Biology for Engineers and Other Non-Biologists
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Week- 02
Lecture - 11
Cell structure and function: Eukaryotes

Hi. Welcome back and today we are going to talk about the second category of cells which are the eukaryotes. Now in my last class, I spoke about prokaryotes and what I mentioned to you last time was that prokaryotes; we spoke about 2 types of cells which are the prokaryotes and the eukaryotes and we spoke that the difference between these 2 categories is based on how the genetic material is really organised. Now if I try to get a (f f) fair idea about the size difference between the prokaryotes and eukaryotes.

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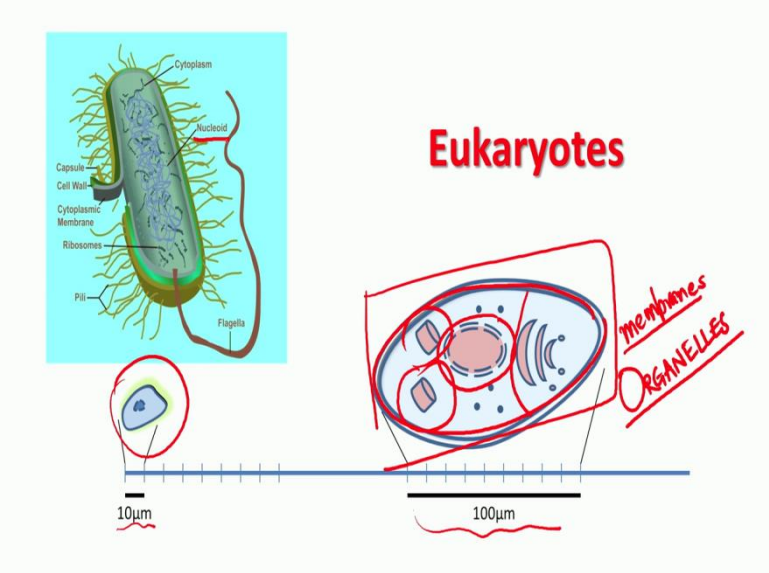

You find that prokaryotes are fairly smaller in size compared to eukaryotes which are much larger. They have a much simpler structure as you can see it in this cartoon while the eukaryotes have a much more complexity where the cell gets divided into multiple sections such as here the nucleus and the other components.

Now each of these sections in a eukaryotic cell is surrounded by the membraned itself. So (the) it is like an addition to the cell membrane which is the outermost membrane. All these components are subdivisions in (turn) themselves are surrounded by membranes and hence they are called as organelles, which is organ like. So what all you had seen in prokaryotes

was DNA was loosely arranged in a nucleoid body but what you find in eukaryotes for the first time in evolution that the DNA is very well organised and it is very well protected.

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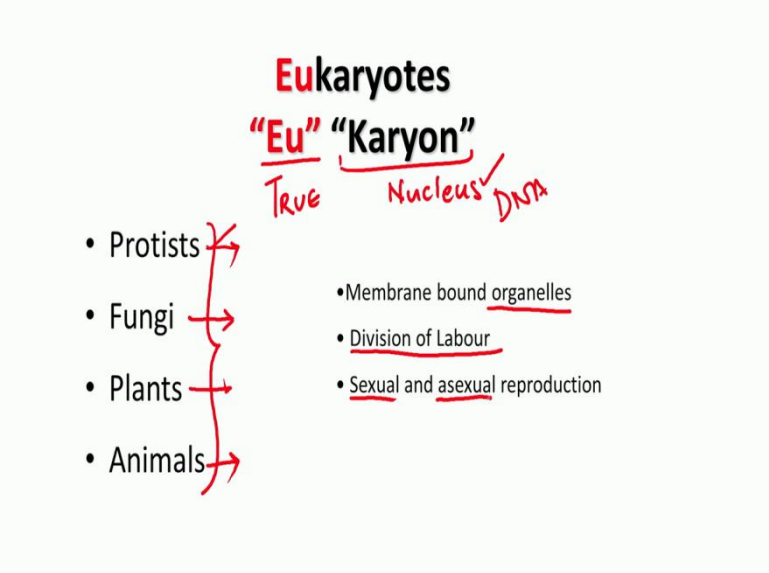

So what does eukaryote really mean, I mean if you were to split the word, "Eu" means true while karyon as I told you last time, it means nucleus. So in this group of organisms, you for the first time see a very well-defined structure which is called as the nucleus and it is this nucleus which houses the genetic material which can be DNA in most of them. Now (eukaryote a) or (eukaryo) eukarya as a domain consists of 4 major group of organisms which are the protists, this is where you come across amoeba and other organisms like paramecium, if you studied in your high school classes, it also consists of the fungal domain which includes mushrooms, all kinds of flowering and non-flowering plants which will (c) come under the eukaryotic domain as well as all the animal cells.

So the eukaryotes unlike the prokaryotes have membrane bound organelles, and the purpose is this allows the cell to have a (sevi) division of labour. And as we had seen last time prokaryotes (m) mainly reproduce asexually, but in contrast to prokaryotes, eukaryotes exhibit both sexual and asexual mode of reproduction. So let us start with some of the basic structures of a eukaryotic cell and what you find is the outermost covering of the eukaryotic cell is what you call as the plasma membrane.

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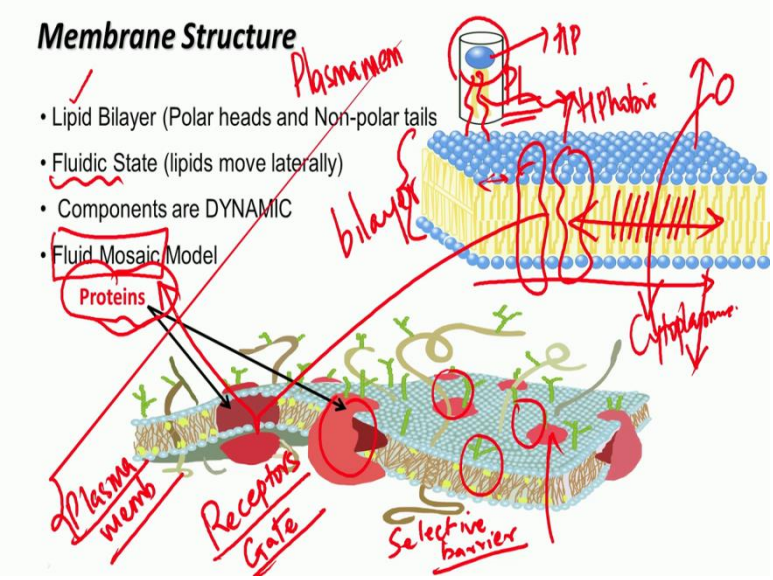

And (sorry no its not) (sorry) yes; plasma membrane. Now as I told you this is a feature which is common both between the prokaryotes and the eukaryotes and it is this outermost layer which segregates the interior of a cell from the exterior of a cell. Now each plasma membrane is made up of monomeric units which are made, called as phospholipids (with) they have a polar head and the nonpolar tails.

And what you find is that these phospho-individual units arranged in tandem and they form a polymeric complex which is what you call as the plasma membrane. And what is interesting is to note that it is not just made up of lipids that is the phospholipids, (rou) on a routine basis if you were to (k) look at the structure of the plasma membrane you find that, it kind of get interspersed in a very random fashion by proteins here and there, it is almost like the mosaic tiles that you see in your homes classically which has no specific pattern, you just have a mosaic arrangement of these proteins.

So there are 2 features to these membranes; one, a mosaic arrangement of proteins and these proteins can be anything, these proteins can be the receptors which can sense what is happening outside and then relay the information inside, these proteins can be the gatekeepers which will allow only specific material to enter from outside to inside. So the (b) whole and sole purpose of the plasma membrane is to provide that selective barrier and act as a gatekeeper, it will make sure that only what is allowed to move in or what is allowed to move outside of a cell goes through this barrier, otherwise no.

So there are 2 major aspects one has to remember about membrane and membrane structure is that not only are they made up of lipid and units called phospholipids, these lipids are highly fluidic in nature. Each of these monomers, it is like they are arranged in tandem and they (li) can literally (t) sway either which way, and that fluidity is the crux for the ability of a cell to change its shape, to move one point to the other, so even though it retains that selective barrier property for example if you have an amoeba sitting, and if the amoeba wants to change its shape and move forward this change in shape is possible because the membrane can contract and can easily rearrange because these individual phospholipid monomers can transition, so they are really fluidic in nature.

And despite being fluidic in nature they maintain selective barrier properties because of multiple proteins which are present, interspersed in the membrane structure. Hence you find that the membranes have what is called as a fluid mosaic structure and these plasma membranes are very important because the polar heads are hydrophilic, so the outer edges, the heads are hydrophilic while the tails which are the long fatty acid chains are hydrophobic. So it is almost like when they are sitting in an aqueous environment they end up forming 2 layers, that is why you call it as a bilayer.

With the hydrophilic ends exposed to the aqueous environment either outside the cell or inside the cell towards the cytoplasm, while the hydrophobic ends come together. So this forms a very nice barrier in (a) terms of, if you look at the thermodynamics of any material to pass through you find that if it all there is a hydrophilic molecule and it has to gain its access say from outside to inside, unless it crosses this barrier of hydrophilic (hy) sorry hydrophobic zone, it cannot go through. And the only possible way it will go through is that if there is a gate somewhere around and this gate is made up of proteins as I mentioned earlier. So the outermost covering of any eukaryotic or prokaryotic cell is the plasma membrane.

But then the whole plasma membrane cannot hold itself, it will end up collapsing unless there is something to hold it together. And this plasma membrane essentially sits on a scaffold of various, (la) I would say, fibrous proteins or scaffold its (alit) you can literally visualize it like a meshwork of wires on which this membrane is sitting, and this forms what we call as the cytoskeleton.

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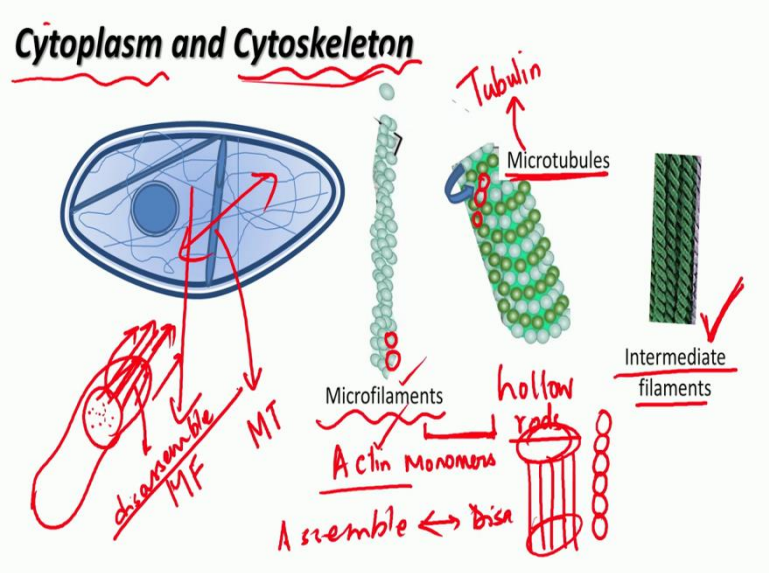

So (you) what you have is the interior of the cell which consists of a fluidic arrangement and that is what we had seen in prokaryotes also which is a cytoplasm, and then the plasma membrane kind of a rests on this scaffold of various fibres and what you call as the cytoskeleton. Now there are 3 different kinds of cytoskeletal elements, and that is interesting to note because each of these elements have different tensile strength and each of them will provide a different rigidity to the cell. So you will have something called as microfilaments which are helical small extensions for polymers of small proteins called as Actin.

So these Actin monomers, so here each circle is an actin monomers, they arrange in an helical arrangement and they form this highly flexible fibres within the cell. So if a cell has experienced some sort of an external pressure from outside and the cell needs to contract for example this contraction would be possible, thanks to the actin fibres. In addition to microfilaments, there are slightly more thicker filaments which are called as microtubules. These are almost hollow rods and each rod in turn is made up of smaller units where each unit arranges in a cylindrical fashion, so it is like a hollow cylindrical rod which is much more stiffer than the microfilaments. So it also helps so in this diagram for example you will find that these straight thin lines are the microfilaments while these rod like structures are the microtubules.

Now the beauty is, just like actin monomers, just like microfilaments the microtubules are made up of another protein called as tubulin and each circle here shows you a tubulin. So how do these tubulins arrange, what is important here is to understand that each tubulin arranges in a linear fashion, like a string of beads. So I want you to imagine each tubulin to

be a bead and if you connect them linearly to each other it is like a string of pearls or a string of beads.

Now take such 13 such strings and arrange them in the form of a cylinder, a hollow cylinder. That is what is a microtubule. So compared to microfilament these are a little more rigid, but then microfilaments are far more flexible. What is again interesting and important to note is that because they are made up of these individual monomers it is very easy for these 2 groups of filaments to assemble and disassemble at short notice.

You know you can literally visualize this as a (li) set of Lego toys where each (pi) small peach of piece of Lego can come together to form a structure and when it want to disobey they just go, you can just separate them. What better when you have these small molecules as small beads coming together if they need to form a filament and then dissociate if there is no more need. And it is this cytoskeleton along with the fluidic ability of the plasma membrane which allows the cell to contract and relax.

And the third category of the fibres are the intermediary filaments. Now intermediary filaments unlike microfilaments and microtubules are more like ropes, you can visualize them as nylon ropes which are twisted and they are much more having a much more higher tensile strength than the microfilaments or the microtubules. So in regions of the cell where there has to be much more rigidity required you will find that the cell consists of micro sorry intermediary filaments.

So let me rephrase it, re-say it. The cytoskeleton is the scaffold or the structure on which the plasma membrane rests and it holds the entire shape of the cell together. It has 3 different kinds of components; the microfilaments which are the most flexible ones, followed by the microtubules which are slightly more rigid but they are hollow tubes, follow cylindrical tubes, and then the most resistant and the most I would say resistant to mechanical changes are the intermediary filaments.

So these 3 group of fibres kind of hold the cell together and because of their ability to easily assemble and dissemble, particularly from microfilaments and microtubules, it is possible for a cell to quickly assemble a change its shape and (re) reassemble. Let me take example, for example if you have an amoeba sitting here, and you and amoeba needs to move forward, what will happen is all these monomers of actin will then start arranging and start pushing towards the leading edge of the amoeba.

So what happens is though they were existing as individual monomeric units, if the need be they immediately organise as rods and push the cell forward. So this is possible because of this property of cytoskeleton. And once it has moved forward and the (pr) work is done, the same filaments will disassemble back to the monomeric units and the shape will change. So it is possible easily because of the cytoskeletal elements for the cells to change their shape.

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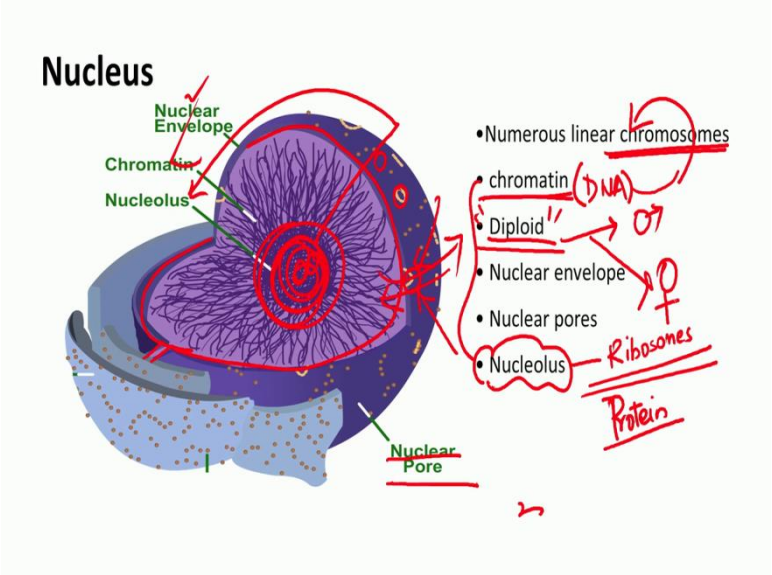

Now let us come to one of the most distinguishing features between the prokaryotes and eukaryotes and that is the nucleus. Now the nucleus in case of eukaryotes is much more well defined because the DNA is very well organised. I mean, you will be surprised to know that if you were to actually measure from end-to-end, the length of extended DNA molecules let us say in humans, it will be at least 2 metres long and yet you find that this fibre which is supposedly 2 metres long and has your entire information coded in it is compacted and stored inside a cell which is about 10 to 20 microns in diameter.

Now how is that possible? (A d) that is possible because the DNA gets reorganised and refolded it is like you take a thread of wool and then you start winding it to form a ball of wool and then further compact it with the help of a class of proteins which is what you call as a chromatin.

So the DNA in case of eukaryotes is organised into chromatins, and this chromatin will loosen up to form chromosomes at the time of cell division. We will talk about cell division later. So unlike prokaryotes which have single circular DNA, here in case of eukaryotes the DNA is much more complex and hence the DNA is much better organised and it is organised

with the help of protein DNA complex which is what you call as the chromatin. And this chromatin is very well organised inside the nucleus and the nucleus and the entire genetic material then gets surrounded by a membrane double membrane structure which is what you call as the nuclear envelope (sorry) the nuclear envelope, so, yes, the nuclear envelope.

Then the other thing which is observed is that this nucleus does not exist in isolation. This nucleus has to communicate with the rest of the cell and it does so because the entire nucleus has numerous opening which is what you call as the nuclear pores. So these are the gatekeepers and these are the channels through which the material can move in or move out of the nucleus.

In addition to this you find that the chromatin in the nucleus is condensed and it (f) gets condensed into multiple structures and forms and then at the centre you have this highly compacted chromatin material which is what you call as the nucleolus. And (t) it is here in the nucleolus that the ribosomes, we spoke about ribosomes in the (r) last video as well where I told you that these are the machineries which actually do the work of synthesising proteins. So what you find is that this protein synthesising machinery is actually produced and assembled in the nucleolus.

So this has been the major difference between prokaryote and the eukaryote whether DNA is far more compact its and the reason it is far more compact is because unlike the prokaryotes which are haploid here you are getting genes from both set of parents, the (me ma) the father as well as the mother. So you find that all the eukaryotes are diploid for every gene you have 2 copies one coming from the father and the other coming from the mother. So this is the basic difference between the arrangement of genetic material between prokaryotes and eukaryotes.

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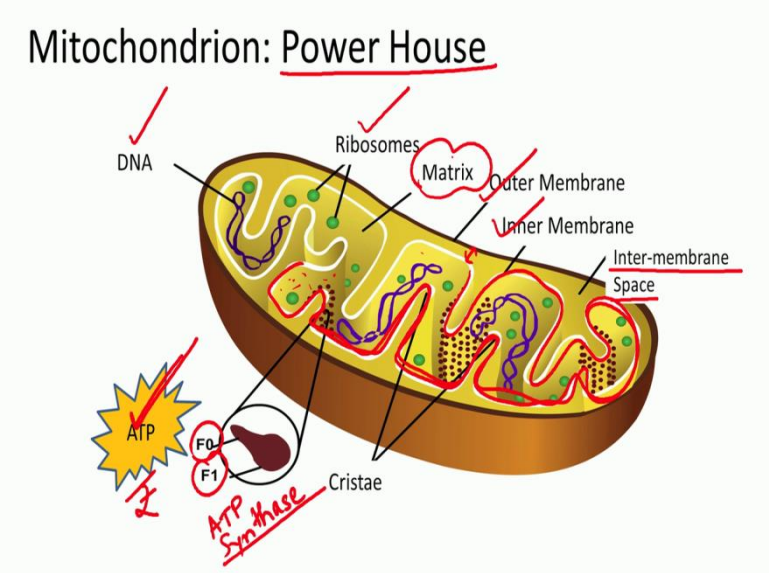

Now let us come to (the) another very important organelle which is present in eukaryotic cell and that is the mitochondria. Now mitochondria is also called as the powerhouse of the cell because as I mentioned earlier also that when you want to do any life activity, the life activity requires energy and there has to be production of energy and that energy or the currency in case of a living world is this molecule called ATP, all right?

Now this energy currency has to be constantly synthesised and supplied to the rest of the cell for other processes to happen. So this actually happens, this process of energy generation happens in the mitochondria and it is again a very specialised organelle. It is again a double membrane organelle, it has an outer membrane, an inner membrane and what you notice intriguingly for the first time is that the inner membrane has multiple foldings and it is not without a purpose, there is a reason for this folding and I will come back to it.

You find that the inner membrane unlike the outer membrane has far more invaginations and it is studied with the set of particles which is called as the F0, F1 particles. It is this particle or F0, F1 it is nothing but the ATP synthesising enzyme, also called as ATP Synthase. And you find that when you have so much of invagination of the inner membrane and every nook and corner of this inner membrane gets studded by this particle, it increases the surface area and it provides sufficient positioning of this ATP Synthase to work.

I will not get into the machinery as to how it functions; if you are interested you can always look at topics of mitochondrial respiration, it will become evident how this ATP Synthase work. But I will insist on one thing; the inner membrane is highly impermeable compared to

the outer membrane of the mitochondria. And the space which is present between these 2 membranes play a very important role in ATP synthesis and this space is called as the inter membrane space.

What you also find is that the inner part of the mitochondria like cytoplasm in mitochondria has a fluidic arrangement which has a lot of ribosomes, it has its own DNA so mitochondria consists of its own DNA and it has its own protein synthesising machinery, you find (is) present or suspended in section of mitochondria which is called as the matrix. So mitochondria is (the) sole purpose is the generation of energy that is ATP and it has very interesting structure because it has its own DNA, it also has its own ribosomes. And I will come back to this again when we talk about origin of eukaryotes.

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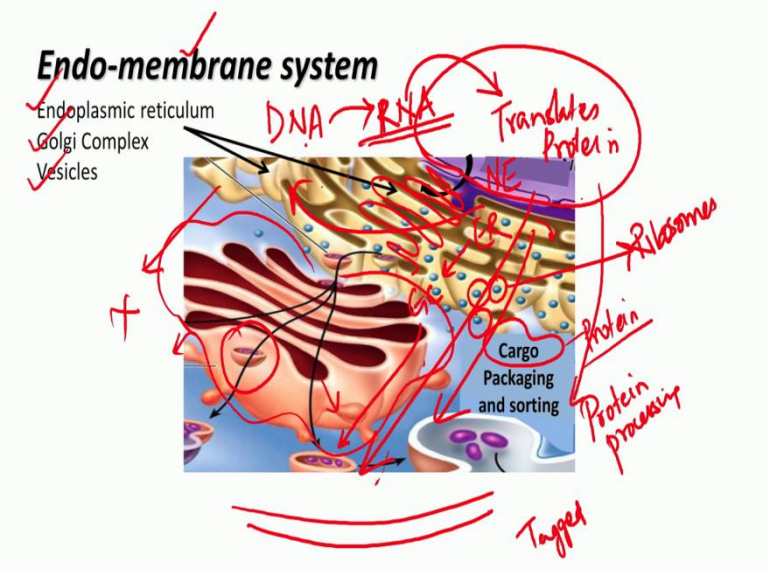

Then we look at the other parts of the cells. So this is the interior of a cell in this slide and what you can see here is that starting from, so if this were the nucleus, from the nuclear boundary moving outwards you see a whole channel of membranes extending all the way up to the plasma membrane, so plasma membrane would be somewhere here. And what you find is that this entire meshwork of these membranes is called as the Endo-membrane system, and it consists of subsections, it has right next to the nuclear envelope, 2 kinds of membrane bags, a set of bags which are studded on their outer surface with ribosomes, another set of bags which do not have ribosomes.

And what is observed, this set of bags or this set of network of channels is what you call as the endoplasmic reticulum. And this endoplasmic reticulum plays a very important role in

protein processing. So we did talk about the central thematic that is DNA is read by and translated (as in fant if) DNA is converted to RNA where kind of decodes the information from DNA and having decoded it, it then passes it on and translates it into a product which is what we call as the protein.

Now once the proteins have been synthesised, the proteins can get further modified and they can even be tagged. For example how will a cell know that a protein which is synthesised here needs to be secreted or a protein needs to be put into the mitochondria. So that tagging process, the postal tagging happens in these organelles.

So that happens partly in the endoplasmic reticulum and then the further fine processing happens in the Golgy complex. Not only does the processing happen in these 2 organelles, the endoplasmic reticulum and the Golgy, at the terminal end of the Golgy you start observing that once a product, which is what we call as let us say a cargo has been synthesised, now in this case the cargo is nothing but the protein and a processed protein.

Once the protein has been synthesised, processed, it kind of starts getting packaged, it is almost like an assembly line where things kind of get packaged and then they need to be sorted and sent to the respective destinations. That kind of sorting of proteins and sending the proteins to the respective destinations within a cell, it can be a plasma membrane, it can be a mitochondria, it can be any other organelle, that happens at the Golgy complex because from the terminal ends of Golgy complex the cargo gets packaged into small small structures which is what you call as the vesicles, and it is these vesicles which are like the ferries which will then ferry the cargo to various parts of the cell.

So I can kind of sarise Endo-membrane system as that part of the cell, which has not only the assembly line for synthesising and processing the proteins, checking the quality control, but is also the section or the postal section, where the addresses are marked on the proteins having marked the proteins it ends up sorting the proteins and it is also the delivery system. And as a result what you find is all the way from the nuclear envelope to the endoplasmic reticulum to the Golgy complex to the vesicle there is a continuity and there is a continuity and the flow of material happening to all different directions of the cell.So that is the importance of the Endo-membrane system.

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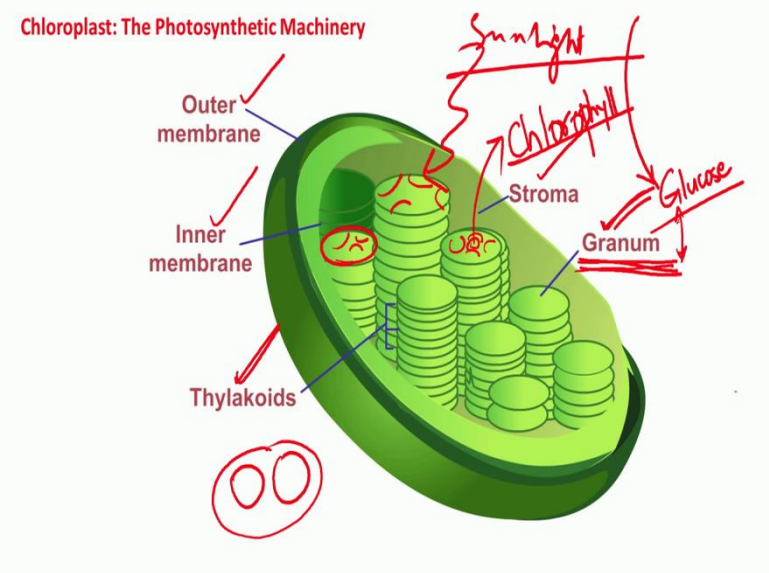

Then if you talk about plants which unlike animals have developed this remarkable activity and ability to convert solar energy into what you call as the chemical energy which is the glucose, you have an additional cell organelle which is called as the chloroplast. Chloroplast similar to mitochondria has 2 membranes, an outer membrane, an inner membrane, a matrix which is called as the stroma. And then you find that this (t) chloroplast has this arrangement of coin like structures which are called as the Granum.

Each coin you can visualize a set of let us say 1 rupee coin and you start putting them one above the other, so each coin will look like a Granum and that stack of coins is what you will call (a) sorry each sorry each coin will be called as the Thylakoid and then the entire stack of Thylakoid will be called as the Granum. So what is the purpose of this Thylakoid, now these are disc like membranes which essentially harbour the light harvesting complex or the I would (lad ra) let me say that each of these discs have these antenna like complexes which are suitably oriented so that they can capture the sunlight.

Now that is the beauty. Here you find that not only are the membranes flattened and are studded with all these antenna (m) like molecules which is nothing but a set of pigments, the most common one for which the plants are green in colour the chlorophyll. So all these chlorophyll molecules, they beautifully arrange like antennas, light harvesting antennas in these flattened disc called Thylakoid, and to accommodate more and more harvesting potential the Thylakoids membranes exist in stacks. And it is here that you start seeing in this organelle the conversion of sunlight into glucose. So this is something which you again find in chloroplast and chloroplast also has its own DNA and ribosomes.

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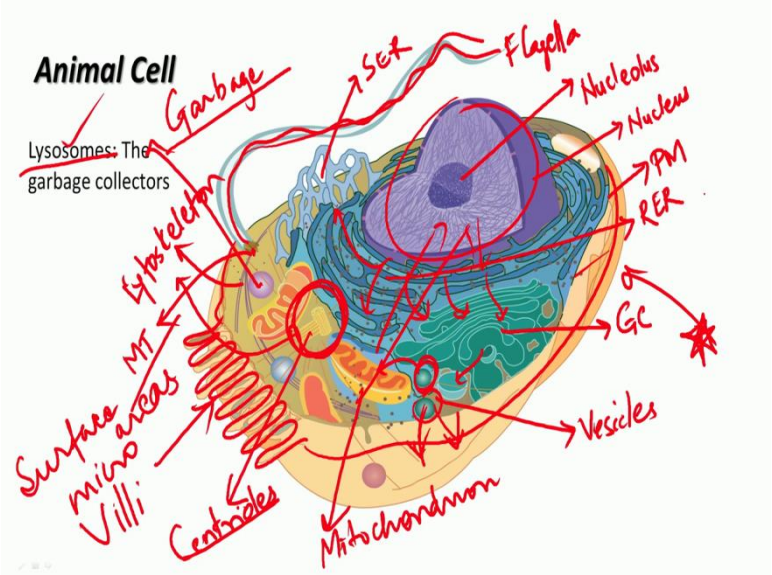

So let us look at the animal cell and what all it will contain and (you) in this exercise you can see the central most part here is what you call as is the nucleolus, this entire structure is what you call as the nucleus. The nucleus keeps on extending into Endo membrane system which consists of (oops) this consists of rough endoplasmic reticulum, the smooth endoplasmic reticulum and the Golgy complex. And you find that it is in these networks of channels that the sorting, processing, packaging and delivery of the proteins and other constituents of the cells happen.

The Golgy complex then ends up packaging its content (ins) the content starts getting delivered either outside or to the mitochondria, so this is the mitochondria; starts getting delivered to the mitochondria and or to the outside if the need be and these structures is what you call as the vesicles. The whole entity of the cell is then surrounded by the outermost membrane which is what you call as the plasma membrane and the whole cell is held in shape because consists of these fibre which are the cytoskeleton.

You also find the cylindrical like objects which is the part of the (m) cytoskeleton which is the microtubules and particularly in the animal cells at one polar end you find a pair of these microtubule like structures which are called as the Centrioles. In addition to all this you also find that (cel) animal cells have some other special organelles which are called as the lysosomes. Now what are these? These are nothing but the garbage collectors. So if a cell is doing so much of function, obviously it is going to produce a lot of waste matter which needs to be collected and appropriately processed and discarded and that happens in lysosomes.

Animal cells for example sperm will propel further with the help of its propeller which is nothing but the flagella. This flagella extends out of the plasma membrane and internally it consists of motors which are made up of microtubules. And then the plasma membrane also consists of, in some cells it keeps on folding itself to enhance the surface area, these are called as Villi or microvilli. (E) especially these are seen in cells for example which are lining your intestinal tract where these foldings will (help) allow a cell, a greater surface area for more and more absorption of let us say nutrients.

So when there has to be a need of the for the absorption of nutrients then this can happen in intestinal cells. So this is how the animal cell look like, so though it looks fairly complex. I again want to reiterate that each of these components of the cells are in crosstalk with each other. Not only are they in crosstalk with each other and there is a dynamic interaction happening at all given point of time, the cell is also sensing things from outside and accordingly responding.

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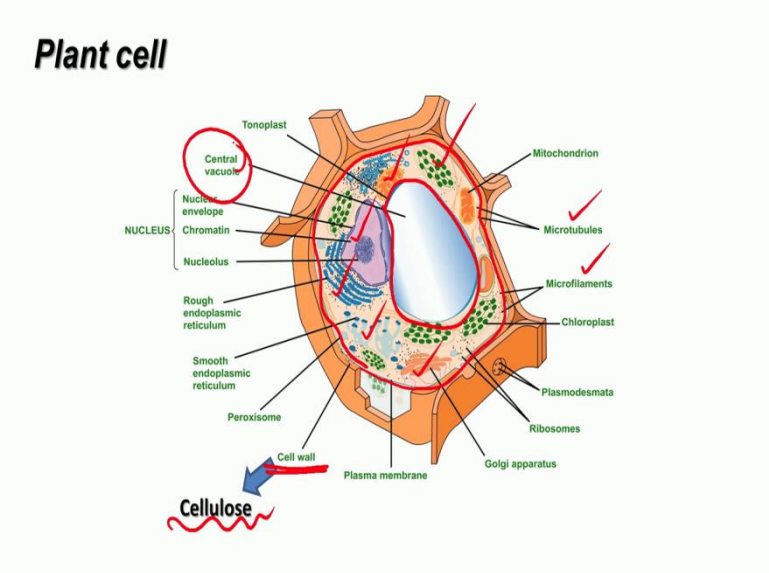

Now these are the common features which you will see and lot of these organelles you will see them again in a plant cell like the nucleus, the endoplasmic reticulum, the soft (en the) the smooth endoplasmic reticulum, the Golgy complex, the mitochondria, in addition to that since (as) the photosynthetic machinery you will find the chloroplast. In addition to that there are 2 additional features which you see in plants, one-way the which by which the plant cells kind of hold on to the ground and resist any kind of attack on them is by having an extra layer outside the plasma membrane which is called as the cell wall. And this cell wall is made up of one of the largest polymers available on the surface of the earth which is the cellulose.

And this cellulose is something that you and I use on a day-to-day basis because all our cotton clothes are nothing but made up of cellulose fibres. (Excuse me) so like animal cells, the plant cells also has microfilaments, microtubules and all the other organelles plus they end up having a central large organelle which is called as the vacuole. It is this organelle which ends up storing a whole lot of water in its inner content (excuse me).

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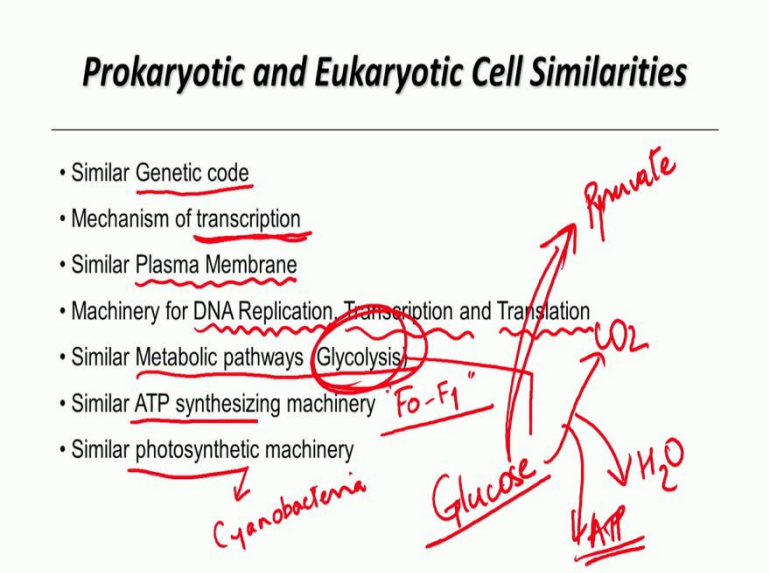

So let us go back and look at what are the similarity between prokaryotic and the eukaryotic cells. I said (Avi) all this while I spoke about the diversity, the diversity was in terms of the presence or absence of nucleus, the presence or absence of membrane bound organelles. Now let us look at the unifying feature because as I said there are common features across life and what as that unifying features. And the unifying features are these; the way in which the information is coded which is what you call as genetic code is similar between prokaryotes and eukaryotes.

The way in which this genetic code is deciphered or read and interpreted is done through the mechanism of transcription is fairly conserved. The structure and the biological activity of the plasma membrane, the outermost boundary of these cells is similar. Even the machinery which is used by these cells to replicate their DNA before they can pass it on to the daughter cells or the decoding process by transcription and its conversion into the actual product of protein which is what you call as translation is fairly conserved right from bacteria to humans. Then the ATP synthesising machinery; remember we spoke about the F0-F1 particle in the mitochondria, its architecture and its mode of action is fairly conserved across evolution.

Even the machinery for photosynthesis, in bacteria we spoke about the cyanobacteria, right? In case of plants you have the chloroplast, you find there is a huge amount of similarity. And then some of the reactions which are very commonly occur in life, the most easy one is the reaction where the glucose which is your stored energy is kind of broken down into carbon dioxide and water, this happens in cytoplasm and mitochondria for the release of ATP. This process where the glucose first gets converted to pyruvate and this first step happens in the cytoplasm. This is what you call as glycolysis. This machinery in cytoplasm which breaks down glucose intermediate, to its intermediate molecule called pyruvate is (f f) conserved across prokaryotes to eukaryotes.

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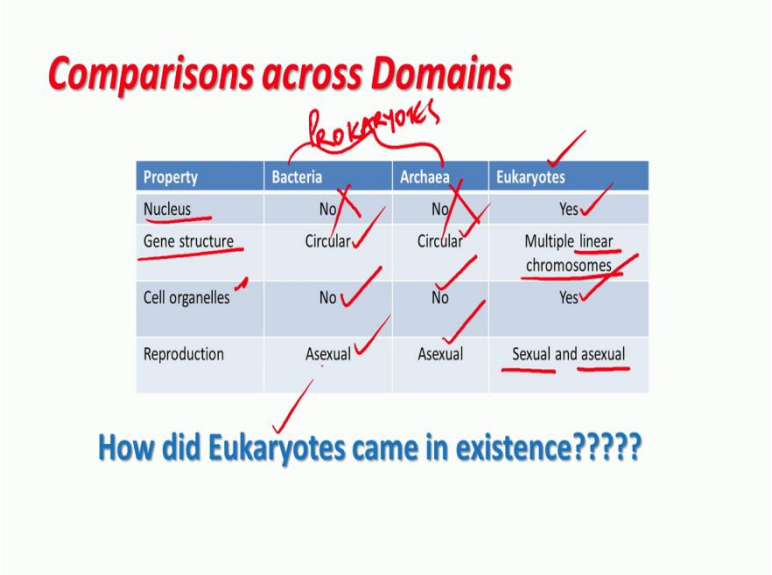

So let us look at the comparison against bacteria, Archaea and eukaryotes. As I said bacteria and Archaea belong to prokaryotes, right? And then you have the eukaryotes. If you were to look at the nucleus, it is not present in bacteria, it is not present in Archaea. Both of them are prokaryotes. But it is very well-defined in the eukaryotes. If you were to look at DNA or the gene structure, the DNA is circular in bacteria and Archaea, but in case of eukaryotes is far more complex and with the help of chromatin is organised inside the nucleus and the can at the time of replication sorry cell division convert to linear chromosomes. There is no evidence of any division of labour in bacteria and Archaea so you do not see any cell organelles, but you see very well-defined cell organelles in eukaryotes.

If you look at the mode of reproduction in case of bacteria and Archaea the mode of reproduction is asexual, but eukaryotes exhibit both sexual and asexual mode of reproduction. So there are, in my previous slide I said, there were plenty of similarities yet they are

differences. So how is it that the eukaryotes came into existence, I mean this has been a puzzling question and it is partially answered by the available evidences that we have today. But before I get to that, I need to explain you a few terms.

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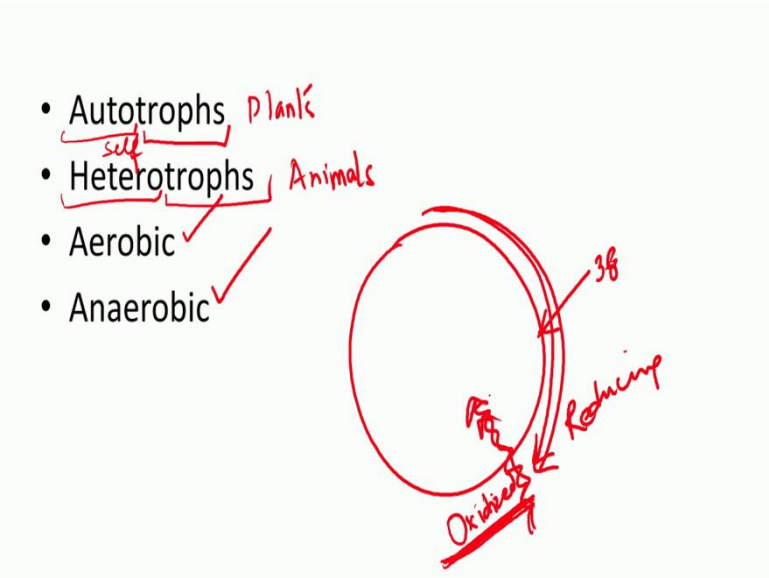

Autotrophs, auto means self, right? Trophic means synthesising, food synthesising. Organisms which can synthesise their own food like plants are called as autotrophs. Organisms which depend on others, like animals which depend on plants, are called as hetero, on others, trophic, right? So this will have plants, this will have cyanobacteria while this will have animals, amoeba, so on and so forth.

Now if you remember we (have) were talking about the origin of the earth and the origin of life I had talked about that the life originated somewhere around here about 3 point 8 billion years, and then for a very long time the earth's atmosphere was the reducing one. Then suddenly due to the advent of photosynthesis, the atmosphere started getting oxidised, right?

Now, a set of organisms which can manage to break down their glucose in absence of oxygen are called as the anaerobic oxygen, (a) anaerobic organisms. That means these guys are able to still obtain energy from glucose by breaking it down (into) glucose into lactic acid (parshit r) or ethanol, while those organisms which later ones the (m) environment became oxidised they should have developed some more mechanism to now utilise that atmospheric oxygen and still break down glucose. So, those organisms which break down glucose with the aid of oxygen, right, are called as the aerobic organisms.

So if you were to look at the history of earth, this becomes very important; the initial phase is reducing, suddenly there is a pressure created which is again what I will call as natural selection in terms of Darwin's theory, you suddenly have a pressure created because the atmosphere becomes highly oxidised.

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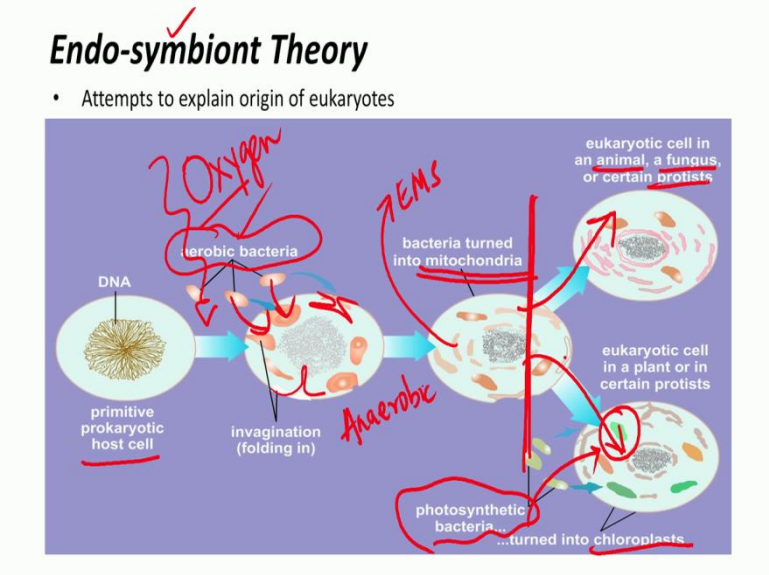

That means the organism should have evolved a process by which despite having oxygen around it should be able to survive, right? So with this background let us look at the theory which explains the origin of eukaryotes and that is called as the Endo-symbiont theory.

What it sees is the life started as a prokaryotic cell with a very simple DNA, but somewhere around the time when there became a need to (s) because of the atmosphere (g) having high amounts of oxygen, some bacteria must have developed the ability to survive in such an oxidising conditions, and they were able to utilise atmospheric oxygen and hence were aerobic bacteria. So somewhere during the course of evolution an anaerobic, an anaerobic

must have engulfed this aerobic bacteria to survive, right? And this aerobic bacteria eventually ended up becoming what we call today's mitochondria.

Simultaneously they must have happened, simultaneously or even later around the same time the plasma membranes must have started invaginating, and this must have left to what we see today as our Endo membrane system. And again if there were scarcity of nutrients, some of these organisms must have realised that they cannot survive on their own unless they develop their ability to synthesise their own food and some set of bacteria must have developed that ability of photosynthesis so this organism might have even engulfed a photosynthetic bacteria which later ended up becoming today's chloroplast.

So it is at this junction the branching must have happened where the plants must have evolved while the ones which could not become autotrophic continued to become the animal, a fungal or the protist group. So this is what the Endo-symbiont theory says, it says that in order to survive an anaerobic bacteria during the course of evolution must have engulfed and aerobic bacteria and this must have led to some sort of a symbiosis which is mutually beneficial relationship which will have then lead to final evolution of the mitochondria and similarly in case of plants there must have been an engulfment of an early photosynthetic bacteria which would have then ended up evolving into chloroplast.

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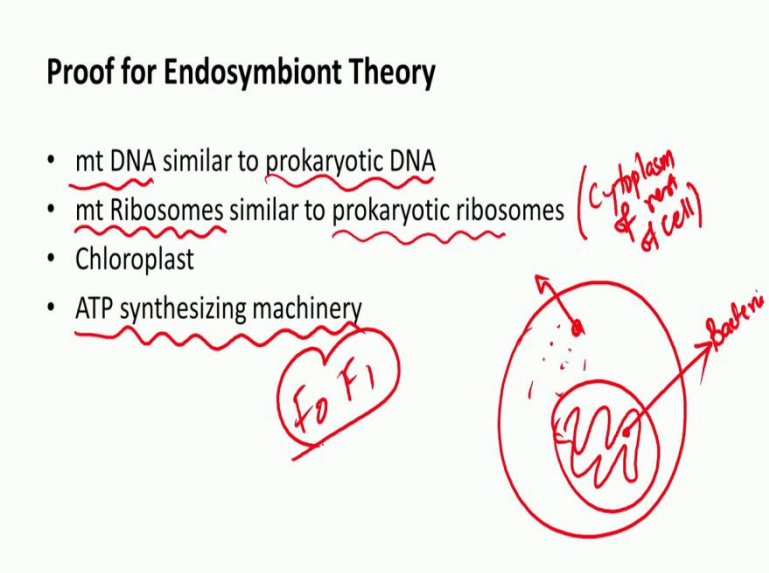

But theories are theories, do you have evidence? And we do, to some extent. If you were to look at the mitochondrial DNA of today's eukaryote you will be surprised to know that it is very similar to prokaryotic DNA. Not just that if you are to look at the mitochondrial

ribosomes you find in terms of the chemical structure, in terms of their size they are very similar to prokaryotic ribosomes. And these mitochondrial ribosomes are, mind you, are different from the ribosomes which will be seen in the cytoplasm of the rest of the cell.

So if you take an animal cell, the animal cell in the cytoplasm will also have ribosomes, will have a mitochondria and within the mitochondria it will also have a ribosome. But this ribosome in mitochondria is similar to the ribosome of bacteria while this ribosome is different. So clearly there are similarities. Similarly you find the same sort of analogy in case of chloroplast and even the machinery which I spoke to you, the structure of F0-F1 particle, the mechanism by which the F0-F1 particle functions, has remained very similar to that of prokaryotes.

Thus we believe that today's eukaryotes have actually evolved from the prokaryotes. So I would like to end this video by saying, eukaryotes have been far more evolved than the prokaryotes, they seem to have come out of prokaryotes and they seem to have a very well-defined nucleus and a very good division of labour, which provides complexity for sure, but it also enhances the efficiency of the organism which may not have been in case of prokaryotes. Some may argue that despite this, the prokaryotes are probably the superior forms, (s) given the fact that they have managed to survive all kinds of onslaughts on this earth for the last 3 point 8 billion years.

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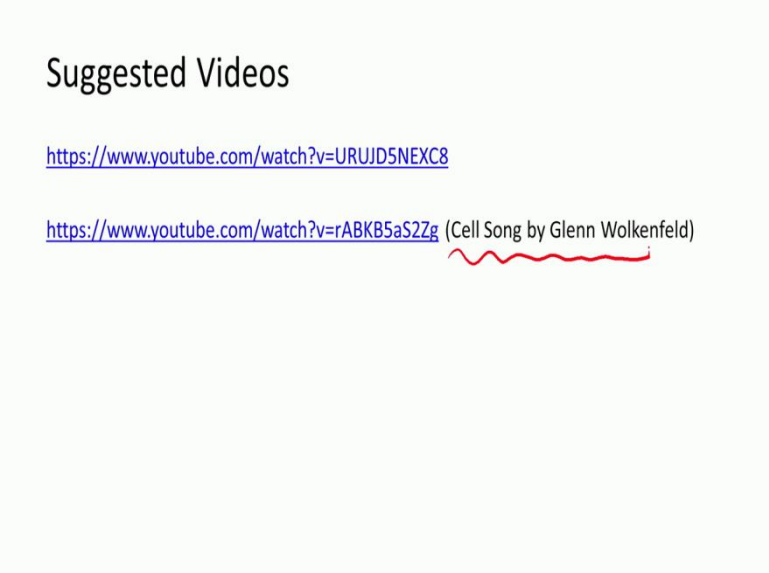

Well I leave that decision for you to make but I would like to suggest a few videos, and there is a very interesting the ones who are musically inclined to just look at this fun song on cell

and cell structure by Glenn Wolkenfeld. And hopefully I will see you again in the next video where we will talk about cell cycle, another aspects of cell division. Thank you.