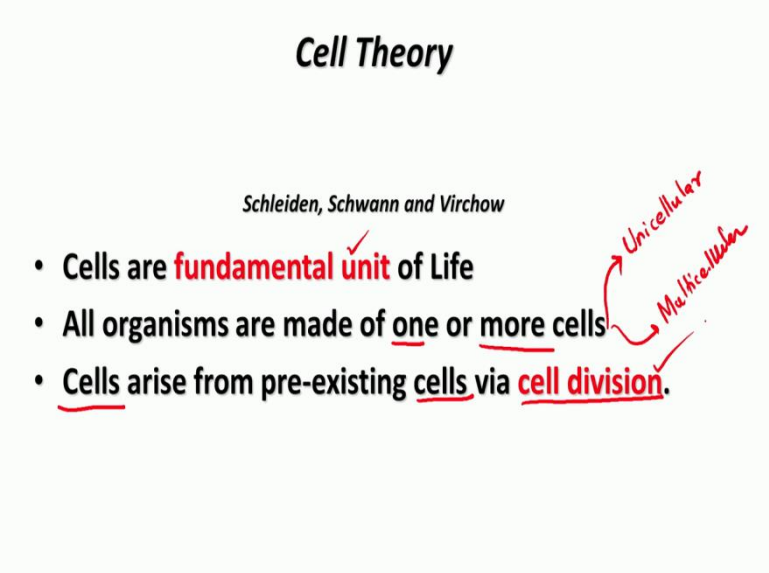

Now, way back in mid-1800, (s) 3 German scientists came up with a theory which is called as the cell theory and this holds true even today and as I said it starts by stating that cells are the fundamental unit of life, if you understand cells and how cells function you can kind of understand how life can function. Also the second point of this theory is each organism, each living organism is made up of at least one cell or more than one cell. So this is what leads to what you understand as unicellular organism or a multicellular organism.

And then the third and the most important feature which we have been speaking about since the first-class is that each living cell will give rise to new cells via the process of cell division that is one set of cells will always arise from pre-existing cells through the process of cell division or what you call as reproduction. So what are the properties of cells and how are they similar to the things that you see around yourself and life, as I told you, life is complex but so are cells.

But what I want you to bear in mind is that just like life a cell is a machinery or a dynamics system where each and every component of that system is in its equilibrium with the other also it is the cell where the various components of the cell the various constituents of the cells talk to each other, communicate with each other and then the effect that you see is a sum total of all these reactions, all these interactions which are happening within a cell.

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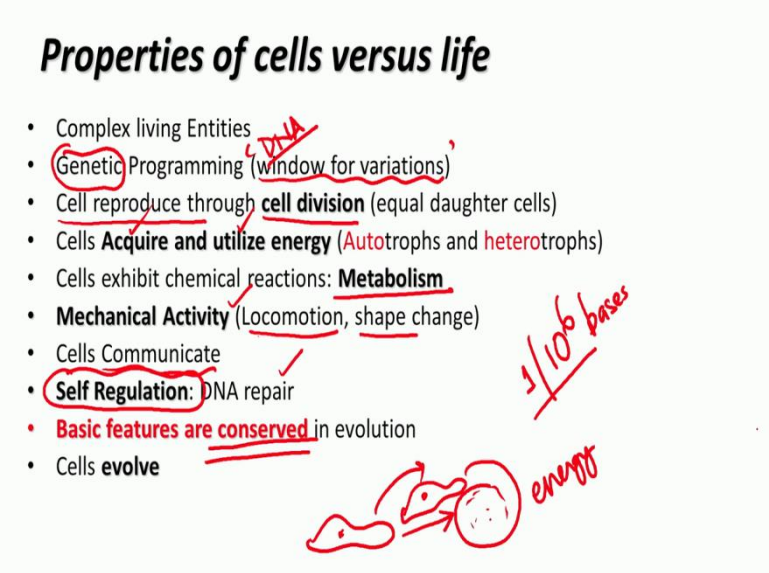

So yes, cells are complex entities and the beauty is each cell which is the most fundamental unit whether you take a single celled organism or a multicellular organism has its entire information packaged which is what you call as the genetic material packaged in the form of DNA in some (case) organisms it can be RNA too, and it is this genetic material which has been discussed in evolution, is the molecule which provides the window for possible variations and adaptations.

So each cell has its genetic code, its information stored in the DNA. Now, how the DNA is stored is what determines different types of cells and I will come to that a little later. The other thing about cells like any other organism whether human beings or dogs or plants is that they reproduce through the process of cell division and they give rise to new daughter cells. Cells like any living organism would like to acquire energy for its sustenance and not just acquire energy, if the need be, utilise that energy for life processes.

For example if there is an amoeba sitting somewhere on the soil and it finds a food particle, somewhere in the neighbourhood, it will try to approach that food particle. It will try to move towards that food particle but the process of these amoeba trying to move towards food particle involves a whole myriad processes; in other words not only does the amoeba to move forward, it has to change its shape, it has to (nee), it has to go and then engulf this food; now all this is a energy intensive process.

So the amoeba will have to have machinery in place where as and when they organism needs it, the energy is supplied. So it not only should acquire energy from outside sources such as

the food (it) which it is trying to eat, it should also conserve energy and then utilise that energy for movement and other body functions.

Now, all this is only possible in a living cell because, as I said, cells are made up of a whole series of reactions which are taking place, which is what we call as metabolism. So the metabolism happens, there is a process in place to acquire energy either from outside or (sy) synthesise the food on their own and then utilise that particular food for generation of energy.

Mechanical activity is another part of life as we mentioned which may either be involved in the process of locomotion or in this case of amoeba such as shape change. Now if an organism is living, it's never living in isolation, it has to communicate with its environment. It needs to sometimes relay the information from outside to inside or vice versa. In such a situation a cell or an organism need to have a system in a place which is capable of doing communication so this fundamental unit of life is also capable of communicating with the outside world and responding to it.

And the best part among all these is that all these processes, whether it is of locomotion, whether it is of generating energy, it is a process of communicating, you find that the cells are highly regulated. These are one of the best features wherein a cell keeps in control its entire processes which has very few margins of error. A classic example is the process of DNA replication; we will be astonished to know that every time a cell's DNA duplicates process will see to it that it duplicates its copy exactly. So much so that the error rate at the time of DNA replication will be probably 1 in say 10 million bases.

So for every 10 million reads, probably a 1 error may happen which obviously contributes to the variation in the daughter cell, but this is the fidelity of the process and this is simply possible because the cell has complete machinery take care of even the repair of any (p pa) parts of the body or the parts of the cell structure as well as the processes. But whether we take a single celled organism or we go across all the way to higher end organism, what is interesting is to note and this is what we all cling onto is that certain processes of life are fundamentally conserved.

When I meant fundamentally conserved, for example how the DNA will store information, in what language all this information is coded, has remained conserved across this billion years of evolution, whether you talk about bacteria or you talk about human beings, you find that that genetic code by which the information is stored is highly conserved.

Similarly, a lot of other metabolic reactions which govern life are also conserved across evolution. So what are these cells and why it has been such an enigma to understand life, and let me bring your attention to one major limitation that we have as humans is a resolution of a human eye. It's not possible for us to see things which are below a few millimetres in size.

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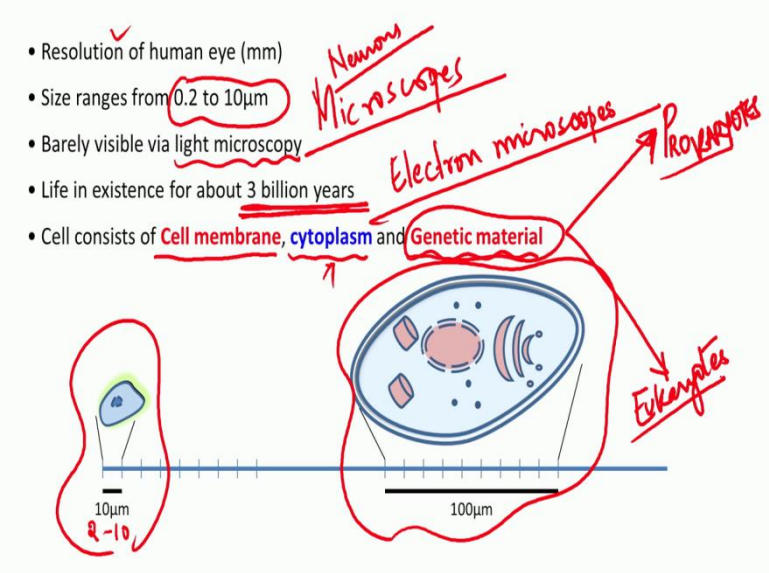

Now this has been one of the major limitations in our understanding of how life works because a lot of these organisms are much smaller; they are about the size range of anywhere between 2 to 10 microns or they can be as big as 100 microns but yet this size is way below the resolution of human eye and this surely required some sort of invention and that came in mainly through the (in) invention of microscopes. Had it not been for the optics and development of different kinds of microscopes, it would not have been possible for researchers to understand how life really works and how the cells really work.

So, coming back to the size of the cells what we find as of today is that most of these cells with few exceptions, have a size in the range of 0.2 to 10 microns. You have exceptions, for example neurons that we would see are much bigger in size than 10 microns. But they are exceptions. (M) most of the cells across the living world are in this size range and as you can obviously see this size range is way below the resolution of human eye and we need the aids of different kinds of microscopes, some of them are visible through light microscopes some of them aren't.

The ones which are not visible through (microscopes) light microscopes, we then (res) resolve to electron microscopes,where, instead of using light as the source of visualisation we

use a beam of electrons to visualize. But whatever the (k) approach you take, one has to appreciate one thing and that is life has been in existence for 3 billion years. And I want to keep stressing on this point because what as biologist or as researchers who may be non-biologist as well, what we are trying to understand are (n) systems and not just one system, multiple systems or probably millions of these systems because there are at least 2 million living species which have been already identified each species being a system by itself that this life has been in existence for last 3 billion years so we are trying to understand the history of life which has accumulated in last 3 billion years.

And it's not easy to understand unless we have appropriate tools at our disposal. So let's come back to the cells. Any cell of any organism which is existing on earth today has 3 (m) common features is that is each cell is surrounded by an outer boundary which is called as the cell membrane. The cell membrane helps in segregating the internal content of the cell from the outer environment. The second most common feature is the cytoplasm. Now this is a fluid, a jelly like fluid which holds entire cell together and it is in this jellylike fluid, the (m) genetic material which is our DNA or RNA in some cases is present. So each cell consists of an outer boundary, the outer membrane, the (v) jellylike fluid called the cytoplasm and the genetic material within the cell.

Now how this genetic material is actually organised within a cell determines 2 major classes of cells or 2 major groups of cells, prokaryotes and eukaryotes (oops). So we divide different types of cells into 2 major categories, prokaryotes and eukaryotes. Today we will talk about the features of prokaryotes and then slowly move on in the next class to the differences between prokaryotes and eukaryotes.

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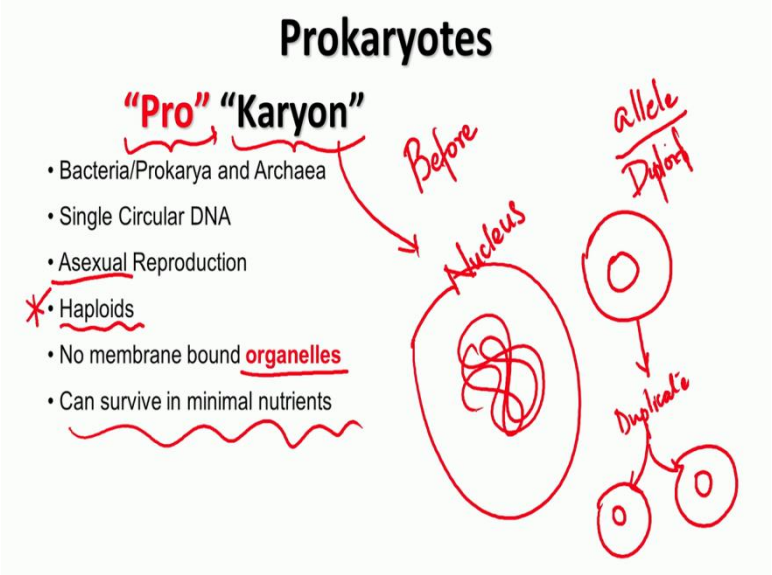

So, what are prokaryotes? The term pro is derived from 2 words, prokaryotes is derived from 2 words, pro and Karyon. Pro means before, and karyon means nucleus. So this group of organisms basically most primitive ones as we think and the simplest of the living organisms, consist of their genetic material which is inside the cell membrane but is not in confined to a specific subpart which is called as the organelle.

Now, what are organelles? Now, organelles are small structures that you observe within a cell which themselves are bounded by membranes. So this feature you do not see in case of prokaryotes. The other things that you observe in prokaryotes is that for most of them genetic material exists as a single circular DNA.

And, these organisms or prokaryotes divide through the process of asexual reproduction. Now what do you mean by asexual reproduction? Unlike higher organisms where there is fusion of the male gamete with the female gamete to form an egg or the zygote (in now a) say for example in humans you have part of the gene set coming from your father and a part of the gene set is coming from the mother, that is what you call as sexual reproduction, that does not happen in these group of organisms.

Here each cell will first duplicate its DNA in the hope that it is duplicating it exactly with as many minimal errors as possible and then divide into 2 daughter cells directly without undergoing the process of cell fusion between 2 independent gametes a sperm and an egg, that process does not happen in case of prokaryotes. So essentially every parent cell will more or less pass on same features to the daughter cells and the other term that I want you to note is

that term called haploids and this will again become important when we talk about cell division, mitosis, meiosis and all. Now, what is haploids?

As I said in, organisms like human beings, where there is a process of sexual reproduction taking place, we always get 2 copies of a gene, say for example if (f) for your eye colour you will have a gene coming from your father and a gene coming from your mother. So each gene, though both of the genes are coding for the eye colour; one version is coming from the father and the other version is coming from the mother which is what you call as an allele.

Now, this situation where, for every gene, you have 2 copies one from father and one from mother is called as a diploid situation. But since (excuse me), since the prokaryotes do not exhibit that, for every gene they have only one copy, now that is interesting. One, they do not undergo sexual reproduction for every character they have one gene.

But this gives enough scope, because if at all this single copy undergoes any sort of mutation and any point of time it becomes a variation and then it is much more easier to accumulate these variations because if it was a diploid organism, the variation may become dominant or may not become dominant and this is something that you will study in your Mendelian genetics, I am not going to cover it here but I want to bring home the same point that prokaryotes are much simpler because they undergo asexual reproduction and they have one copy of a given gene and hence are called as haploids.

And the other most intriguing feature of prokaryotes are they can survive in any form of minimal nutrients. You do not have to grow them with complex carbohydrates sources, you give them basic carbon source and they are able to survive very well.

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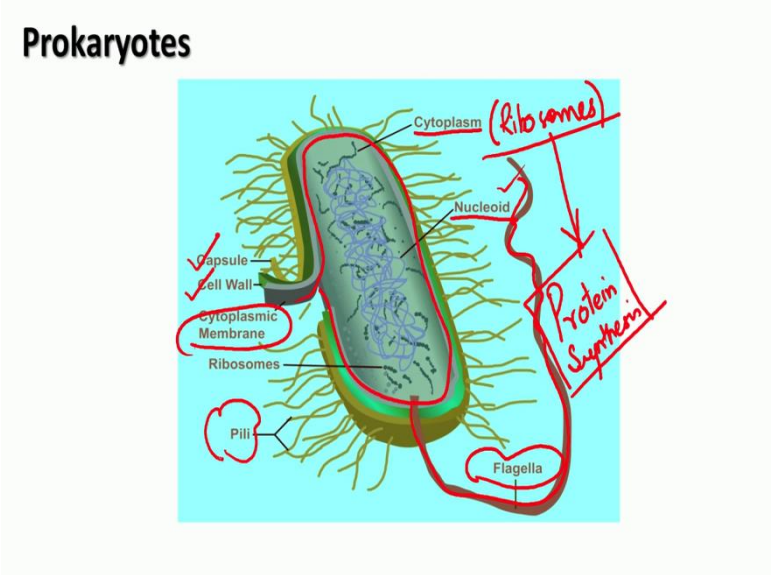

So let us look at, now here is a diagram which kind of recapsulates what I just said that the DNA in case of prokaryotes is a loosely circular, in this case it is not looking exactly circular but this is a single piece of DNA which is running around and it is kind of centred within the cytoplasm and it is not surrounded by any kind of a membrane itself. Such a structure is what you call as the nucleoid.

In addition, this DNA is floating in this jellylike substance which is what you call as a cytoplasm and the cytoplasm consists of tiny little components which are called as ribosomes. Now these ribosomes become important because they are the basic machinery which is required for protein synthesis and I will come back to this later in other videos when we are talking about protein synthesis.

It is a very indispensable component of a living world. So the cytoplasm is like this jellylike fluid which has the small tiny organelles called ribosomes though they are not membrane bound and these ribosomes play a very important role in the process of protein synthesis and then you have the genetic material which is kind of aggregated loosely in the cytoplasm not surrounded by a membrane and this structure is what you call as the nucleoid.

All this is finally enclosed in almost all the organisms by what you call as the cell membrane. So this is what it is, this grey one, right? Now this has to be there in all the organisms, but within prokaryotes you can have categories where in the cell membrane may be further protected by a cell wall or a capsule.

Now these 2 features of not mandatory but they may or may not be present. Another interesting feature which the prokaryotes have is a long (f) hair like or projection which is what you call as the flagella. This is literally like the propeller. So if of bacteria has to move forward and it is residing in an aquatic environment for example, if this particular filament, the way you have it in sperm cells, this particular filament allows the prokaryote to move forward.

In addition to this, there are small tiny hair like projections in some of the (bek) prokaryotes which is what you call as the Pili. So in terms of organisation and structure, the prokaryotes of the simpler ones where the genetic material is not enclosed exclusively by a membrane itself, in fact it exists as a nucleoid body and (the) DNA is fairly simple.

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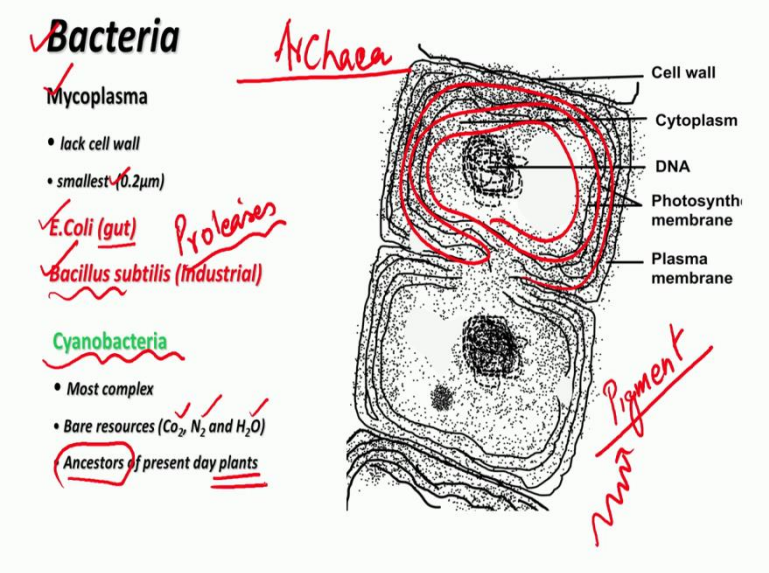

So what all comes under prokaryotes? Prokaryotes is a group which consists of 2 major domains, one is bacteria the other one is Archaea. This is something I told you even my previous class. So it has 2 major groups of organisms, the bacteria and the Archaea.

Let us look at bacteria first. Now (the) bacteria again is a huge class of these organisms and some of them are for example Mycoplasmas which are the (sm) smallest known bacteria and they do not have a cell wall. Other common examples which you are possibly aware of already are the E. coli that you find in your gut and another very important and industrially a very important microbe which is the Bacillus subtilis. In fact most of the industrial (enz the) enzymes and detergent companies for example which are (u) used to make detergents, make

use of certain products of these Bacillus, particularly a group of enzymes called proteases and a few other.

So bacteria is one of the largest classes and even within the bacteria somewhere across the course of evolution you come across a very unique organism which is called as the cyanobacteria. You have fossil records of cyanobacterium which are seen even today and you find as in this picture (as) I show you in this slide, it is a little more complex.

If you notice in this cyanobacterium what you observe is the same cell membrane keeps on the refolding into multiple layers and so it is not just the cell membrane which is just a single boundary, you find that the cell membrane keeps on folding and it is in these cell membrane that the organism houses a very important pigment which has a potential to absorb solar energy or sunlight.So in what is now all know today is that the cyanobacterium although one of the more complex ones, can survive on very bare resources like carbon dioxide, nitrogen and water.

And it is these group of bacteria, because of their ability to capture sunlight and convert that solar energy into chemical energy which is what you call as the glucose and sugars are believed to be the ancestors of the present day plants. So you (f) find that though it is a very simple organism the DNA is not really as complex. It has still evolved during the course of Earth's history and it has come to a situation where it has developed a capacity to on its own utilise solar energy and convert that into chemical energy, and hence are believed to be the ancestors of present day plants.

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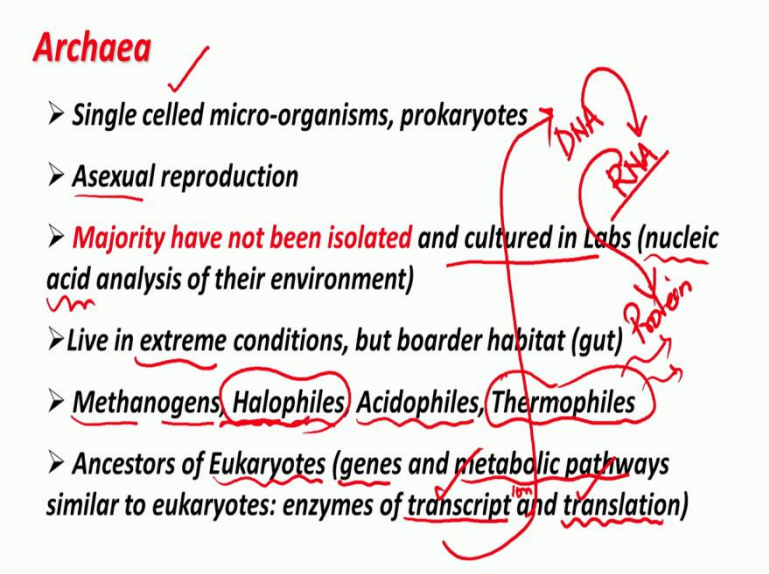

More about Archaea; now Archaea is another unique group of prokaryotes and like bacteria, they are single celled, they do show asexual reproduction. But what has been challenging with this particular domain of living organisms is that they all are found in very extreme habitats, such as the hot water springs, the volcanic eruptions, deep down in ocean beds and or an highly acidic or a high salt content lakes. And you find that although you see them in these natural environments, when you try to isolate and culture them in the lab and you try to then study it, it has not been very successful.

And hence we do not know much about them but there are a few things which (have) you have still figured out about them and (that's) thanks to our ability to at least isolate their nucleic acids from the environment in which they grow. So if you take a hot water spring water and try to isolate nucleic acids which is DNA and RNA from there, and study it, you kind of get an insight into how these organisms are and what they are capable of.

What we know about these Archaea is that they are different from prokaryotes because they grow in extreme environments and hence have managed to survive and they show abilities like ability to produce methane, hence they are called as methanogens. They have an ability to survive in high salt, halo means salt, phile means loving. (This is) this is about is called as the salt living organisms. They can grow in lakes and ponds which have very high salt content. There are acidophiles, which love more of an acidic pH and they survive only under acidic conditions and then you have those microbes which are growing in thermal vents and hence are called as Thermophiles.

Now why they are important, I mean it's, it's no one's guess that if you are having an industrial setup and you are looking for a certain chemical conversion process, you will be astonished that a many a times a lot of catalysts or enzymes which are being used in some of these industrial processes, if they need to be heat resistant are usually derived from these group of organisms like the thermophiles.

So given that these groups of organisms grow under extreme conditions it is possible to isolate important enzymes and reagents from them and use it for the human benefit. What is another interesting feature and we now have sufficient proof about Archaea, is that when you try to compare certain genes and certain metabolic pathways, the metabolic certain pathways and genes which are found in Archaea are found to be very close to the eukaryotes, the other higher end organisms.

So for example if you are going to look at the enzymes which play an important role in transcription; now this is a process wherein (oops sorry) this is a process wherein the (it) genetic (ma) information which is coded in DNA gets converted to an intermediary step or RNA and then even the enzymes which are involved in the process of translation which is a next subsequent step wherein information then gets passed on and gets decoded from RNA into protein. You find that the enzymes involved in these 2 processes in Archaea are very similar to the present day eukaryotes the higher (end) end organisms.

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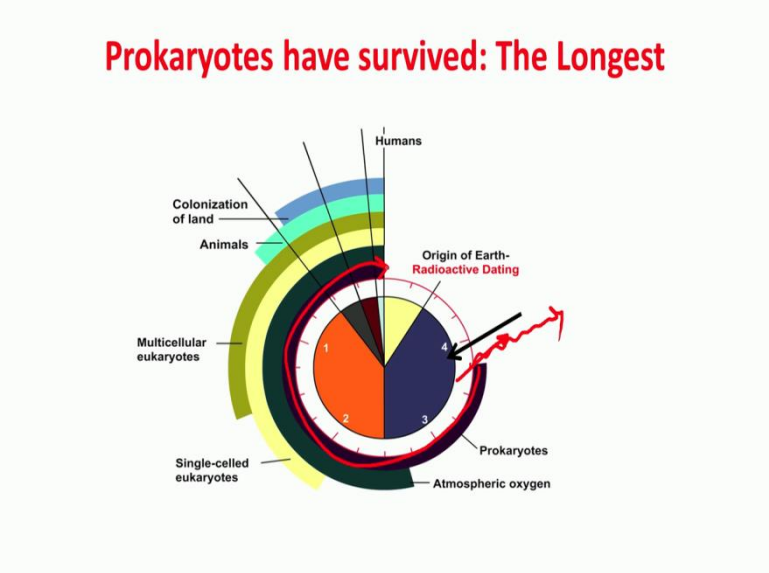

So let us look at this other interesting aspect. I had mentioned earlier that the life evolved somewhere around this stage about 3.8 billion years ago, because that is where we see the earliest fossil records. And what is intriguing and rather perplexing is to note that though prokaryotes involved (in be) the first set of organisms as of our understanding today to evolve, they have continued to survive till the present day today.

So though we call it to have a very simple structure because they just have a single circular DNA, they do reproduce asexually yet is group of organisms you find have survived beyond slots which the earth must have experienced in last 3 billion or years and has still continue to survive and thrive. Now how is that possible? Now that is a very interesting thing to look at and the reason we think it is possible is because though these organisms do not reproduce sexually they do have a potential to acquire variation and they do this by the process called as horizontal gene transfer.

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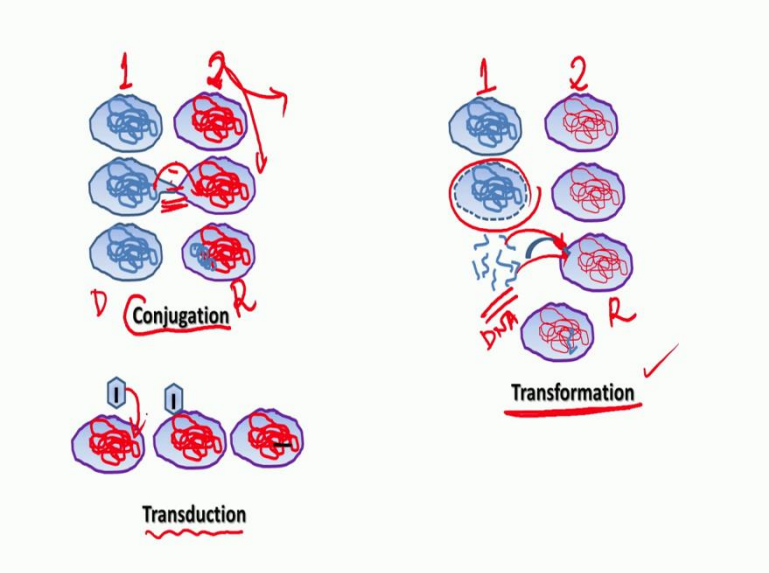

So what happens; let us take this example (now) there are 3 major forms of this horizontal gene transfer in prokaryotes; the process of conjugation, wherein let us assume this is one bacteria and this is another bacteria. And the second bacteria requires certain favourable features of the first bacteria.

So what happens is the 2 bacterias come together and connect through their membranes and I will tell you later why they are able to connect through membranes because that is the specific property of biological membranes, we will come to it a little later. And they form this connection and then the favourable features are passed on, mind you, not all the features, the required features can be passed on from the donor cell to the recipient cell.

So this process is what you call as conjugation. And that favourable character will then be acquired by the bacteria 2 and as the bacteria 2 divides; it is going to pass on these favourable characters to its daughter cells. The other form of horizontal gene transfer, which accounts for this variation, is the process of transformation. Now assume again that you have 2 bacteria living in neighbourhood, bacteria 1 and bacteria 2.

Now bacteria 2 is needs to survive and for some strange reason, the bacteria 1 has either died and as its dies all its material is disintegrating and then its DNA gets fragmented. The bacteria 2 finds there are a few useful pieces of DNA which if (it) it acquires will give it a survival advantage, it ends up picking a few of those favourable DNA fragments; mind you here, this bacteria has already died unlike in the process of conjugation.

Now, in such a case the recipient again ends up receiving favourable characters from the extra DNA or rather the DNA which is floating around in its environment. This process is what you call as transformation. And a third form is transduction wherein there is a genetic information happening between a virus and a bacteria.

So although is group of organisms reproduce asexually and they try to, in their all complete honesty, pass on the complete set of genes as close to themselves the daughter cells, if there is a need in the environment to acquire variation they do undergo the process of horizontal gene transfer, either through the process of conjugation, transformation or transduction and hence these group of organisms have managed to survive for such a long time because they are far more amiable to variations than probably a diploid organism.

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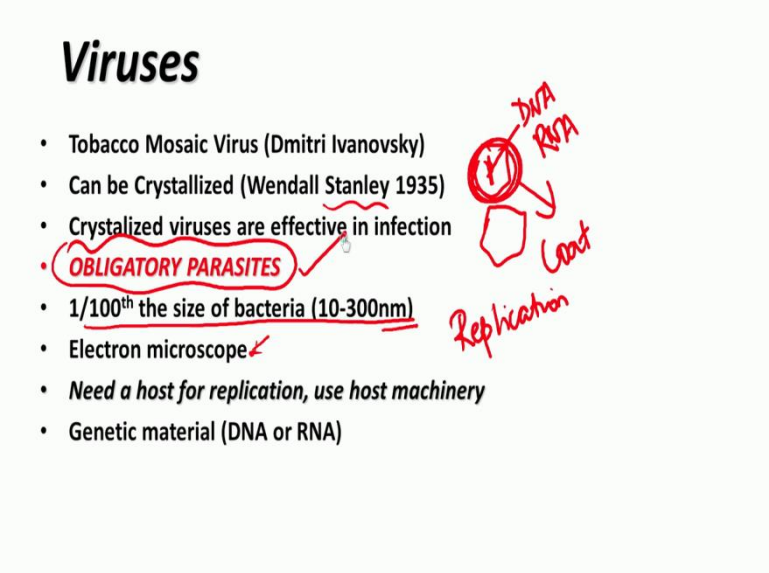

So then let us come to one last group which is the viruses. Now by the end of 19thcentury and thanks the discovery of penicillin, more or less people or scientists thought that bacteria are the smallest possible organisms on Earth. But then there were a few diseases which could not be explained by bacteria, especially the tobacco mosaic disease in tobacco plants.

Now it was the effort of this Russian scientist called Dmitri Ivanovsky, who was trying to understand what causes this tobacco mosaic disease in tobacco plants and what he did was that he took the sap of an infected plant, passed it through multiple filters, such that the smallest of the known bacteria at that point of time will not go pass through the filter, collected the so-called bacteria free filtrate and put it on an uninfected plant and what he

found is that despite getting rid of all the known bacterial forms, the filtrate was still able to infect the new plant.

Later it was realised by Wendall Stanley, when he tried to crystallise what was here, he found that these are some protein like particles which are capable of crystallisation and these protein like particles, on their own, cannot replicate. So in a sense they are not completely living but when the infect a living organism, they then can initiate the process of their genetic replication. So in other words just for them to propagate they need to infect another living organism and hence are called as the obligatory parasite. So these viruses are much smaller than bacteria, in fact in the nano meter ranges and hence for a very long time they were not discovered till the advent of electron microscopy.

And as I mentioned unlike bacteria and higher organisms, though these particles retain a genetic material which is surrounded by a protein coat, for example (the) if this is a DNA or it can be RNA, it is just encapsulated in a protein coat. But, on its own, this cannot replicate unless it infects a living organism. So you can in a (f) sense say that these are a group of (we) cannot call them as organisms completely because they still need to depend on (a) another living organism, but they are kind of obligatory parasites.

So what have we learnt in this video? We have talked about what is, what are prokaryotes, and we have seen that they do not have a well-defined nuclear structure. So prokaryotes are a group of organisms where the nuclear material or the (d) what you call as the genetic material sorry, the genetic material is organised as a nucleoid body, it is not surrounded by any kind of a membrane and the whole organism consists of cytoplasm and a cell membrane. In addition to cell membrane the (popra) the prokaryotes may or may not have a cell wall and they all undergo asexual mode of reproduction.

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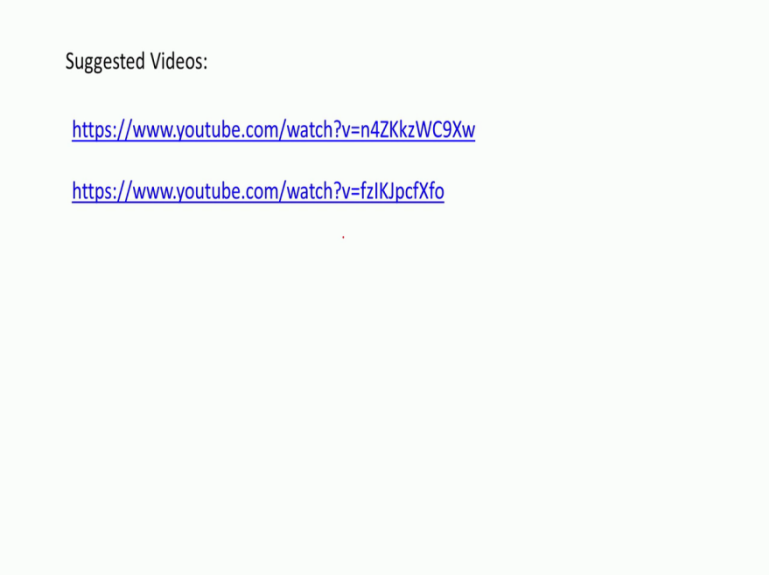

In contrast the more complex organism which involves the plants, the animals, the fungi and the protists, all belong to the class of eukaryotes where the entire genetic material is very well organised within a special membrane bound structure called as the nucleus. We will talk about the eukaryotes in our next class, but for those who are interested to know more about prokaryotes and how the asexual reproduction in prokaryotes really happen, I would suggest you to go through the 2 suggested video links and with that we conclude this video and we will meet again in the next one, thank you.