**Indian Institute of Technology Kanpur**

**National Programme on Technology Enhanced Learning (NPTEL)**

**Course Title**

**Bioenergy**

**Lecture – 11**

**Electron Transport Process in Light Reaction**

**By**

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**IIT Kanpur**

Welcome back to the lecture series on viability.

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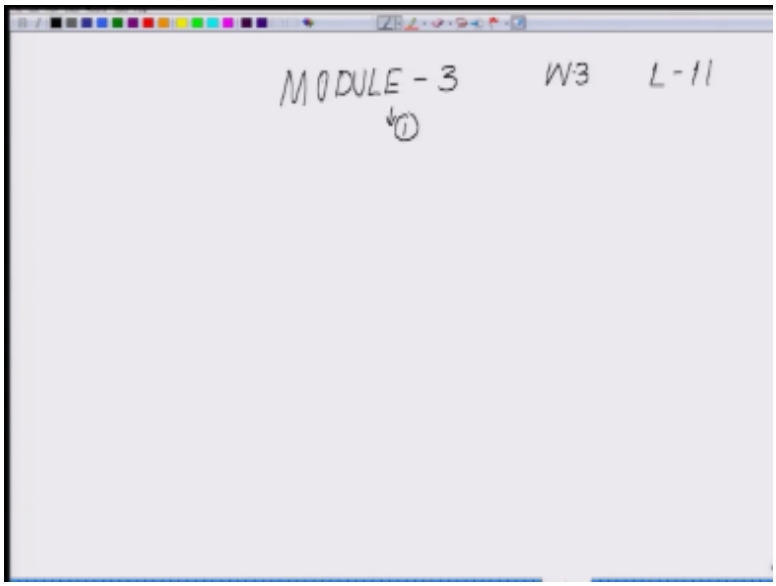


So to start the third week so we are into module 3 which is also week 3 w 3 and in sum total this is the eleventh lecture and in module three this is first lecture of module 3 okay so in the last class when we concluded our lecture we talked about the complete outline what we will be discussing so the first thing what we will be discussing today's in today's lecture will be the outline of electron transport from for the system two to system 1 then we will talk about the how the physical structure of the photo system looks like third we will talk about splitting of the water add water splitting clusters and in between we will talk about the formation of ATP because of the proton gradient which is created across chloroplast membrane or thylakoid membrane okay. So let us get back to the slides.

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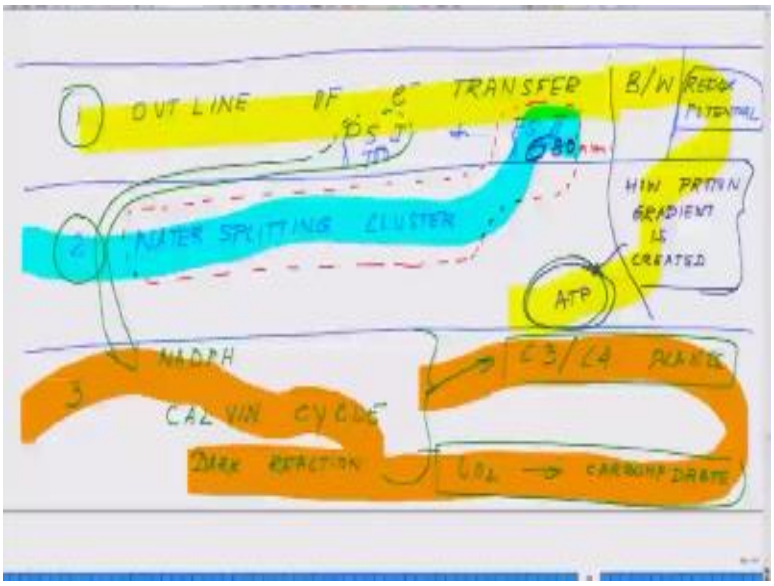


So this is where we ended our slides last time so this is what we decided we'll be talking about the outline of the electron transport followed by the formation of the ATP water-splitting clusters and after that we will talk about the dark part of photosynthesis which is a dark cycle o the calve in cycle but today we will be concentrating on those three aspects the electron transfer and the physical structure of the photo system followed by ATP formation and concluded by what is fitting collector.

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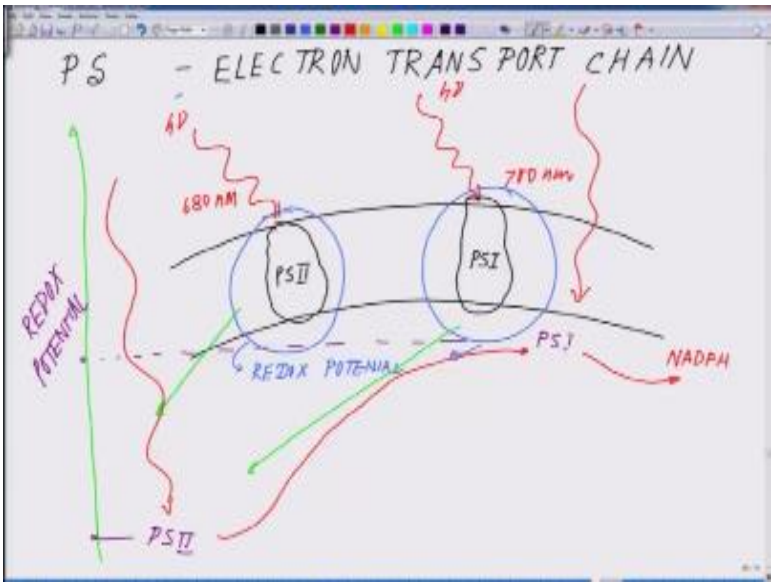


So let us start again so electron transport chain in photosynthesis left r on class fourth chain so this electron transport chain while we talking about the way I will explain this transport chain is based on the red ox potential so we have already told just to have a recap that for the system one and for two system two are sitting at two different locations on the Tyler Cloyed membrane so essentially to say so if you look at the slide so it is something like this if this is the thylakoid membrane.

So say for example here you are having photo system 2 and at a physically different location you have for the system 1 this is the first thing what we have described about their differences if I had to enumerate all the differences the second difference is something to do with absorb absorbance of light so one of them is all the way up to 700 the other one is at six 80nanometers maximum it can absorb so this is the second difference there is a third difference and the third difference lies this whole complex is sitting at a different red ox potential as compared to this what does that physically mean.

That means that the overall electron accepting power or electron donating power of photo system 1 is different from photo system 2 and such difference arises because of the complex and its surrounding environment what kind of proteins are surrounding it what kind of charge moieties

are present in those protein and what are their electron donating or a electron accepting power decides that what will be the red ox potential so today what we will do we will map these two systems so we will plot them on an axis like this where y axis what I am drawing now we will talk about the value of the red ox potential okay.

And so what we observe that for the system to is sitting at a much more different red ox potential as compared to the red ox potential of photo system 1 so examples for system one is sitting here okay then we will of course assign the values and everything and then we will observe how when the light for example light is falling on photo system 2 and photo system 1 how the electron is traveling and you will see it is an up sell transport how the electron is travelling and finally how the electron is being funneled form for system one to form the NADPH so this whole journey of electron we will be mapping on the basis of the values of the red ox potential of each one of these complexes which are present out here and will enumerate all the different kind of proteins and the different components which are making this whole electron transport chain present in the photo system.

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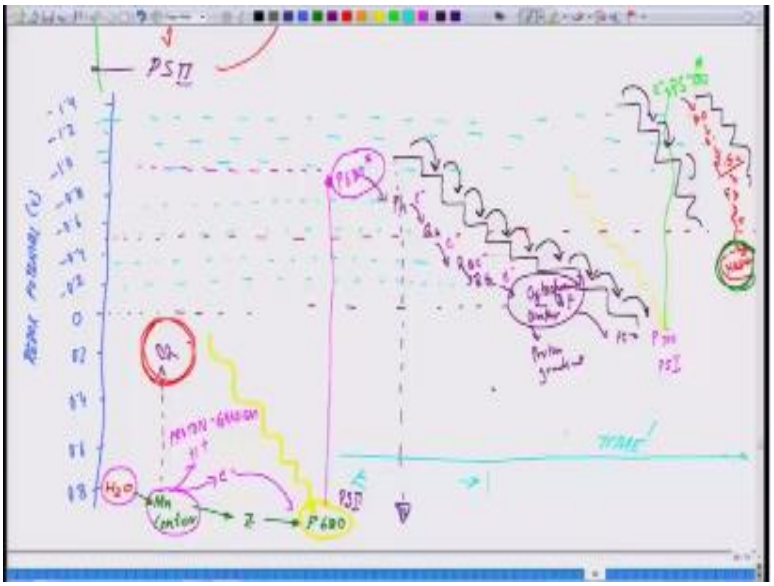

So moving onto the next slide in order to map as I told you who I am just putting the values now so you have zero then you have to point to 0.4 0.6 0.8 and this is your y axis which is the doc potentially involved okay enforce now above zero exactly same way this will go on so you got in the positive values so minus 0.2minus 0.4 0.6 minus 3.8 minus 0.8 minus1 1.2 1.4 likewise 144 okay, so the scale is now ready now if you look at the red ox potential of water red ox potential of water is how out here.

Now we are just placing the different component which are involved in it okay very interestingly as I told you the in the photo system 2 it is something called a manganese cluster which will be talking about the water splitting the red ox potential of manganese cluster is more positive than that of water what does that physically means that physically means manganese cluster can pull the electron from the water much more easily so if I had to place the manganese cluster in this scale you will see the manganese cluster of the sitting somewhere out here yeah.

So somewhere out here you have the manganese center or manganese cluster whatever you call that which has so the electron will flow like this give in a situation we will talk about that wide electron flows like that and from here there is a complex called z it complex and this is where it can this is thep680 or the photo system 2 we remember we talked about in the just earlier we talked about that one second.

So p680which is essentially showing the photo system 2 so what is happening here is again coming back to the name so light is falling light falls here once the light falls here after this series of electrons are excited and they are excited all the way up to almost up to100 other somewhere out here so this is where the e 680 excited state electron chlorophyll start setting so there is an electron so light falls on the chlorophyll molecules at 680 at for the system to the electron is rejected this electron all the way move having a Rodolfo potential of minus 1 volt okay so it has all already shoot up.

so now what is the situation is that atp680 you needed electron in order to bring that chlorophyll molecule back to its ground state because the chlorophyll molecule is now devoid of one electron that electron is supplied from water molecule out here this is water molecule which is getting

trapped in the manganese cluster in the manganese cluster what is happening is there is electron which is generated which move here it generates proton we generate the proton gradient which leads to the proton gradient and the byproduct of this whole process is oxygen and we will talk about this reaction how this reaction happens okay.

But essentially what is happening from the water the electron is being taken up by the manganese cluster and is funneled to photo system 2 which is out here so the electron which was rejected by the chlorophyll molecule of photo system 2has reached a reduction potential of minus1 volt but that chlorophyll molecule which lost that electron comes back to its ground state because the electron is supplied by the water molecule.

So once again just follow me so p680 which is for system to gets excited the chlorophyll molecules eject out electron the electron travels all the way to minus one electron volt of minus 1 volt of red ox potential the chlorophyll molecule which is now devoid of for which is almost oxidized because of losing an electron is brought back to its ground state by obtaining an electron who supplies that electron simultaneously underneath sort a system to there is something called a manganese cluster or our water splitting clusters.

Which traps the water molecules squeeze out the electron supplies it to photo system 2 and in that process it generates a bunch of protons which creates a proton gradient and simultaneously the output of that reaction is there is oxygen which is liberated out okay sup to the cities clear now what is happening to this electron which is gone all the way up at minus 1 electron volt now let's follow me with the slides so from here it is starts donating the electron to a nearby just let me mark the zero that will be easy for me to follow.

So it donates the electron to a nearby molecule called Co fighting ph okay from here it donates to QA and I will tell you what exactly that does that mean from here it is donating to QB then it comes to qh2 these queues are nothing but these are called Queen owns okay and from there it comes to something called cyto chrome B F complex so this be actually BF complex and which is also involved in creating a proton gradient from here it is and by this time you must be

observing that it is it is almost reaching from minus 1 electro- 1volt it is almost reaching point 2 volt okay.

So three two plus two sign in the plus to sign in funnel so in this process what is happening to try to understand it so out here the electron which moved and its closest proximity there is a protein called 30 fight in few fighting gets reduced by obtaining that electron soon as it gets reduced it transfers this electron come back to its ground state by supplying it to Queen own Queen on get reduced then queen on supplies that electron to QB again comeback to its ground state similarly from QB it moves to qh2.

So what is happening is that in this whole process there is an electron which is hopping down and the molecules which are sitting out here are getting oxidized reduced of reduced oxidized reduced oxidized reduce oxidized likewise reduce and coming back to ground state reduced coming back to its ground state reduced coming back to its ground state it is accepting an electron and in that process it is getting reduced and then coming back.

So this whole thing so you can imagine it is almost a continuous aware of different kind of proteins which are present there which has the ability to accept electron recalls because you have to look on your left hand side on this they are all sitting at different kind of red ox potential and they are in physically close proximity so that is one of the things which have to keep in mind that this red ox potential ensures that their electron accepting power is different from each other.

So instead for the electron to jump from pre 682 q a is occluded because in between there is physically another protein which is setting which is co fighting which has a different red ox potential which allows it to extract the electron much more faster much more better than the next one so what is happening is that in this whole process the electron is following a staircase as if the electron is jumping the staircase is the way we jump through the staircases but now think of it the electron could have followed another trajectory electron could have moved like this it does not do like that and what is the significance of it will come later into it okay.

In that whole process so while this is happening simultaneously another thing has already happened at 42 system1 so here we have the PS p700 or for system 1 ps1 okay so simultaneously light also had fallen there and the electron from here which is rejected out went all the way up to almost 1.4 – 1. 4 p.s 700 so this is the electron which is once again okay this is where the electron is sitting okay now this electron again follow the cascade exactly the way this cascade you see so okay fine I will take care of it here okay.

From here it is given to an electron acceptor a zero and by the time this happens let me just throw another line which will help in to kind of you know okay because knap finally when it happens it is around point four so a 0 to a 1and then it comes to something called iron sulfur cluster there is an iron sulfur FX or iron sulfur cast clusters from there it moved to something called far red ox in FD from there it comes to ferredox in p and some here it is given to nadp.

So this is the n strongest reluctant which is formed it so you remember I told you that there is a strong reluctant in the form of nadph which is from this there is a strong oxygen in the form of if you follow here this is that strong oxidant which is form here this molecule is the strong reluctant which is form here and there is another thing which is formed because of the proton gradient so now what I will do so again if you look out here he will observe the same thing which have been followed by nature as if there is a staircase model of electron hopping down like this and each one of these proteins is you again map them if you have any confusion if you map them you will see on the scale they are standing at a different red ox potential okay.

So this is very critical it's kind of a basic fundamental understanding which I want you people to imbibe that the way nature has designed this machinery is an amazing it is not a continuous thread of our continuous aware like a copper or aluminum at these are proteins which are sitting at different red ox potential each one of them has a different power to accept and donate electron such that the electron which is coming will prefer this one followed by next one and they're physically like that.

So the electron that's why I was trying to tell you electron cannot jump back like this but what is the advantage it is getting by doing so now the advantage is in front of you think of it that if

electron would have safe example and just a when you take between4001 and forth system too if you see this distance from here to here if the electron has gone up and similarly gone down when the time window of this event would happen this much whereas here what you see the time window has gone.

So there is a time you are getting a lot of time in this whole process while you are along the electrons though it is speed wise it is a slow process but why nature followed such a slow process instead of making it a fast process you can think several of course I mean what nature thought we do not know but we can speculate one of the biggest advantage by allowing the electron to you know trickle down like this you are increasing the time so in other word you are increasing across the membrane you are increasing the time it's something like by allowing the electron to you know hop down like this.

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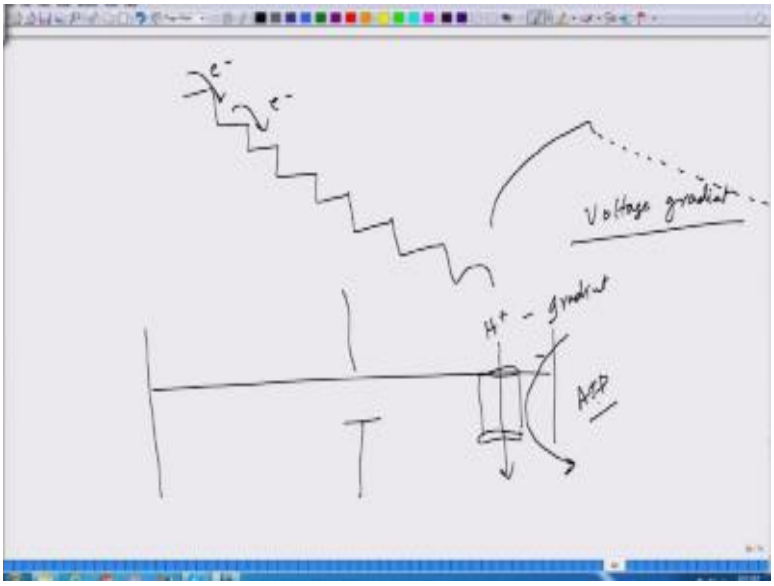


In a staircase model electron is hopping through you are increasing the time window across the membrane in a way that you know as if there is a battery which is getting charged and it is getting discharged like this so the time window helps it to maintain a polaric polarity across it for a longer period of time simultaneously this polarity helps to funnel the protons across in a

gradient because you are maintaining a voltage gradient across the membrane by allowing the electron to move slowly and this helps to maintain a proton gradient and which essentially leads to the formation of the ATP molecule.

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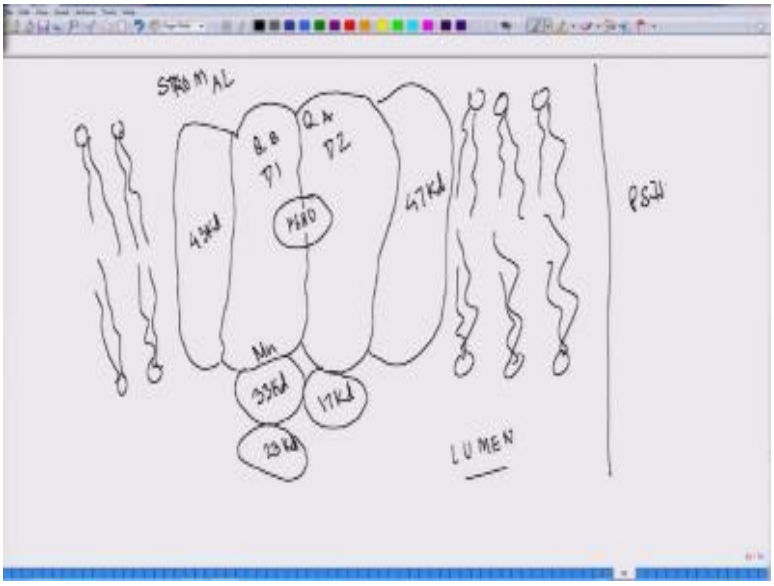


Now what we will do we will talk about the physical structure of the photo system 1 and 4system too so physically if you look at it so the physically the structure of water system to is something like this for this you people can refer to a book by stryer or even you can refer to and basic biochemistry textbook very will observe this so this is how the physically the structure kind of looks like and this is how they are sitting on the membrane.

So you can refer to strayed or lenninger or any of the standard textbook in biochemistry and or void at our void okay so this is your p680center or the reaction centers what we have already talked about these are those q1qvq a and these are different proteins so this one is called the d1 unit this one is called the d2unit and you have a 43 kilo Dalton protein the flanking there is a 47kilodalton protein flanking on the other side and this is wary of the manganese cluster sitting and underneath you have a 33 kilo Dalton protein and these there is a lot of work going on in this area to do get a single crystal of this kind of structure to add to figure out how this whole water

splitting is taking place. So this is the stromal side once again stromal side and this is the luminal side which is present there so this is what we talked about is for two.

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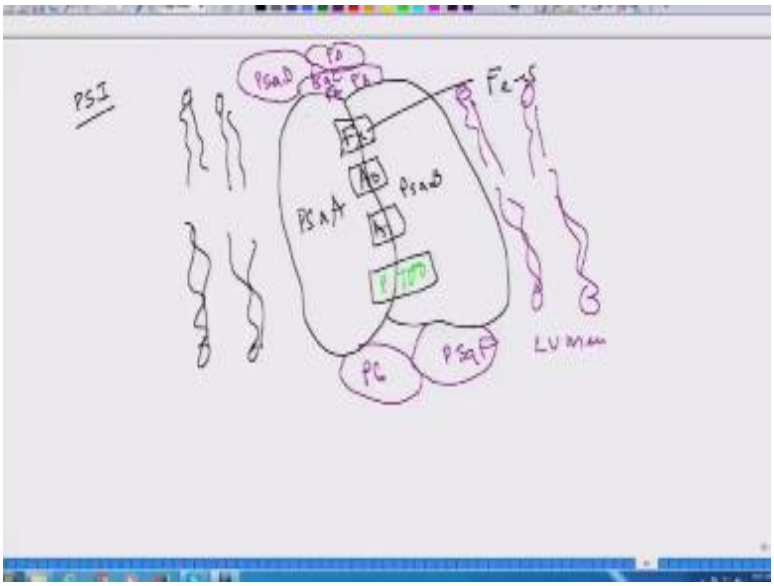


Now we look about what system one is also similar so you have these lipid membrane on which these are embedded so you have this big chunk which is called PSA a and you have other side which is PSA you have the FX which is the iron sulfur cluster which is present there underneath you have this a zero you remember this a 0we talked about here the a1 these are the electron acceptor and here is the main reaction Center t700 which is present there then underneath you have the last row sign in pc here you have PSAF and of course this is a lumen and here you have the lipid bailer which is sitting there.

And on this side you have p is a see where you have the FA and FB which is the ferredox in complexes which are present there than here sad and you have FD into the ferredox in ok so physically this is how the structure looks like and if I had to draw this whole thing in one platform it will looks something like this it is back to the slide which will help you to kind of understand how that structure will look like so okay.

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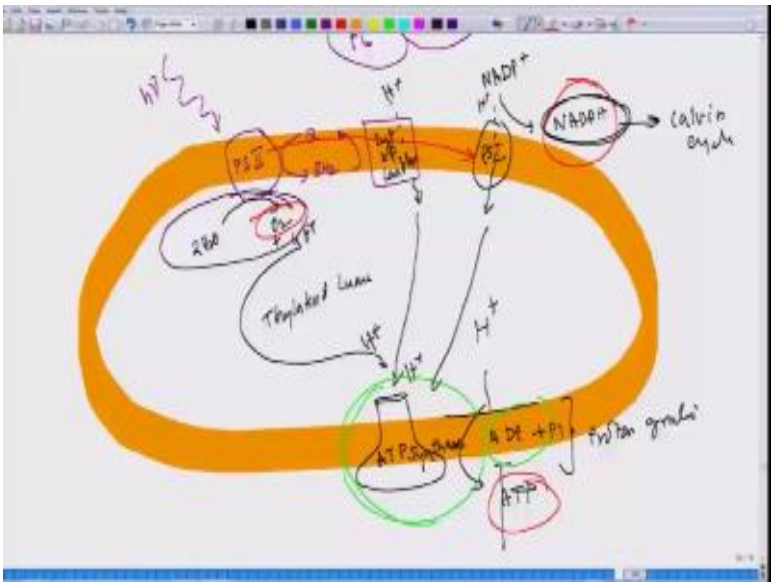


So this is how the whole Tyler Cloy membrane structure looks like hear what you are having is a photo system 2 where the light is falling H nu and this is where we known to qh2 and all the transfer taking place and so you have the cytochrome BF complex sitting in between this we have already I have shown you this whole thing on the scale of red ox potential so now I am just physically drawing it we have photo system one sitting here which generates nadp+ to nad ph which is going to the Calvin cycle or the dark cycle and out here I told you.

So there is a proton gradient which is formed here there is a proton gradient witches form here and there is another proton gradient and out here underneath it you have this 2 h2oforming oxygen plus 4 h plus which is the protons basically and this is the thylakoid lumen and underneath out here you have this interesting structure called ATP syntheses which is converting the adp plus TI to ATP and this is regulated by a proton gradient which is funneled by all sorts of protons which are coming here at h plush plus and lot of this h plus which are coming here.

So this is where the another  aspect what I was telling you is the ATP synthesis and ATP formation taking place so let us number them so you have the NADPH form here you have the oxygen form here you have ATP which is a week as well as strong reluctant is form here and out

here the electron is transferring from up here, so this is the whole scheme of things if I have to put it in one platform to see how this whole process looks like okay so let us again scroll down what all we talked about we talked about for the structure of the photo system 1 and 4 system 2we talked about their differences then we map them based on their different component on the scale of redox potential.,

And how the electron is hopping slowly from one step to another step and this step l likewise and so and so forth and now what is left for us to figure out very briefly will spend next five minutes to talk about what is happening here how this stuff is getting evolved as compared to the other stuff like because I told you that there are two processes which are happening out here so but how this process is taking place so regarding this manganese cluster to let me tell you that we thought we know a lot of things yet we do not know much about this structure because it is very tough to get a single crystal of manganese cluster it is exceptionally challenging as of now but what we know is there.

So I will just put one schematic for you what possibly happens or at least documented in that textbook and for that you people can go through the bio organic chemistry chapter in Shriver and at kin's it is the inorganic chemistry book by Shriver and Atkins and I will just put the picture for you people to have a look at it just the same way it is suggestive you can go through Stryker you can go through the Menninger they will get an idea similarly through Shriver and Adkins gives you an fair idea what is happening.

So before I draw this just try to understand what happens in this man is question so manganese cluster there are manganese there are at least four known at least move for known manganese atoms which are sitting there at different oxidation states so manganese oxidation state varies from two to all the way to six okay but here the manganese atoms are sitting and at it's very tough because we are living in an oxygenated environment most of the time you will see manganese at a higher oxidation state live at six because it is getting oxidized because in the presence of fair but in the manganese cluster these manganese sits at a lower oxidation state which is thrown an amicable to achieve.

But it does somewhere or other it does and in a close proximity there is a tyrosine molecule coming from one of those protein complexes what you see why we are drawing the for the system to and some way or other we do not know how that really happens to water molecules gets trapped into it and then what happened is that it is split up the two water molecules in a very unique way by you know moving through at least four sets of reactions and what we get an output as an oxygen coming out the byproduct and bunch of protons what we have already documented in this slide and a bunch of electrons. So I will just draw it for you.

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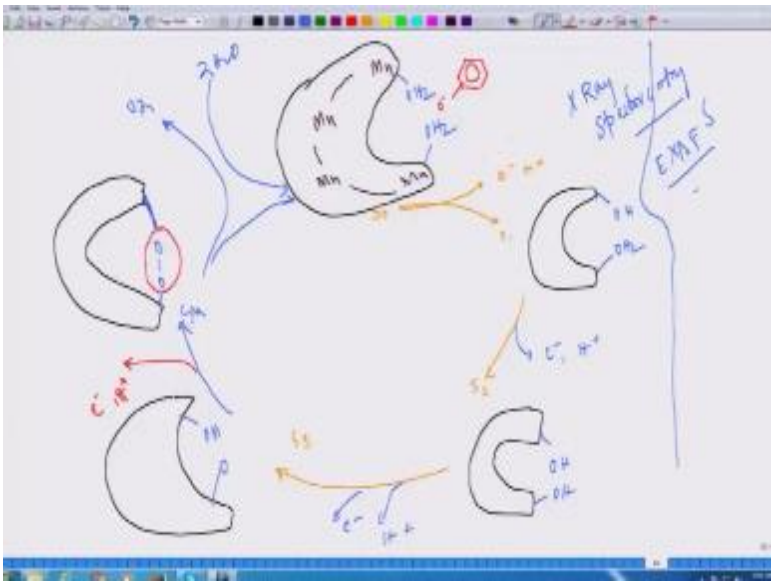

So just to give you a feel exactly how the manganese cluster as of what we know so I told you said that there are four manganese which are almost arranged in a sea kind of fashion something like this okay so these are the four manganese atom so now the water molecule so what you see here is 0 H to hear you have the oh2 and in a very close by forever try to see the CD or tyrosine residue which is present their oxygen like this ok this is the tyrosine listen I am NOT getting with a complex drawing of it.

So now so this is how it looks like and there are different stages different phases which are being numbered as is 0x1 and so and so forth so the first reaction would happen out here is electron is being ejected out and a proton is being electrically jetted out and what you see is in s1phase is you have of course a cluster sitting there so I am NOT redrawing this cluster again so this cluster will continue in all my drawings so I'm just putting it like this okay so what you observe is you have on this side you have 0 h other you have 0 h 2.

So what has happened is that one hydrogen has gone out so now next stage from here which is we are reaching into the s2 at the f2 again now looking at the structure okay and this is what you observe you have a h4 h we are into s2and in that process in simultaneously here you have another electron and another proton which has been given off now from here we will move on to s 3phase which is s 3 s 3 is again okay out here again what you are having is 0 H and a very unusual situation having an oh and while doing so there is another electron and a proton has been given up now from here we reach 2'sforces which is the final phase fit which is what we observe is they form an ox or bridge out here scrolling Oh.

Out here oh oh so this complex is where oxygen is being liberated out what you see out here this oxygen is being liberated out and while going for this is you have another electron and H + which is giving out so if I have to count all of them so the oxygen is giving out and this is where I told you that 2h to the cycle continues so 2h2o is fed to the earth two molecules of water is being fed to the manganese cluster they bound on the two ends of the seas as you could see and from thereon it slowly state those two molecules in four different this is what we know as of now but in future if a single crystal structure comes and one can see really this is what is happening then we will make more sense.

So as of now this is based on x-ray data whatever a little bit of an extra data what we have available out here so essentially most of these data are coming from x-ray spectroscopy so what it basically says that so going to the lack of the single-crystal the detailed structure of the clusters are unclear but the sea state of the bridge or m and for arrangement is indicated by the x-ray spectroscopy or it is also called y X AFF so coming back where we diverged into this whole domain I told you that there are two aspects which is very important for able to understand from

the by energy perspective one aspect is the formation of or the splitting of the water in the photosynthesis which in itself is a big domain where people are trying to emulate the manganese cluster.

Because then we will have abundant of water on earth and we can utilize the hydrogen which is liberated out from the situation and from here you can make a fuel cell by you know having those protons and passing it through Navion and all those kind of thing proton specific membranes you can make hydrogen okay that is one route we'll talk about this in the advanced technologies the other route are the part of the reaction if you remember now going back to that reaction again.

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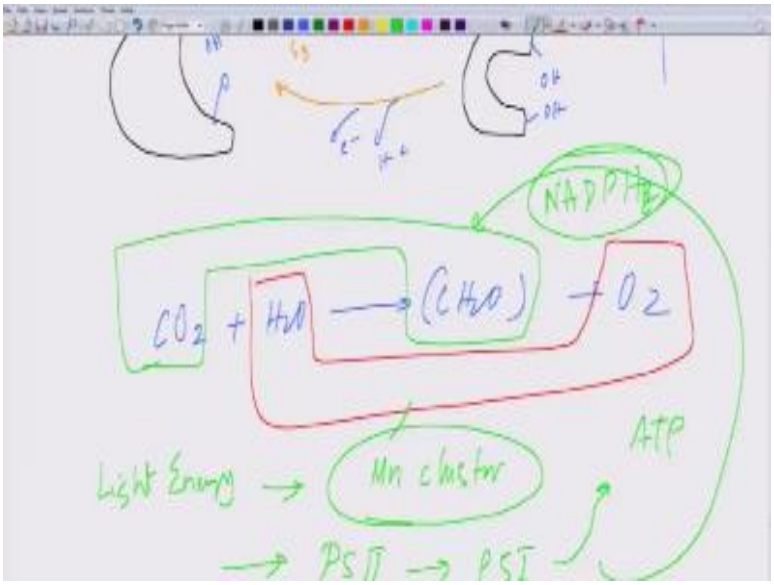


So basic reaction when we started this whole was co 2 plus h 2 CH2 o plus oxygen so now you people know how this reaction is taking place what you do not know how this reaction is taking place we will talk about this reaction next so this is what we talked about the whole manganese cluster and governing by light energy and cascading through photo system 2 240 system 1 the cascading of electron and generation of ATP and finally to run this show we have na dph okay.

So we will close in here with this overall background of the light reaction and our tail piece will be to talk about the dark reaction we will talk about how carbon dioxide is sixth which is another so there are two big one of the biggest areas in bioenergy is that carbon dioxide fixation or carbon dioxides sequestration so that falls under that part where we will talk about how theco2 molecules form those wonderful carbohydrate and what are the significance in terms of c4 and c3plants YC force are more efficient as compared to see three what are those reactions but what you have to understand here is there are two aspects to this one is the light reaction one is the dark reaction.

So now today we are concluding the light reaction of photosynthesis where we talked about the whole architecture of photo system in terms of our system one photo system two for the system to is having a manganese cluster underneath it which is of course considered as part of the photo system 2itself when the light falls through the Action Center the electrons are funneled out from the chlorophyll molecules from four system 1 and photo system 2 but having fade this will bring you to a very different kind of a are these two electrons different so you see there is one electron which is traveling out here is an electron traveling out here are of course when you talk about electrons it is just an electron.

But are these two different kind of electrons are these different kind of wave of electrons or particles electrons moving out because they attain a different kind of red ox potential okay so we talked about the location of the photo system one and system two in terms of their spatial location they are red ox potential and then we talked about the hopping of the electron and how the whole oxidation reduction of the red ox chemistry governs the flow of electron in a slow pace in order to allow the set of reactions which includes.

So the formation of the ATP out here and NADPH we could see out here now put his oxygen and of course funneling into the dark reaction so next class will start with the dark reaction and it will finish of the whole part of photosynthesis which will lead a foundation stone for the biomass formation on the float of what followed by next phase one stone move will talk about the processing of the bio mass okay. Thank you.

**Acknowledgement**

**Ministry of Human Resource & Development**

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**Ashish Singh**

**Badal Pradhan**

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**Padam Shukla**

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**Shubham Rawat**

**Shikha Gupta**

**K. K. Mishra**

**Aradhana Singh**

**Sweta**

**Ashutosh Gairola**

**Dilip Katiyar**

**Sharwan**

**Hari Ram**

**Bhadra Rao**

**Puneet Kumar Bajpai**

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