Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning(NPTEL)

Course Title
Bioenergy

Lecture -09
In Photosynthesis O_2 Comes from Water Molecules

By
Prof. Mainak Das
Biological Sciences & Bioengineering &
Design Programme
IIT Kanpur

Welcome back to the lecture series on by energy. Yesterday we talked about in our previous classes about photo system 1 & photo system 2 how photo system 1 photo system 2 varies, I told you then in the space of location of places they are located at different locations there is one more thing to add up to that both for system one and system two stays at a different kind of reduction potential or redox potential each one of these four systems have a different ability to lose electrons.

One lose faster than the other there how such things are being achieved so the wave four systems develop is that say for example our system may have a mix of chlorophyll a and chlorophyll b but that number can be varied so for example if I say each photo system is made up of 100 molecules of chlorophyll so there may be a 4 system where they will be say so one option is at 50- 50 so50 chlorophyll A 50 chlorophyll B.

But anything which ships say for example one has said 10 chlorophyll-A other will have a 90 chlorophyll B or the and think the other way rivers one has 10 chlorophyll b + 100 chlorophyll-a now look at the spectrum here back to the spectrum but I agree for you.

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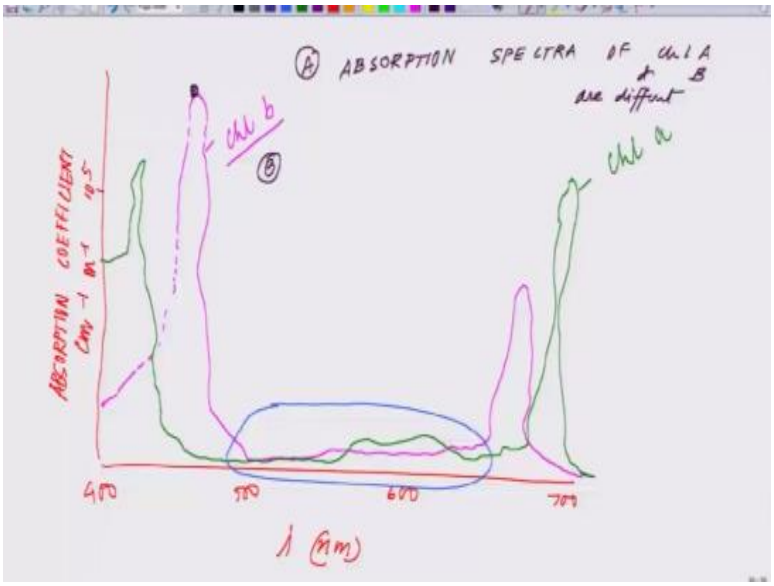

Now based on that number the spectra the overall light-absorbing ability is going to shift again look at the spectra carefully look at this respect I so this is the zone for chlorophyll the pink one is the further chlorophyll b and the green one is for chlorophyll a, now say for example in your system you have a photo system where there are out of 100 molecules just this is just for your understanding sake I am telling hundred molecules.

They do not think there is millions of such molecules in chapters in there but they have a finite number 44 system one and photo system 2 but their proportionate number of chlorophyll A and B are different in for system one there may be a different proportion of chlorophyll A and chlorophyll B similarly in photo system 2 there will be a different proportion of chlorophyll a and chlorophyll b.

And these differences completely change their optical properties they are light absorbing potential and the way and their redox potential these are apart from so there are three things now I am adding from the previous two lectures point one we have two photo systems and we will talk about how this all being discovered actually it was discovered like that only that way I'm telling you the experiment the way I'm telling is they giving you this explanation.

Point one, there are two different water systems for system 1 for system two and as I will proceed further they are indicated by different wavelengths p680 p700 will come to that that is basically telling and there is correspondence so that essentially telling you that which one is which one for system 1 for system two second thing they are especially located at different location third important aspect is that they have different proportion of chlorophyll a and chlorophyll b, fourth they are standing at different redox potentials.

So in other words their light absorbing power light absorbing ability and electron addiction ability is entirely different these three or four concepts I really wish get clear in your brain because that will be a big help to understand the whole basic architecture of photosynthesis okay so from here let us coming back to the slide.

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So we talked about the dye-sensitized solar cell we will be dealing with it you remember we talked about the reaction centers so this is the topic what we will be dealing now is.

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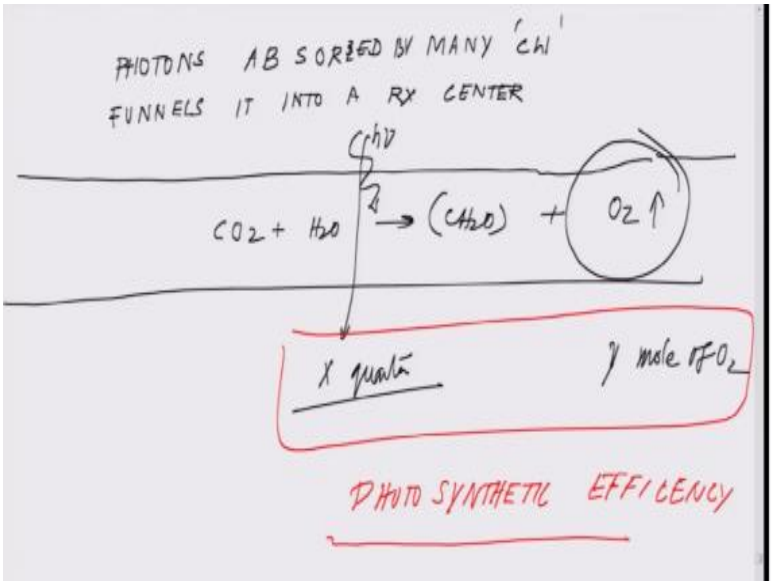

Photons absorbed okay absorbed by many chlorophyll CHL stand for chlorophyll funnels it into a reaction Center a reaction center so in the last class I told you that light is falling is not that at every point there is a reaction taking place each one of the chlorophyll molecules are getting oxidized by leaving an electron sitting the next molecule but the real reaction Center is only unique and I also mentioned in previous classes that you really cannot locate the reaction sitter but how that was discovered.

Well put on a statement for you that will help you to realize that how that was being discovered so basically the output of photosynthesis so before you get into that just before they put the statement there the output of photosynthesis is measured, so if you look at look back at the basic reaction co_2 + H_2O CH_2 O + oxygen so the output is measured by the output of oxygen, so if you have a probe by virtue of which.

You can measure the output of oxygen then you can measure the rate of photosynthesis so in other word so let us add one more thing into it right so if I am giving this much quanta of light say I give x quanta of light then what is the y mole of oxygen which is evolved so this is how the

efficiency of photosynthesis photosynthetic efficiency is being determined, okay. Now what is important here so moving to the next slide out here?

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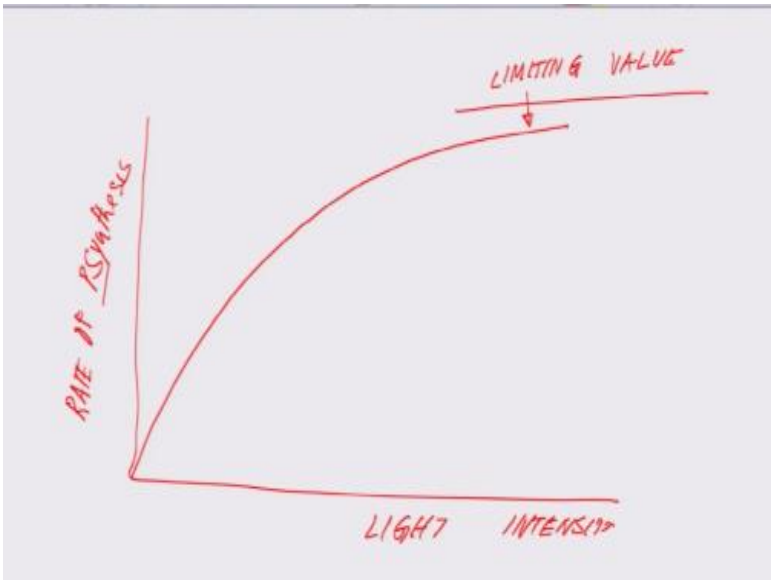

So measurement of the dependence of the rate of photosynthesis on the intensity of the illumination that it increases linearly at low intensities and reaches a saturating value at high intensities, so this was discovered that something very interesting graph for you to look at so this was what I just now explained the rate of photosynthesis okay and the light intensity, so what you are seeing is that this is where the limiting value is being approached.

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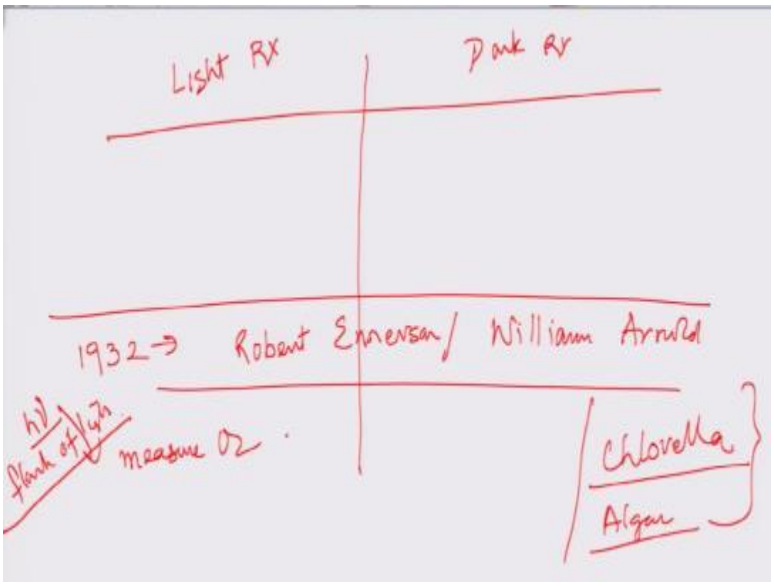

And followed by this so as we talked about the as saturating value is observed in a strong light because chemical reaction utilizing the absorb photon become rate limiting this experiment provided the first intimation that photosynthesis can be separated into light reaction and a dark reaction, what who is much earlier than that if this was one area around 1932 there was an experiment which was done by Robert Emerson and William Arnold.

This experiment was really critical what they did that they as I showed you in the previous slide measured oxygen as a function of s and they use so chlorella what they have used ok Chlorella this is basically a an algae so they measured the oxygen by exposing the flash of light measured oxygen with as I showed you in the previous slide flash of light and what the observed was very interesting.

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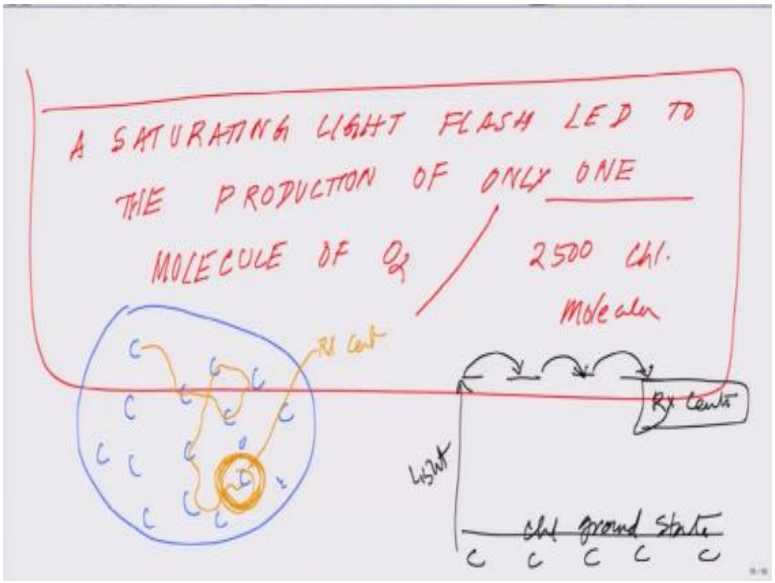

The observation is one of the critical experiment saturating light flash led to the production of only one molecule of oxygen for 2,500 chlorophyll molecule this is that critical statement which is significant, so when 2,500chlorophyll molecules are illuminated what you are seeing there is a single oxygen molecule is being pretty it means that every chlorophyll molecule is not leading to the reaction so it means that so based on that and several other experiment it was proposed that what is essentially is happening is something like this.

Out here so first again revisiting the reaction Center concept where so these are the chlorophyll molecule which are sitting at different reaction Center chlorophyll a chlorophyll b respective of it and when the light is falling like this so it is kind of traveling through and then is one particular Center which we call as the reaction Center and the way it possibly works one of the currently accepted theory is that there is light the light energy which and then there are hopping off energy transfer taking place this level.

And eventually it reaches to the reaction centers so and these are the chlorophyll which are sitting at the ground state and these are the chlorophyll which are sitting so these are the chlorophyll at ground state and these are the clothes which are sitting at the higher state so this is

How by very simple experiment back in the early nineteen hundred it was discovered that the whole process is not one-to-one like one light will fall on a chlorophyll and will generate an oxygen it is not like that so you need a cluster of chlorophyll molecules to initiate the reaction of oxygen formation and simultaneously these are the reactions which laid the foundation for to kind of reaction the light reaction and the dark reaction taking place in the hole for synthetic apparatus okay. So now come back we will move on to the next slide we will talk about one second okay.

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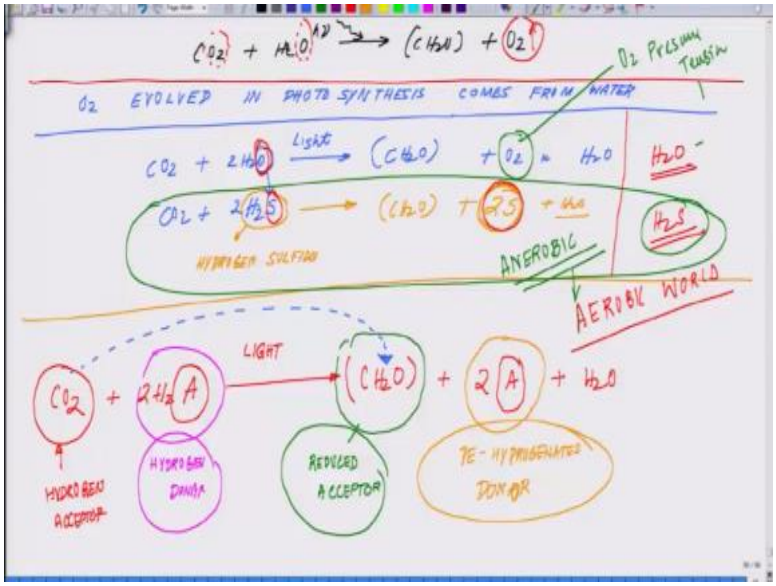

So we talked about another concept so the very basic reaction if you again go back to the basic reaction I will keep on following this basic reaction because that is where lies all most of our understanding so this is where the light is falling okay and what we are talking about CH_20 + oxygen now the question is which was posed was, how oxygen is getting evolved? Is that coming from carbon dioxide or is it from water.

Again look at the reaction carefully you will realize what I am trying to ask you so here is oxygen which is getting involved how you prove that this is coming from here or this is coming from here it can come from both sources right because both have oxygen you can split the carbon

dioxide it can release oxygen you can split the water it can release oxygen so there is no one has told the molecule that you have to come from this spot, so how to prove it.

Now we know of course in the beginning we said that is a water is kind of getting a split and oxygen is odd but how that reaction took place how that was kind of being discovered so the way it was done I will just put two reactions in front of you, you remember I told you that there are hydrothermal vents where there are no sunlight it life does evolve and those are the regions which are rich in hydrogen sulfide those of you just forgotten just go back to those lectures and realize.

Because it has some link and that is why I might possibly made it a point to bring this aspect for you that why I mentioned that thing out there so let us put the two reactions out here which will Help you to realize one of the very seminal contribution so what we are claiming is this okay oxygen evolved in photosynthesis okay oxygen evolved in photosynthesis synthesis come from water and how to prove it okay comes from water, so in front of you I am putting two reactions now Co_2 carbon dioxide to $2H_2O$ waters in the presence of light making CH_2O + oxygen plus you can have water whatever okay fine.

Now $Co_2 + 2H_2$ now I replace this oxygen with sulfur which is you remember now the hydrothermal vent which is rich in hydrogen sulfide and CH_2O + 2 sulfur + H_2O this was the reaction which led to the understanding of a generic reaction what is the generic reaction now I am drawing the generic reaction for you, is this oxygen H_2O what we are claiming as the currently the electron source H_2S also can be electrons.

So instead of H_2O you put H_2S and what you are getting the output is sulfur so essentially when in the beginning I told you that role of when we are splitting the water it is just an output which is coming out because it was not really maybe it was never planned not only what nature needed was an electron and it was looking for a very I should say a source for electron which is very easily available one of the easily available source.

It may have found in water but he never taught that this will led to the evolution of oxygen and that was one of the biggest event which happen in history when from the whole life form moved from anaerobic life form to aerobic, so essentially what we are telling that possibly very early in the environment this was the kind of reactions which were happening earth which was rich in hydrogen sulfide rich in all sorts of nasty gases and that is where probably life evolved.

And at some point as earth was cooling down as everything was coming down the hydrogen sulfide level was going down and nature was in a hunt for another perennial electron source and nature's perennial electron source became water we do not know how many billions of years it took nature to make that transformation from H_2S to possibly water but what nature did not anticipate it or maybe it anticipated we do not know.

That the outcome of it will be evolution of oxygen and that was a turning point because the cause of the evolution of oxygen earlier this is the world war which was anaerobic and all the organisms which are surviving were adapted to survive in the absence of oxygen but with the evolving oxygen most of the anaerobic species which were present on the floor of earth slowly started getting extinct because they could not withstand the oxygen pressure or oxygen tension so possibly it is at that juncture what we see the modern-day world from non-oxygenated environment to oxygenated environment or a ship Trump's in aerobic to our current day Arabic world.

And this evolving oxygen leads to the evolution of species which are adapted to oxygen environment as to there are several microbial life forms which grows in absence of oxygen in absence of light deep inside the hydrothermal vent and a life form very similar to Martian environment, environment in the Mars where it is emulated that that where it is believed that similar environment exists as in the hydrothermal vent where even in the absence of oxygen such process takes place.

And that was the reason why I wanted to show so the generic reaction now I will put the light of this wisdom will put the generic reaction and this is very critical for all the biomass producing mechanism available on earth h_2 now I am putting a I am NOT putting o or s in the presence of

light leads to CH_2O + 2A again I am just circling the a plus H_2O okay now this one is let us put is the hydrogen accepted.

Leading to the biomass formation and this one the contrary this particular molecule is your hydrogen donor in other words this is the source for all kind of reduction reaction and CH_2O now I am putting it in green because this is the biomass what we are talking about is your reduced acceptor because this is getting reduced because of the addition of hydrogen to carbon dioxide and this one is your dehydrogenated donor why it is a dehydrogenated donor.

Because hydrogen has been removed whether it was the H_2S or whether it is a water sorry hydrogenated donor very interesting to note that.

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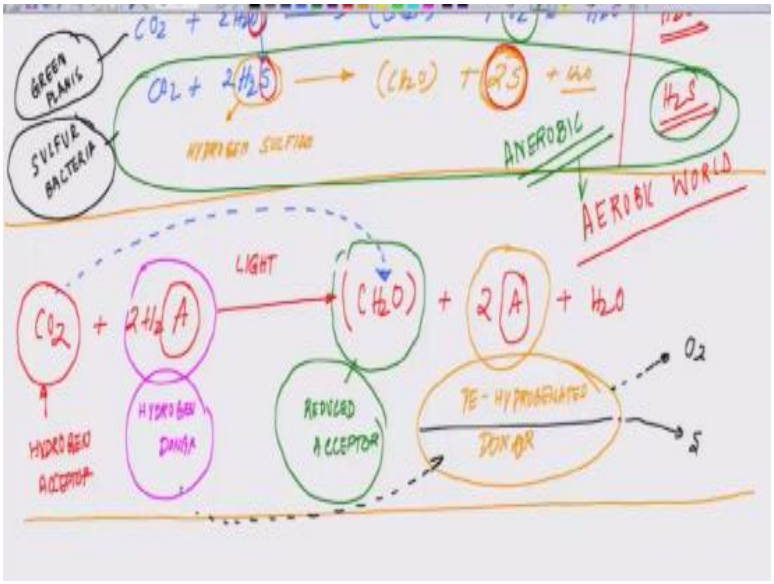

One second let me the hydrogen donor h-2a is H_2O in green plants and H_2S is in photosynthetic sulfur bacteria so this is the second reaction what I just now showed you this is basically the sulfur bacteria and this is what is happening in the green plant, these are the two critical things what we are dealing with and oxygen evolution would then be a necessary consequence of this

dehydrogenation process these dehydrogenation process what Is happening out here leads to oxygen or sulfur okay.

So the availability in 1949 specially of different kind of heavier isotopes with the radioactivity was already discovered these kind of processes could be mapped with different kind of oxygen isotopes it was being observed that indeed the oxygen is getting evolved from the water not from the carbon dioxide and that is why this reaction is very important for you guys to mark that how these things are happening with this and we will take up each part of it in our subsequent lecture.

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