Bio-energetics of Life Processes

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Lecture - 20
Mitochondria and Chemiosmotic hypothesis

Welcome back, to the 20th lecture which is the 5th lecture of the 4th week on bioenergetics of like processes. So, as of now we talked about light dependent way of ATP synthesis which happens in photosynthesis and we talked about the 2 photosystems and water splitting manganese cluster. And the proton gradient which is created across the thylakoid membrane and which eventually results in activation of ATP synthesis to synthesize ATP by coupling a ADP molecule with phosphate.

So, today we will conclude with another form of ATP synthesis which happens in the mitochondria, which is independent of light. The basic framework is pretty much similar and the basic framework is driven by a set of initially when it was formulated it is called hypothesis called chemiosmotic hypothesis proposed by Peter Mitchell around 1960's followed by the experiment by (Refer Time: 01:38) which we have already discussed where we have shown the pH gradient could lead to the formation of ATP.

There is one thing which I mentioned that, the gradient which is created across the thylakoid membrane in the chloroplast was exclusively because of the pH difference. A higher number of proton on one side and lower number of proton on the other side, but in the case of mitochondria that potential drop is not only pH dependent, but also there is a potential difference across the membrane. So, it is the summation of 2 different potential drop one is the pH the other one is the across the membrane.

So, we will talk on this so, to start off with let us talk about the structure in very brief about mitochondria all of you have must have studied this is our lecture 20.

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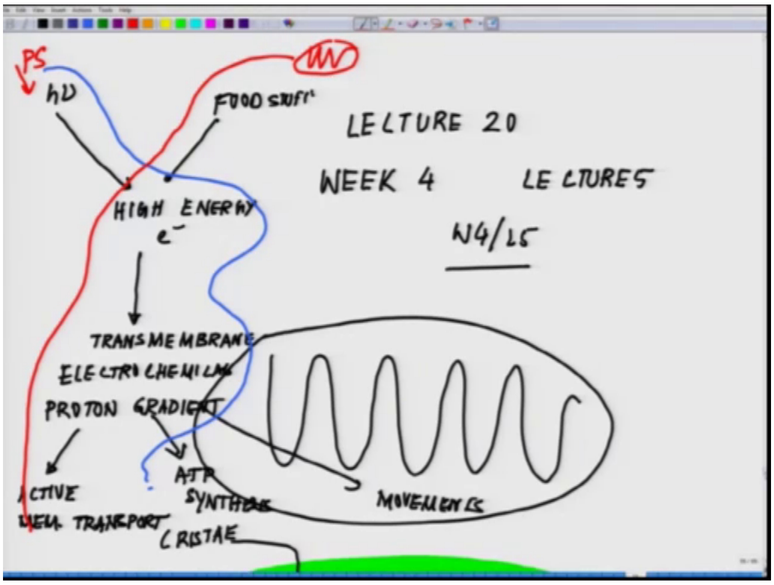

Week 4 lecture 5 W4 l5 and mitochondria. Whenever, we draw the mitochondria in any textbook, you will see something like this. This is how the mitochondrial structure is being drawn and if you kind of go at a slightly higher magnification of this image, it will be something like this.

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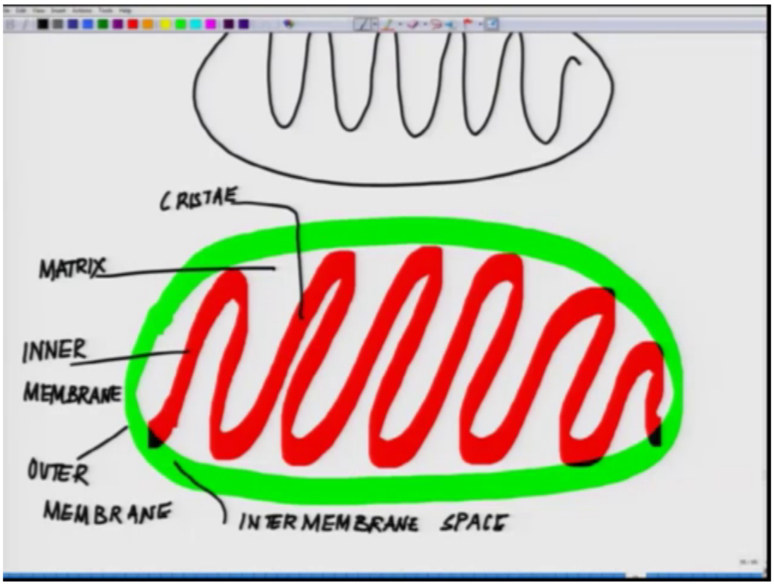

Right if this is the outer membrane of the mitochondria outer and the inner of course. Then, you have the inner force are like this something like this. So, this is the overall structure of the mitochondria and if you look at this structure, a little bit more carefully, this is the area which is called the matrix of the mitochondria. Ok then, you have the inner membrane which is this one, the inner membrane then you have the outer membrane which is this one and then you have inter membranous space ok.

So, this is how more or less the mitochondrial structure looks like and the inner membrane is folded into these are called cristae. This is precisely how it looks like and mitochondrial oxidation begins with large amount of acetyl coenzyme a and are produced in the matrix of space from fatty acids and (Refer Time: 05:10) we will come later on to that. And where we are starting the whole matter is something like this.

So, you have sunlight, here foodstuff both of them results in high energy electrons. These high energy electron leads to trans membrane, this is what I was discussing in the beginning; trans membrane electro chemical proton gradient. And this proton gradient leads to active membrane transport, this leads to ATP synthesis, this further leads to different kind of movements.

So, the major chunk. So, what you have as of now I studied is this part. Now, today we will be studying about this fragment same. So, here this is what we talked in photosynthesis; here we will talk about what is happening in the mitochondria ok. So, this is what is the overall framework of the mitochondrial structure Now, what is chemiosmotic hypothesis or chemiosmotic coupling? So, although we know that the citric acid cycle constitute part of the aerobic metabolism. None of the reaction.

So, if you look at the mitochondria what is happening in mitochondria what is the aerobic reaction what is happening. So, if you look at the mitochondrial structure let me draw it. So, that we will remember it.

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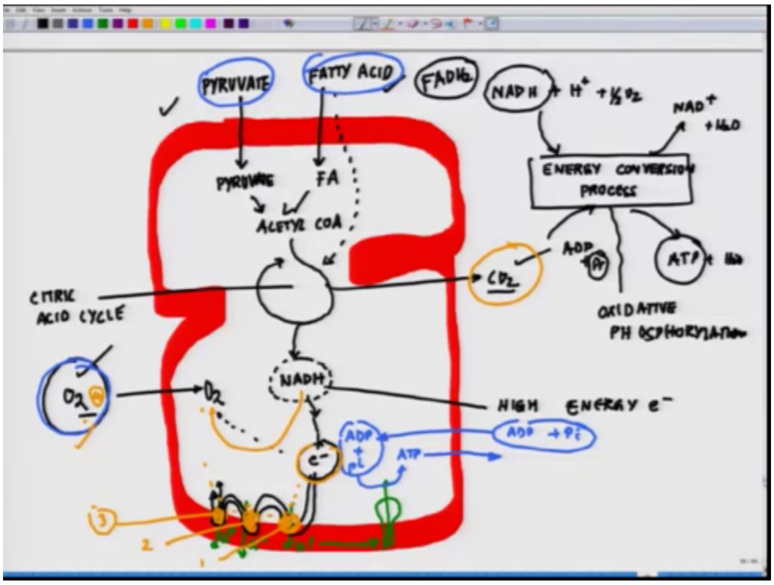

So, this is how the mitochondrial structure what is happening in in those inner and outer spaces ok. Now, so, you have the pyruvate, you have the fatty acid; this pyruvate and fatty as fatty acid enter the system where I am just showing fa as fatty acid. There it form acetyl coenzyme a that was I was telling you. Acetyl coenzyme a took part into the citric acid cycle or the Krebs cycle, the citric acid cycle and citric acid cycle liberates out carbon dioxide ok.

This goes out of the mitochondria and out of outside the body and this is where all the carbon dioxide is being generated, but this process produce something called NADH. This NADH moiety, now here is the catch and in this process, there is this oxygen getting into the system. The mitochondria takes up oxygen and gives out carbon dioxide unlike photosystem where CO2 is being taken and oxygen is being produced. So now, this oxygen does some wonderful things and this is where we are going to come we will finish this drawing.

But before we finish this drawing, we will talk a little bit more about chemiosmotic hypothesis that will kind of give you an idea. So, basically what you are observing here? This is a summary of flow of major reactants into and out of the mitochondria. So, these are those major reactants which are going and these are this is which is the output ok and this is another input. So, you see 3 inputs, but we are mostly concerned with this input what is happening to this input pyruvate and fatty acid enter the mitochondria and are metabolized by the citric acid cycle as you could see here.

So, these are entering and these are taking part in the citric acid cycle which produces NADH. So, this is the product of citric acid cycle 1 second ok. Now, what is happening to that NADH? In the process of oxidative phosphorylation. So, here the oxygen is coming and this is taking part in a phosphorylation process in the process of oxidative phosphorylation high energy electron from NADH. So, this is the source of high energy electron. So, in the process of oxidative phosphorylation high energy electrons from NADH are then passed to oxygen by means of a respiratory chain in the inner membrane.

So, essentially what is happening? The electron from here is passing through the electron transport chain like this. And in that process this oxygen which has entered. So, in the process of oxidative phosphorylation high energy electron so, here is that high energy electron coming from NADH are then passed to oxygen. So, this is actually getting transferred to oxygen, but why this route you follow the route out here through a respiratory chain oxygen by means of respiratory chain in the inner membrane producing ATP by a chemiosmotic mechanism. And in that process at every step there is a generation of a proton gradient H plus, H plus, H plus and this H plus leads to the formation these H plus ions.

Now, remember this structure I showed in the last class ATP synthase ok. Now, this ATP synthase transfer that H plus ions and out here, you have ADP plus P i leading to formation of ATP and this ATP is being sent out. So, and this ADP and P i from where these are coming? These are all again coming from outside ADP plus P i these are trans located.

So, if you look at the inputs which are coming inside the mitochondrial matrix are pyruvate, fatty acid, oxygen, ADP and P i and what is giving out? Given out by it is CO2. So, I am just put different color for you to understand. Ok NADH generated by glycolysis or the citric acid cycle in the cytosol also passes electron to the respiratory chain. Since, NADH cannot pass across the mitochondrial inner membrane; the electron transport from cytosolic NADH must be accompanied indirectly by means of one of the several shuttle system that, transport another reduced compound into the mitochondria after being oxidized this compound is returned to the cytosol where it is reduced by NADH again ok.

So, electrons are transferred so, this electron what you see out here, this electrons are transferred from NADH to oxygen from NADH to oxygen through 3 large respiratory enzyme complexes. So, these are those respiratory enzyme complexes which are present here. So, it is it kind of hops through it and what is the significance of this hopping that is what I am going to come through. And the most important of these proteins are grouped into large respiratory enzyme complexes each containing trans membrane protein that hold the complex firmly in the mitochondrial inner membrane.

Each complex in the chain has greater affinity for electron than it is predecessor. And the electron past subsequently from one complex to another until they are finally, transferred to oxygen which has the greatest affinity for the electron. So, essentially what we are talking about? If we arrange these complexes in terms of their redox potential we will observe each one of them. If if this is the third one, if this is the second one, if this is the first one; this one this has more affinity, the second one, the third one is the highest and the fourth one; oxygen has the maximum affinity for for the electron to be picked up.

So, each one of them has a higher potential to pull up the electron. Realizing so, going by the redox potential graph if we look at it what we have done for photosynthesis. You will realize in the respiratory transport chain exactly follows the same module, where every protein complexes which are present there has a different affinity for electron. So, the 3rd one what I am just showing hypothetically here has the highest affinity, but even more higher affinity is with the oxygen ok. This is how the electron get transported to the oxygen well what is the significance of this? Why nature does something like that? Now on a simplistic node if you have to put it.

So, this is something which is happening here NADH, plus H plus plus half O2 ok. It is coming here into the energy conversion process here you are having the energy conversion process. this is leading to NAD plus plus H2O and out here the ADP plus P i generating ATP plus H2O this process is oxidative phos phor rylation because it is phosphorylation because you are adding a phosphate group the major net energy conversion is catalyzed by the mitochondria in the process of oxidative phosphorylation the mitochondrial inner membrane serve as an elec energy conversion machine changing part of the energy of NADH and FADH2that is another one which takes part into it FADH2 oxidation into phosphate bond energy in ATP. So, this is what essentially is happening in the mitochondria ok?

Now, why nature follows this peculiar mechanism? So now, here is an analogy why nature does it nature does some very clever and tricky things. So, if you look at this reaction in real life suppose.

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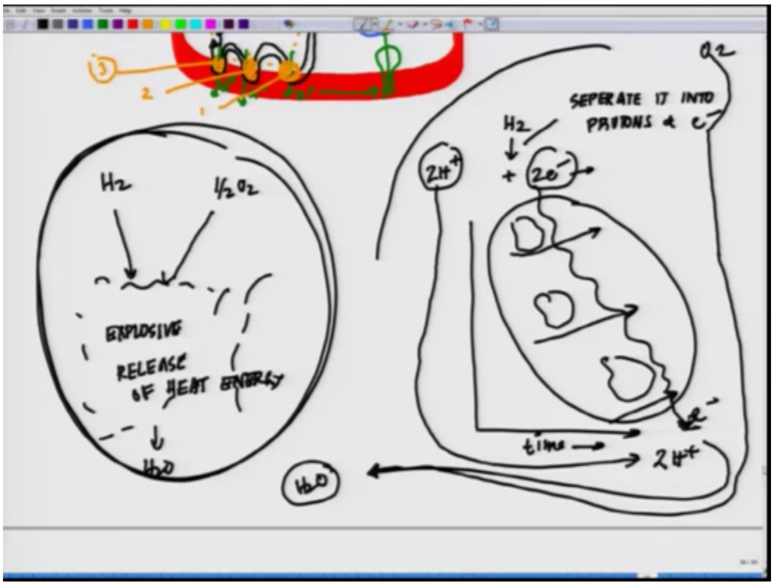

You have hydrogen you have half oxygen and you allow them to react, this will be a reaction which will like you know do not want to see this is a explosive release of heat energy to make water; explosive release of heat energy to make water ok. Now, what is happening here? Think of exactly the same situation you have H plus half O2 is making water.

But this is not that of an explosive reaction why is it so? Now, what nature is doing is something very interesting. Nature is following up this reaction in a very different way. It is picking up H2 and after picking up H2, what it is doing? It is doing something like this 2 H plus plus 2 electron ok. Separate it into protons and electrons, separate it into protons and electronsand then allowing this to roll through different proteins of different electron capturing ability. And allow these 2 electrons do you know flow through slowly ok. And eventually what is happening this 2 H is through this proton gradient is coming whereas, the electron is reaching from here 2 electron plus 2 H plus. And this eventually leads to the H2 and here is that half oxygen which is coming from coming inside the mitochondria leading to formation of H2O.

So, if you compare this reaction and if you compare how the biology does it then you realize biology exactly does the reaction, but in a slightly different way. In this illustration basically, what we are showing? Is how most of the energy that would be released as heat if hydrogen were burned is instead harnessed and stored in the form of useful energy to the cell by means of electron transport chain. So, this is the significance of the electron transport chain in the mitochondrial inner membrane.

The rest of the oxidation energy is released as heat white mitochondria. In reality, protons and electrons shown are removed from hydrogen atom that are covalently linked to NADH or fadH2molecule. So, these are the ones which are this has become part of the NADH. So, what I essentially wanted to show? If you remember what you are buying in this whole process? You are buying time, you are allowing the electron to slowly move through.

So, in that process instead of a violent reaction like this, you are allowing the reaction to happen slowly much more slowly. And the energy released by the passage of electron along the respiratory chain is stored as an electrochemical proton gradient, across the inner membrane. And if you look at the gradient which mitochondria follows. So, this is how it looks like in mitochondria.

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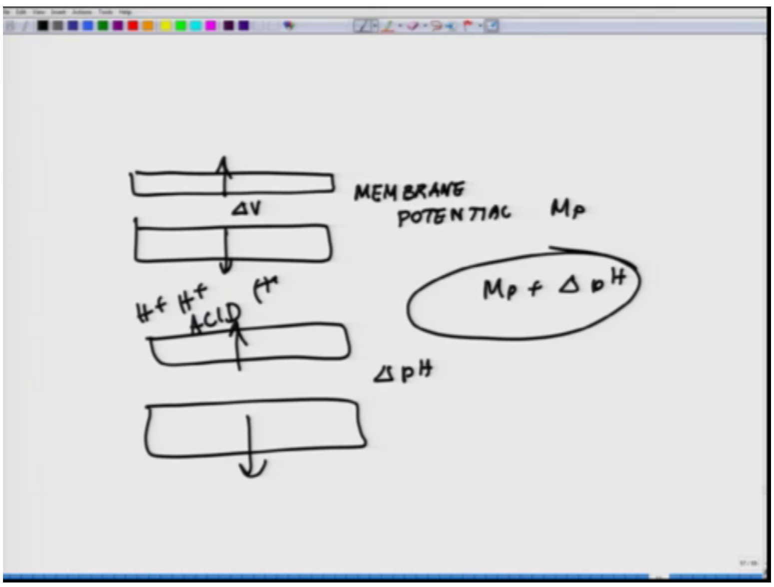

So, across it there is something called delta v, which is your proton motive force or force due to membrane potential there is an membrane potential. We can represent by MP membrane potential and you have a pH potential which is across the mitochondria because inside it is more acidic ok

Because you have lot of protons which are present there, this is the proton motive force which gives it is delta pH. So, basically membrane potential plus delta pH is the one the 2 component of the electrochemical proton gradient; the total total proton motive force across the mitochondrial inner membrane consists of large force due to membrane potential. And the next one is by the concentration gradient which is delta pH, both forces act to drive the protons into the matrix space. And energy stored in the electrochemical proton gradient is used to produce ATP and to transport metabolites and inorganic ions into the matrix space that we have already talked about.

So, if we look at the chemiosmotic coupling now in the light of this. So, chemiosmotic hypothesis as proposed in early 1960s consisted of 4 independent postulate. The first one is the mitochondrial respiratory chain in the inner membrane is proton trans locating, it pumps proton out of the matrix space, when electrons are transported along the chain. That we have already seen; electrons are transported along the chain like this. And protons are transported out, this is the first mitochondrial ATP synthetase complex also translocate proton across the inner membrane. You could see that the picture itself tells you being reversible it can use energy of ATP hydrolysis to pump H plus ion across the membrane.

But if a large enough electrochemical proton gradient is present, proton flow in the reverse direction through the complex and drive ATP synthesis ok. The third one is the mitochondrial inner membrane is impermeable to H plus and o H minus and is generally anion and cations. And the mitochondrial inner membrane is equipped with a set of carrier proteins that mediate entry and exit of essential metabolite and selected inorganic ions that we have already discussed.

So, this is essentially is the core of the energetics processes, which are involved in the biological system or in the life processes. Starting from so, we start with chemo synthesis, photosynthesis and then we talked about photophosphorylation in chloroplasts and now we talked about oxidative phosphorylation in mitochondria. These are the most fundamental reaction which governs what we call present day life forms.

Thank you.