

**Cell and Molecular Biology**  
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**Week 02**  
**Cellular Structure**  
**Lecture - 07**  
**Eukaryotic Cells (Part 1)**

Hello, everyone. This is Dr. Vishal Trivedi from the Department of Biosciences and Bioengineering, IIT Guwahati. And in this module, we are discussing the different types of cells. Based on the structures, the cell could be of two different types: it could be a prokaryotic cell or a eukaryotic cell. In the previous lectures, we have discussed prokaryotic cells.

We have discussed the structure of the prokaryotic cell and how the different components are present in the prokaryotic cell. We have discussed the cell wall, the different types of analytical barriers present in prokaryotic cells, chromosomal DNA, and plasmids. In the previous lecture, we also discussed how you can isolate the plasmids from the bacterial cell, how you can use them for different types of applications, and how the plasmid is actually spreading resistance or different types of properties. In today's lecture, we are going to discuss eukaryotic cells.

So when you talk about the eukaryotic cell, as I said, we are going to discuss the two types of eukaryotic cells. One is called the plant cell, the other is called the animal cell. So let's start our discussion about eukaryotic cells. So the higher eukaryotes have multiple organs to perform specific functions, whereas the cell is the structural as well as the functional unit of life and contains all the necessary infrastructure to perform all the functions. So, besides, we have different types of cells; we have prokaryotic cells, eukaryotic cells, and within the eukaryotic cells, we have plant cells and animal cells.

So, before getting into the details of what the different organelles are and what the structures of the eukaryotic cell are, it is important to understand the difference between plant cells and animal cells. The structure of the eukaryotic cell is much more complex, and it contains many membrane-bound organelles to perform specific functions. It contains a nucleus isolated from the cytosol and enclosed in a well-defined plasma membrane, so one of the classical features is that eukaryotic cells actually contain membrane-bound organelles to perform specific functions. And then you have the two different types of eukaryotic cells: the plant cell and the animal cell. Let's see what the differences are between animal and plant cells.

These are the properties of the plant cell, and these are the properties of the animal cells. So what you see here is the cell wall. The cell wall is present in the plant cell, and the plant

has a very robust and good cell wall that is made mostly of cellulose. The cell wall is completely absent in the animal cell. Then the size of the plant cells is very, very large compared to the animal cells, which are comparatively small.

Then the chlorophylls, chlorophyll is the light pigment, right? Chlorophyll is the light pigment that is present in plants and is completely absent in animals. There are exceptions where animal cells also have chlorophyll, such as in the case of euglena, right? So euglena is an animal cell, but it also contains chlorophyll. Then we have the vacuoles; there are large vacuoles present in the plant cells, and the purpose of these vacuoles is to collect food material, or sometimes they also collect toxic substances. Because the plants are much more exposed to the toxic substances, whereas in the case of the animal cell, it contains a small number of toxic substances. Then we have the mitochondria.

The mitochondria are few in the case of plant cells because plant cells are not very motile. The plant cells are static. You have seen that the trees are present in the soil. So they don't move around. That's why they don't require a large quantity of energy for motion.

And that's why they don't have a very large number of mitochondrial cells. Whereas in the animal cell you have a huge amount of animal cells because animal cells are very motile. So because of the animal cell's motility, they need a larger amount of energy, and that is why they have a greater number of mitochondria. Then the lysosomes are almost absent in the plant cell, whereas they are present in the animal cell. Then we have the glyoxysomes; the glyoxysomes are present in plant cells but are absent in animal cells.

Then you have cytokinesis; cytokinesis means cell division. This is what we are going to discuss in due course. The cytokinesis is the cell division; cell division is always by the plate method in the case of plant cells, whereas it is by constriction in animal cells. So, these are some of the notable differences between the animal cell and the plant cell, but overall the basic properties of these two cells are actually very similar. They both have plasma membranes.

They both have many of the organelles that are present. So let's start discussing the different types of organelles that are present in eukaryotic cells, and then we will take up some of the organelles that are exclusively present in plant cells, and so on. So let's start our discussion with the first organelle, and that organelle is called the cytosol. Cytosol is nothing but the water or the liquid part that is present inside the cell. So you see the cell that is there, and it has a nucleus in the center, and in between, whatever you see is actually called the liquid part, which is called the cytosol.

So cytosol is the liquid part filled inside the cell, and it contains water, salt, and macromolecules, which means it contains proteins, lipids, and RNA. It has an array of microtubule fibers running throughout the cytosol to give the vesicular structure to its destinations. Within the cytosol, you have different types of microtubules running. So these

microtubules are actually creating the roads within this cytosol, and on these roads, only the vesicles are moving, and that's how they are actually delivering their content. Just like when you are ordering material from Amazon or Flipkart, the guys come to your place.

But how are they coming? They are coming because there is a road. There is a road to your home, and that is how they come using these roads. So these roads are made up of the microtubules, which we are going to discuss in our subsequent lecture, and they will use these roads; you can imagine these vesicles as the courier guys who are coming to your home and actually delivering to your place. And how they are delivering that is a part of the very extensive vesicular structure system, and they actually have a very well-defined vesicular transport system, which is going to help the cells deliver the material to their destinations. Besides this, the cytosol exhibits sol-to-gel transitions, and such transitions regulate multiple biochemical and cellular processes.

So the sol and gel transition is actually making either the cytosol thicker or thinner, and because of that, the localized sol and gel transition is actually going to make the substrates more concentrated or less concentrated. And because of that, they can enhance or change the rate of these reactions very nicely. So apart from these functions, the cytosol has many other functions. So cytosol has no well-defined functions; it serves as a medium to exchange materials between the different organelles. It plays a role in various processes, such as where signal conduction or translation is going to take place.

So cytosol has the cellular machinery that is responsible for translation, which means the production of proteins, right? So the production of protein is called translation. And that is happening within the cytosol. Now, one of the things that people very often use interchangeably is the term cytosol or cytoplasm, and there is a big difference between the cytosol and the cytoplasm. It is very important that you get clarification: cytosol is actually the liquid part; this is the liquid part, whereas the cytoplasm is actually consist of this cytosol and all other organelles, so if you take the cell, it has a nucleus, right? So outside this nucleus, whatever you have is called the cytoplasm; it contains the cytosol, and it also contains the different types of organelles.

So that is very, very important for you to understand that you should say cytosol when you are talking about the liquid part, And you say cytoplasm when you are talking about the content that is outside the nucleus. So let us move on to the next organelle, which is known as the nucleus. So the nucleus is the central processing unit of the cell, and it is homologous to the processor in a typical computer. The nucleus is also called the master of the cell because it regulates and gives the instructions to the cell on what it should do. Why is it so? Because the nucleus contains the genetic material, and that genetic material has all the information about what the cell has to do.

So the nucleus is very well present inside a double membrane structure, right? The liquid that is filled inside the nucleus is called nucleoplasm, and nucleoplasm actually contains

different types of molecules; it is a viscous liquid that contains nucleotides and enzymes to perform replication, transcription, and the DNA damage repair system. So the nucleus contains the nucleotides, which are required for replication as well as for transcription, and it has the replication machinery. The replication machinery means it is actually going to make another copy of DNA, which is required when the cell is going through cell division. It contains the genetic material, the DNA, in a complex fashion involving several proteins called histone proteins, compared to bacterial cells. The DNA is present in a complex with the proteins, which are called histones, to pack into nuclear bodies or chromosomes.

So when we talk about the chromosome, it is an authentic chromosome that is present in the eukaryotic cell. The chromatin in the eukaryotic nucleus, like the DNA content, is present in two forms: it can be euchromatin or heterochromatin. Chromosomes can be present either as euchromatin or heterochromatin. Euchromatin is a part of the chromatin where the DNA is loosely packed and is transcriptionally active to form messenger RNA, whereas heterochromatin is non-active or inactive, which means the eukaryotic cell has the mechanism so that it can make some portions of its genome active and some portions inactive. Why is this so? Because they don't want to expose their whole DNA to the cellular machinery and various types of toxicants, and because of that, they can protect themselves.

So the DNA that is present in the heterochromatin is actually going to be more densely packed, and because of that, it is protected from any kind of damage. So they will be protected from the damage. and it is transcriptionally inactive. So the portion that you require, for example, if there is a requirement for the insulin molecule, if we require insulin, then that insulin gene is actually going to be present in the euchromatin, and that's how insulin is going to be transcribed within the nucleus, and that's how insulin production is going to start in the cytosol. Since the nucleus is present inside this particular double membrane structure, it is actually well protected from the cytosol or well separated from the cytosol by the very complex structure, which is called the nuclear membrane.

So the nucleus in eukaryotes is present in a double layer of membrane known as the nuclear envelope. What you see here is the nuclear envelope, where you have the nuclear pore, and this is the only portion through which molecules can come in or synthesized molecules can go out. The outer membrane of the nuclear envelope is continuous with the rough endoplasmic reticulum and has ribosomes attached to it. The space between the two membranes is called the perinuclear space. The nuclear envelope often has the nuclear pore.

As per the calculation, an average nucleus has 3000 to 4000 pores per nuclear envelope, so you have these types of nuclear pores. The nuclear pore has a diameter of 100 nanometers and contains several types of proteins; it is a gateway for the transfer of material between the nucleus and the cytosol. You cannot just get anything into the nucleus because, in that case, there are many DNA-damaging agents that are present in the cytosol. So, they will not get in because the nuclear pore actually has a mechanism to discriminate between who will

be allowed to enter and who will be allowed to exit this DNA. The RNA formed after the transcription from the DNA within the nucleus will move out of the nucleus into the cytosol through the nuclear pore.

Similarly, the protein from the cytosol crosses the nuclear pore to initiate replication, transcription, and other processes because you require the signal from the cell; you also require the cellular machinery from the cell so that you can perform the different types of functions, for example, replication and transcription, which are also governed and completely controlled by the nuclear core. Now let's move on to the next organelle, which is called the mitochondria, and the mitochondria is also known as the powerhouse of the cell because it is responsible for energy production. And that's why, if you recall when we were talking about the plant versus the animal, the animal has a greater number of mitochondria because it requires more energy compared to the plant cell. And as the organelle is actively involved in the generation of a molecule called ATP to run the cellular activities. Mitochondria are double-layer membrane-bound organelles with different structural properties.

The outer membrane is smooth. So this is what you see. This is a double-membrane structure, and the outer membrane is smooth. So, this is the outer membrane. What you see here is a smooth membrane that covers the entire organelle with a large number of integral proteins known as porins. So on this outer membrane, you have the proteins that are called porins.

And the porin allows the free movement of molecules less than 5000 Daltons within and outside the mitochondria, whereas large molecules or proteins move into the mitochondria through the transporter involving the signal peptides known as the mitochondrial targeting sequences. So it's not like the nucleus that anything will be allowed to get in or anything will be allowed to go out. There is a small size, like if it is a size of 5000 Daltons, that is the molecule which is going to be allowed to get through the porins, but if it is bigger than this, suppose you have 50,000 Daltons, then that protein has to go through a well-defined mechanism, which means it should have a signal peptide, and that signal peptide should be of a mitochondrial targeting sequence. So don't worry about these targeting sequences and all these kinds of terminologies because we are going to discuss that. The inner membrane is folded into a membrane projection called the cristae.

So what you see here is the inner membrane, which has been folded in the form of the cristae, and the cristae occupy a major portion of the membrane and house machinery for anaerobic oxidation as well as the electron transport chain to produce ATP. Due to the presence of the inner and outer membranes, the mitochondria can be divided into two compartments. First, in between the inner and outer membranes. So this is the compartment, right, and it is known as the intermembrane space, while the second compartment inside the inner membrane is known as the matrix.

So this is the matrix that you see here. The protein present in the intermembrane space has a role in executing the program of cell death or apoptosis, which we are going to discuss in subsequent modules. Matrix is the liquid part present in the innermost part of the mitochondria, and it contains ribosomes, RNA, DNA, and enzymes to run the Krebs cycle and other proteins. So this portion that you see is called the matrix. The matrix is actually going to have the cellular machine; it contains the ribosomes so that you can have protein production. Because you know that the mitochondria have their own mitochondrial DNA, it can do transcription and translation, and that's how it can produce proteins.

Then it also has the RNA, DNA, and the enzyme for running the Krebs cycle and all of the proteins. Mitochondrial DNA is circular DNA. It has a full machinery to synthesize its own RNA, which means it can synthesize messenger RNA, ribosomal RNA, as well as transfer RNA and proteins. A number of differences exist between the mitochondrial DNA and the DNA that is present in the nucleus. One of the classical differences is that mitochondrial DNA does not contain introns, so it does not contain introns compared to the DNA that is present in the nucleus.

Now let's talk about the ATP-generation machinery. So this is the ATP generation machinery that is present in the plasma membrane, and the system that produces the energy is called the electron transport chain. which is actually a very, very large complex, and that's why these are labeled as complex 1 to complex 5, and these are all complexes that are integral proteins and are present in the inner membrane of the mitochondria. During the metabolic reactions such as glycolysis, the Krebs cycle produces a large amount of reducing equivalents in the form of NADH and FADH<sub>2</sub>. The electron transport chain processes the reducing equivalents and the flow of electrons through the different complexes. So what happens is that the electrons are moving from complex 1 to complex 4, and that causes the generation of the proton gradient across the membrane.

So what happens is that it is actually going to accumulate a large quantity of protons, then the protons expelled into the intermembranous space return to the matrix through complex 5. And this is what you see here: the complex 5, which is called ATP synthase. What happens is that when the electrons move from complex 1 to complex 4, they are throwing protons from this side to that side. And that is how there will be an accumulation of the proton, and then when this proton comes back to the matrix side, it is utilizing this complex, or this ATP synthase, and because of that, the ATP synthase is coupling the ADP plus Pi to generate the ATP, and that is because ATP synthase is a very, very big complex. It has the F1 unit as well as the F4 unit, so ATP synthase is a mushroom-shaped multimeric protein complex mainly composed of two proteins, FO and F1.

FO is a membrane-bound portion. So this is the FO, which is a membrane-bound portion, and F1 is the complex present in the lumen towards the matrix. The FO-F1 complex of mitochondria harvests the proton motive forces to catalyze the phosphorylation reaction responsible for generating ATP. Now, what are the different reactions? What are the

different functions of mitochondria? So, the first and most important function of the mitochondria is that it is involved in ATP production. Then the second is that it is actually responsible for the generation of reactions of species to kill the infectious organism. So when there is an injury to the infectious organism within the mitochondria or within the cell, it actually induces the production of reactive oxygen species.

Reactive oxygen species (ROS) refers to any molecule that actually contains a single electron. So, because of this single electron, they are very, very toxic. Right? So, because they are toxic, they are actually being used as a weapon to kill the microorganisms. Then the mitochondria are used to track the tree of a family. If you see how sexual reproduction occurs, during sexual reproduction, you have the two species, the sperm, and the ovum.

Ovum is actually a complete cell; it contains all other organelles, including the mitochondria, whereas the sperm contains only DNA and lacks all other organelles. So when there is a fusion of the sperm and ovum, it takes the DNA part from the sperm, whereas it contains all other organelles from the ovum. So, because of that, when the zygote is being developed, it actually contains the mitochondria, and that mitochondria is from the mother's side. Mitochondria remain constant because even if this particular individual undergoes sexual reproduction, the mitochondria will carry forward, and that's why you can use the mitochondria to track the family tree. Then the mitochondria also have a role in programmed cell death or apoptosis.

So apoptosis is what we are going to discuss in the subsequent modules, but I have provided a very short write-up to help you understand what apoptosis is. So apoptosis is a programmed cell death involving a series of events involving cellular metalloproteases known as caspases in an adverse event of exposure of the cell to a cytotoxic agent or to environmental conditions. It activates the cell surface signaling to activate the cytosolic proteases; in addition, it disturbs the mitochondrial membrane potential to cause the release of a protein called cytochrome c. As you remember, right when we were talking about the transport of material within the cytosol and outside, we said that the porin only allows the 5000 dalton proteins, right? But if there is a membrane potential problem, if there is a drop in the potential, then that will allow the leakage of proteinaceous substances from the mitochondria, and one such protein is called cytochrome c. And once cytochrome c is released from the mitochondria, it actually activates the different types of DNAs, and that's how the DNAs destroy the DNA present inside the nucleus.

And ultimately, it is going to destroy that particular cell, and this is actually a very programmed death, and that's why this is called apoptosis. Now let us understand the first process of how the mitochondria actually synthesize ATP. So to understand and explain this process, people have put forward a theory called the chemiosmotic hypothesis. So what it says is that the F1 particle, so you remember it has two particles: one is the FO particle and the other one is the F1 particle. FO is the integral membrane protein that is solely responsible for holding the F1 and also provides the path for the protons to enter.

Whereas the F1 is actually a multimeric protein complex that contains three different proteins. It contains a protein called the alpha subunit, the beta subunit, and the gamma subunit. So this is the gamma subunit that is present in the center, and the function of the gamma subunit is that it actually only transfers the complexes from the alpha to the beta. So what you see here is that these alpha and beta proteins, or the subunits, could be present in two different conformations: either they could be present in the loose binding conformations or the tight binding conformations. So when they are present in the tight binding conformation, they will bind that particular molecule very tightly.

So, what will happen at the beginning? In the beginning, the ADP and Pi are actually going to come and bind to the loose binding site. So once they bind to the loose binding site, the gamma subunit is actually going to take these molecules and put them into another subunit, and once they reach another subunit, the ADP and Pi are actually going to mix with each other, and that is how they are actually going to form the ATP. As soon as it forms ATP, it will again be flipped to another subunit, and that subunit is an open complex, and that is how it will actually release ADP, and then it will take up new molecules of ADP and Pi. So, this cyclic event is going to continue for many rounds, and that is how it is actually going to keep giving you ATP synthesis. So I have requested one of the professors in the MRC, and based on my request, I think he has shared a movie that actually explains these processes very nicely.

So Professor Walker, we should be very grateful to him for sharing these very good animated schemes. So in this scheme, they have shown how ATP synthase is actually synthesizing ATP utilizing the different types of complexes. So, what you see here in this movie is what you see here. These are the membrane-bound structures, and this is what you have: an integral protein. So what you see here is that this cyan color portion is actually the FO particle, and all these you see here are F1 particles.

This is what you see: the gamma chain, whereas this blue and yellow is the alpha chain, and this is the beta chain. So, what you will see is that when it is utilizing the proton motive force, it is actually rotating, and when it is rotating, it is actually accepting the ADP and Pi, which are in the loose binding site. And once the loose binding site is rotating, it converts into a tight binding site, and that is how the ADP and Pi are mixed together, generating the ATP. Again, there is a rotation, and because of that, it will get converted into the loose binding site, and that's how the ADP formed in the previous cycle is going to be released. So this is a very, very good movie to understand the whole process, and that's how you will be able to, you know, appreciate how these events are actually happening.

So what you see here is actually showing how the ADP and Pi are combining with each other. So you see these are different bonds through which the ADP is combining with the Pi, and that is how the ADP is formed and how it is actually released from the system. So this is all about ATP synthesis and its mechanism by ATP synthase. And what we have discussed so

far is that we have discussed the eukaryotic cell, and within the eukaryotic cell, we have discussed the differences between the eukaryotic cell and plant cells. And then we have discussed the nucleus, we have discussed the cytosol, and we have also discussed the mitochondria.

Now, in our subsequent lecture, we are going to discuss some more organelles from the eukaryotic cell, and then we are also going to discuss some more interesting aspects related to the cell. So, with this, I would like to conclude my lecture here. Thank you.