Bio-energetics of Life Processes
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Lecture - 16
Photosynthesis–VI

Welcome back to the lecture series on bioenergetics of life processes. So, we have started with photosynthesis. So, today we will proceed with photosynthesis. One of the interesting things in photosynthesis is, I have already talked to you that it consists of two photosystems; and one of the byproduct of photosynthesis is evolution of oxygen and light is essential as we have talked, in the very first lecture of water or are the prerequisite for photosynthesis to happen.

One interesting aspect which was realized pretty early in photosynthesis is that, there is not a linear relationship between what is the instant light falling on the leaves and what is the oxygen evolution what does that mean? That means, say for example, I say because it is a energetic process, someone has to keep a balance sheet to understand that how much solar energy is being used and how much oxygen is being evolved and what is the efficiency.

So, it was believed that say for example, x quanta of light or x quanta of photon is falling on a surface, then a corresponding y or x quanta of oxygen will be evolved there should be an some stoichiometry; it was observed; that it is not kind of a very linear like you know, one photon, one oxygen like not like that. It is something like after several photons the oxygen is getting evolved. In other word, you need a good number of photons to fall on the chlorophyll molecule, before the oxygen is being getting evolved. That set up a very interesting idea initial phases and eventually hypotheses are now kind of it is believed is that, not all chlorophyll are involved in evolution of oxygen apparently. Suppose we look at the whole structure of the leaf there are millions of chlorophyll molecules in one cell.

So, it is not that every chlorophyll will lead to the energetics reaction of evolution of oxygen. Because why we are talking the evolution of oxygen because that is your output, that is how you are evaluating how much what is the efficiency of the system it seems like there are reaction centers in other word let us put it in perspective..

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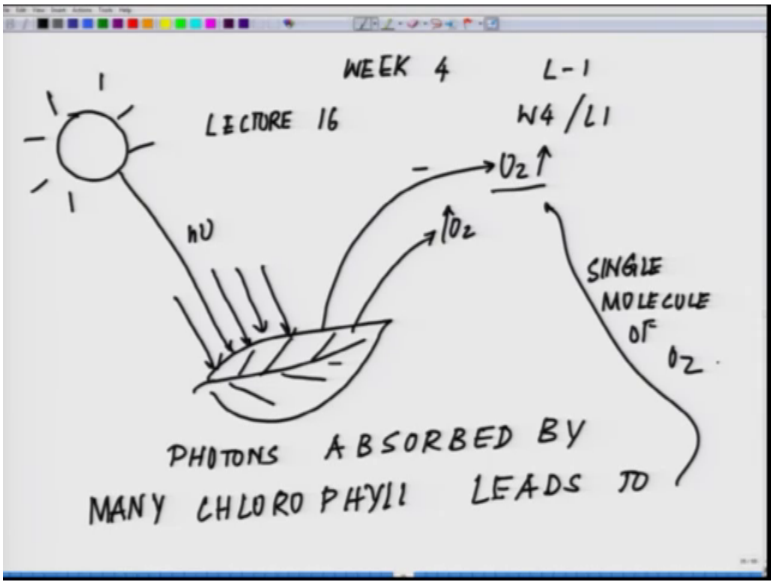

So, this is our week 4 lecture 1 and this is essentially or lectures 16 W 4 L 1. So, what does that mean is say for example, we are talking about leaf surface and light is falling which is ok. So, we are evaluating based on the oxygen evolving out ok. So, it has been observed after quite a good number of photons which are hitting upon, you have one oxygen molecule which is getting involved. In other word the photon absorbed by many chlorophyll leads to photons absorbed by many chlorophyll leads to evolution of single molecule of oxygen ok.

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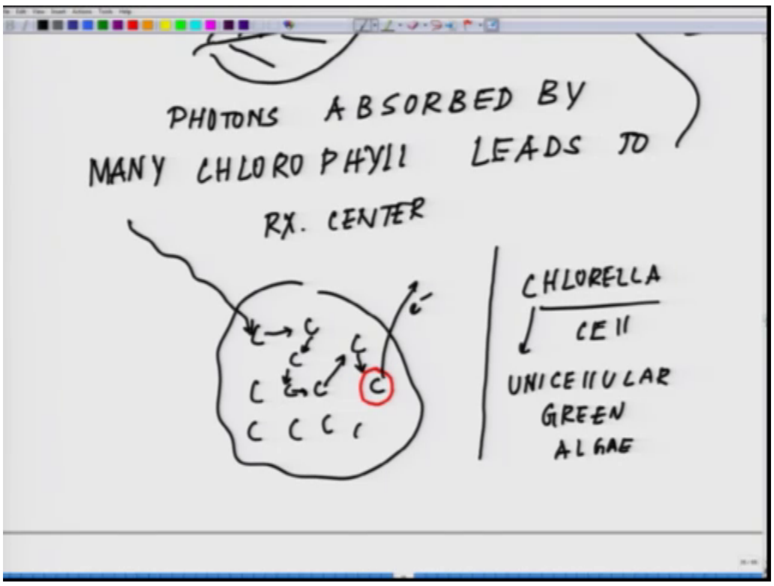

So, that brings us to a concept called reaction center in the chlorophyll molecules. That means, say for example, this is all a location of several chlorophyll molecules are sitting there and say for example, light falls on this. So, the energy kind of get transferred there are several forms of energy which are getting transferred and one of them out of this will be the reaction center, from where electron will be emitted out.

So, in 1932 Robert Emerson and William Arnold measured the oxygen yield of photosynthesis in chlorella ok. Chlorella is a easy model system to work with chlorella cells which is a green algae it is a unicellular, unicellular green algae ok. These unicellular green algae when exposed to light flashes lasting for few microseconds they expected to find that the yield per flash would increase with the flash intensity. Until each chlorophyll molecule absorbs a photon which would then be used for the dark reactions, but the experimental observations was entirely unexpected.

What was the unexpected aspect on it? It was a saturating light flash led to the production of only one molecule of oxygen per 2500 chlorophyll molecule.

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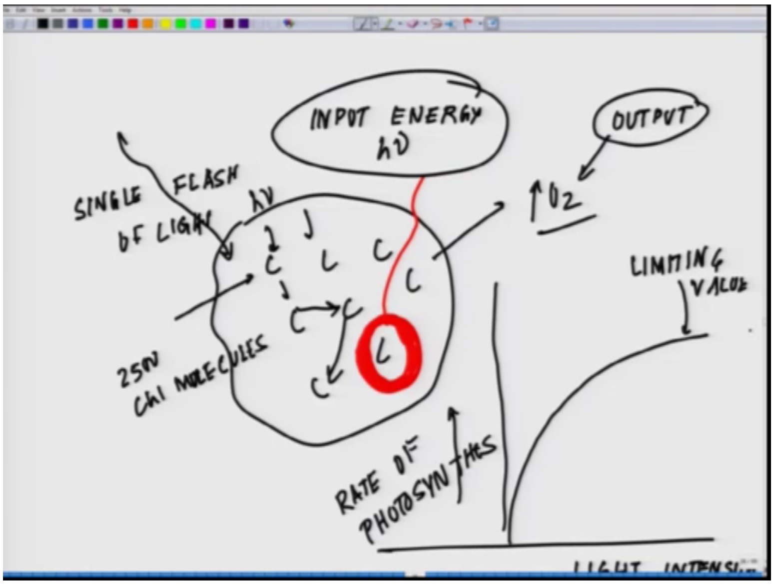

So in other word if this is the site where there are 2500 chlorophyll molecules which is kind of estimated based on the per unit density of the chlorophyll molecule, it was observed and this is single flash of light single flash . So, one can calculate the energy what you are giving single flash of light, what they observe is single oxygen which is getting emitted out. So, in other word if you draw a graph it will come something like this, in the y axis sorry in the x axis you have light intensity and in the y axis you have rate of photosynthesis and this is the limiting value .

So, this gave birth to the concept of photon absorbed by many chlorophyll photons absorbed by many chlorophyll is funnel to a reaction center. Now what is critical is? What is the reaction center and how to identify? As of now to the best of my knowledge no one can really predict which one is the reaction center, and how this reaction center is being determined among all this same cast of chlorophyll molecule is also a very unresolved and a mysterious question, but it does exist ok. The energy level of chlorophyll at the reaction center is lower than the other chlorophyll ok. So, they in other word the energy level out here is lower. So, the way it works is something like this, if you kind of think it like that these are the chlorophyll which are sitting at ground state.

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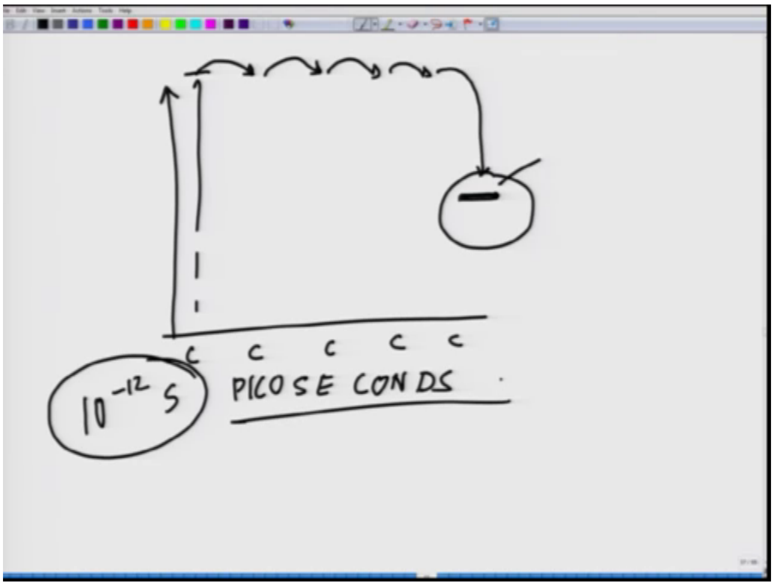

So, there is a light which is falling on it and which takes this chlorophyll at a higher state there is an energy transfer to the next to the third, and when it comes to the reaction center. So, this is where the reaction center, it is sitting at a lower energy ok. The energy level of the chlorophyll at the reaction center is lower than the other chlorophyll which enables a reaction center to trap the excitation ok. So, this is what the figure is telling you. The transfer of energy by direct electromagnetic interaction between chlorophyll and then the reaction center is very rapid occurring. So, this is the timeline or time window we are talking about picoseconds. So, to trap such a reaction of that intensity is exceptionally challenging ok. So, this is all about the reaction center what you needed to know; that kinds of in terms of energetic gives you an idea what is the input energy and what is the output input energy in terms of photons ok.

So, this is the first point I want you to kind of take into account, the second thing is second aspect is oxygen evolved in photosynthesis.

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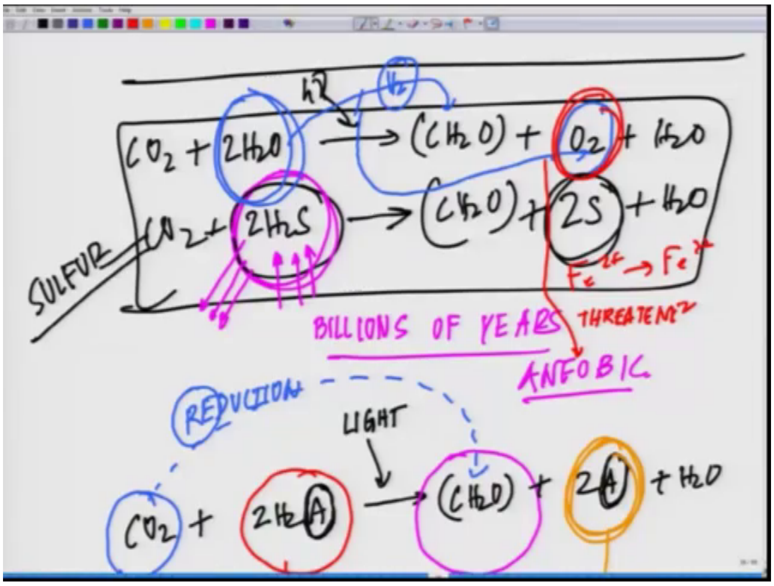

PS is photosynthesis comes from water, this is the second concept. So, if I put the two equations side by side CO 2 plus 2 H 2 O where light is falling you have CH 2 O which is your carbohydrate oxygen plus H 2 O. Now if you replace CO 2 with 2 H 2 S hydrogen sulfide if you remember I talked about this, what you are going to get is CH 2 O which is again the carbohydrate plus 2 sulfur plus water ok. So, this is the sulfur that is formed by photosynthetic bacteria is analogous to the oxygen, that is evolved in plants. So, this is what are the sulfur bacteria does and Van Nelle proposed a general formula for photosynthesis, and the general formula for photosynthesis is like this.

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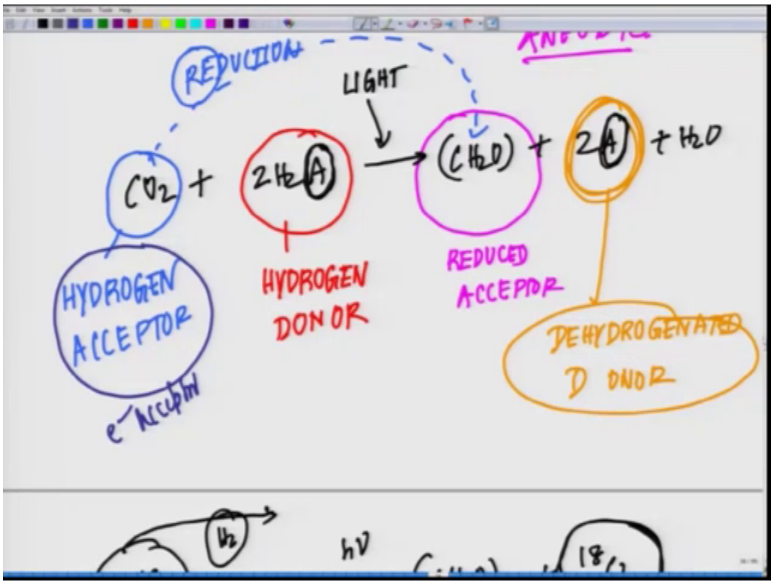

CO 2 plus 2 H2 A keep this in mind this A in the presence of light forming CH 2 O plus 2 A that A which is coming from that side plus H 2 O `.

Now, what is the C? So, CO 2 out here is your hydrogen acceptor in other words CO 2 is getting reduced hydrogen acceptor because it is accepting hydrogen it is getting reduced to this situation. So, this is a reduction reaction happening here whereas, H 2 A this is your hydrogen donor, this one is hydrogen donor this product which is carbohydrate is your reduced acceptor and 2 A is dehydrogenated donor this is that dehydrogenated donor, which has donated the hydrogen or the electron dehydrogenated donor ok. So, this is how the reaction occurs and one can prove it very easily if you have radioisotope like you know.

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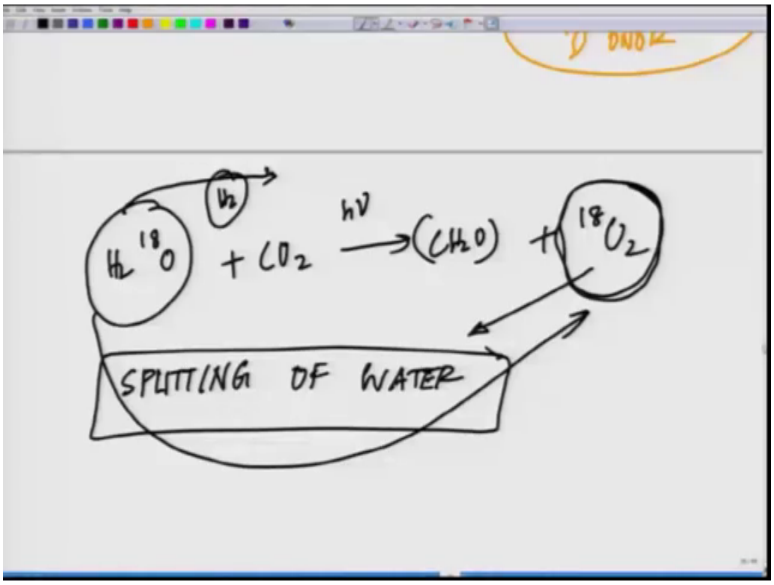

You have H 2 18 O I have different oxygen isotope with CO 2 in the presence of light you have CH 2 O and what you are getting is 18 O 2. So, if you see the mass of this one, which will be higher and that is how you can figure it out that oxygen is getting evolved by splitting of water splitting of water.

So, it seems that nature learned long back how to split water and if nature could split water and could lead to the evolution of oxygen and of course, the other product which is been getting used up here is the hydrogen; that means, for those who dream of having a world of clean energy by hydrogen evolution nature already knows the trick and that is the beauty of nature. It has learned in its own laboratory of billions of years by playing with its own atoms how to split any molecule and that is the charm of studying these things. That you know the whole world is you know looking towards energetics clean energy by hydrogen economy you must have all seen somewhere you know they want to store hydrogen that is the cleanest form of energy and blah, what is important is nature does it nature does it very elegantly in stick just nature does not produce hydrogen, in the air it utilizes the hydrogen for all its reduction purpose.

So, this brings me to that point what I was trying to highlight in the beginning that, the world or life systems energy economy is governed by a perennial electron donor. You needed a perennial electron donor all the time because if you see out here the world was a harsh place lot of hydrogen sulfide and the perennial electron donor at that time was hydrogen sulfide. All those sulfur loving bacteria and all those things survive some billions of years ago. Still they could be seen in anaerobic conditions, but then as the earth was cooling down if you remember one of my previous lectures I told you, as the earth was cooling down hydrogen sulfide and all these things were lowering down.

So, nature had to search for another perennial electron source and that is where nature picked up this wonderful molecule water nature picked it up for its hydrogen supply or electron supply, but simultaneously nature while splitting this started evolving a very strong oxidant called oxygen and that was that great point in the history of chemical evolution or oxygen took over and as soon as oxygen took over, all these anaerobes were threatened and because all iron 2 plus become f e 3 plus everything which was there were getting oxidized higher oxidation states were picking up. And that is why this transition called the great transition over another millions of years pretty much all our ecosystem started depending on oxygen and that was the rise of aerobic situation..

But it is still there are places where you have the other modus operandi still operating where H 2 S is being used and is being utilized ok. Now coming back to another concept which I wanted to highlight in this lecture is, there is something called hill reaction which is illuminated chloroplast evolved oxygen and reduced electron acceptors.

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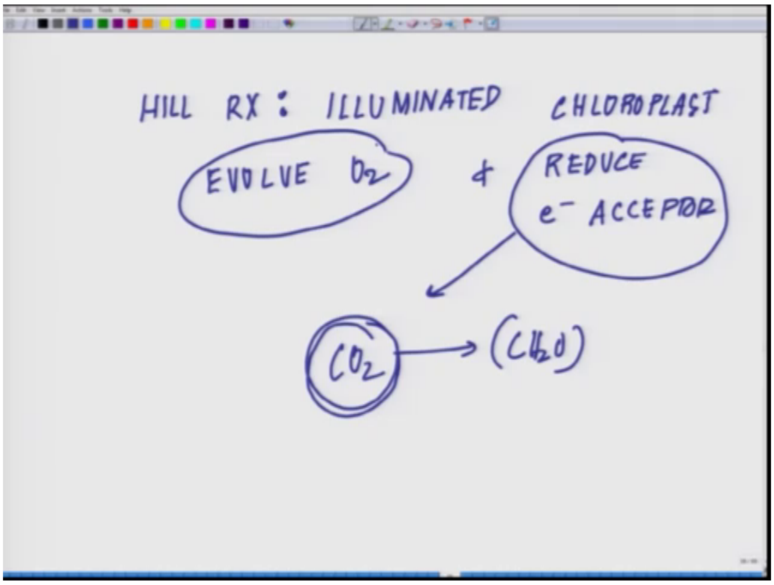

So, this is one concept I am not going to the detail of the reaction, how it has been done, but just you needed to know the basic message which is given. Illuminated chloroplast illuminated chloroplast evolved oxygen and reduce electron acceptor, and if you realize reduce electron acceptor; that means, CO 2 becoming CH 2 O.

So, essentially this is that electron acceptor if you just see the previous slide, this one hydrogen acceptor ordains which is essentially an electron acceptor. So, you can replace that electron acceptor with another electron acceptor and prove this fact and it evolves oxygen which is a strong oxidant. There is another interesting concept before I go into the architecture of it is that two light reactions interact in photosynthesis.

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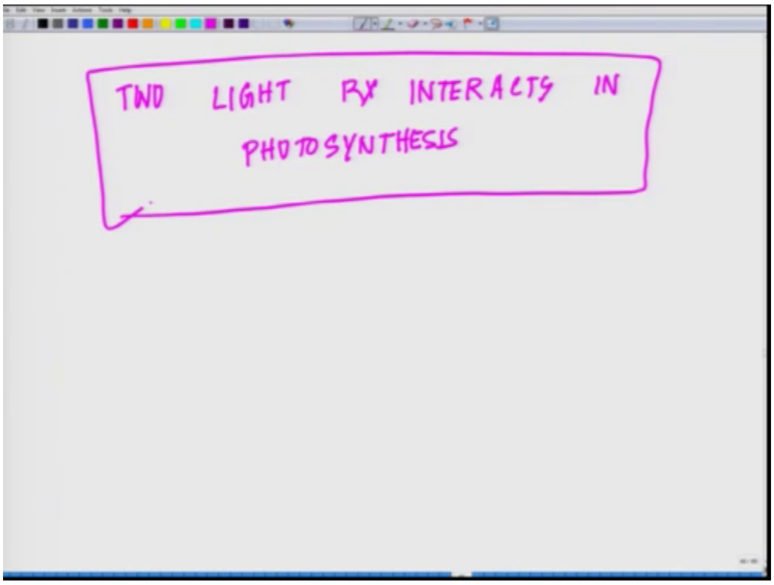

So, two light reaction interacts in photosynthesis what does that? Apparently it looks like that photosynthesis is governed at two different spatial location, a single unit of photosynthesis especially and this is; am talking about the evolved plant models what, we are currently more interested in to there are two specific centers.

So, if you go back pretty one of the very let me go back and yes out here.

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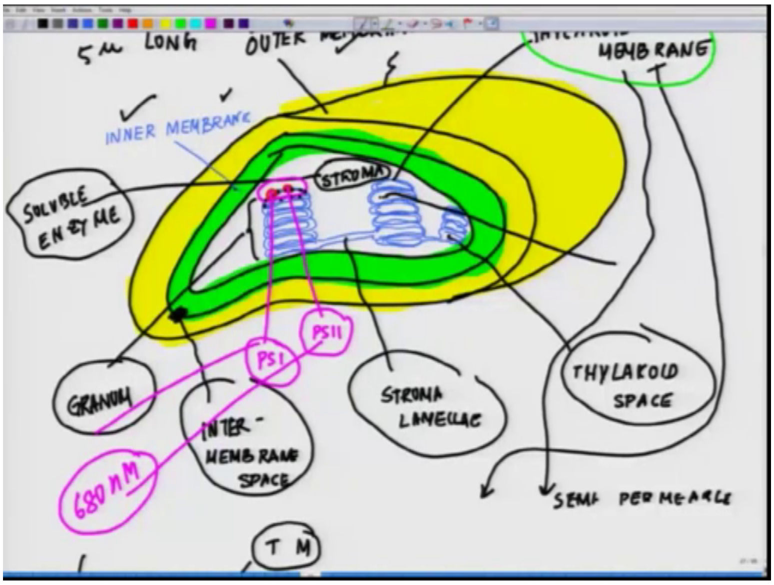

Now if you look into this picture, if you see it carefully. So, this is where the photosystems are being placed. So, out here there are two unique centers called photosystem 1 and photosystem 2. There are two unique photosystem model modules which are there. So, investigation of the dependence of the rate of photosynthesis on wavelength of incident light led to the discovery that, chloroplast contains two different photo systems. The photosynthetic rate or the rate of oxygen evolution, divided by the number of quanta absorbed gives the relative quantum efficiency of the process ok. So, that is the energetic. For a single kind of photo receptor the quantum efficiency is expected to be independent of wavelength over its entire absorption band, this is not the case in photosynthesis the quantum efficiency of photosynthesis drops sharply.

So, this part is very important the quantum efficiency of photosynthesis drops sharply at wavelengths longer than remember that longer than 680 nanometer ok. Although the chlorophyll still absorbs light in the range of 680 to 700 nanometer. However, the rate of photosynthesis using long wavelength light can be enhanced by adding light of shorter wavelengths such as 600 nanometer. The photosynthetic rate in the presence of both 600 and 700 nano meter, light is greater than the sum of the rates when two wavelengths are given separately.

This part is very important and I wanted to kind of keep an attention. The photosynthetic rate in the presence of both 600 nanometer and 700 nanometer light is greater than the sum of the rates when two wavelengths are given separately ok.

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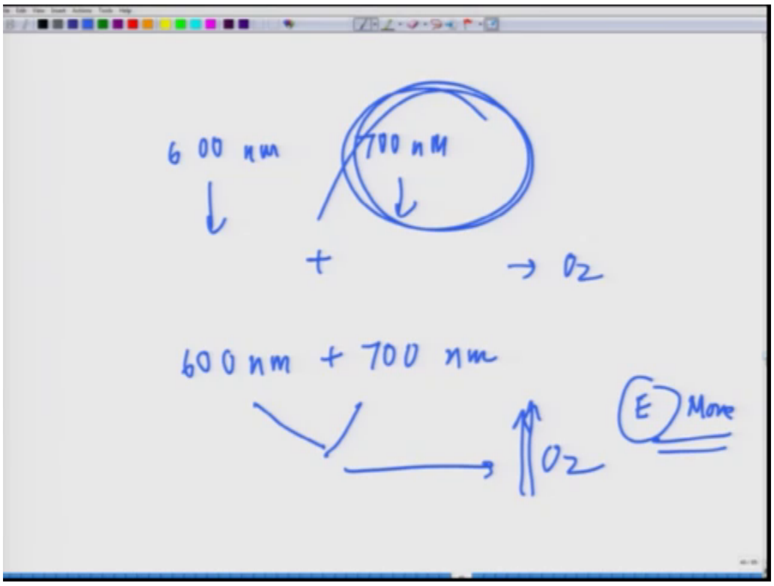

So, if you give these two wavelengths together, if you give 600 and 700 nanometer separately, and add the efficiency in terms of oxygen evolution or you give 600 nanometer plus 700 nanometer together and oxygen evolution. You will see here the efficiency is more is efficiency is more. So, that led this observation is called a red drop and enhancement phenomena, let one of the scientists in this field Emerson to propose that photosynthesis requires the interaction of two light reactions, both of them can be driven by light of wavelength less than 680 nanometer, but only one of them by light of longer wavelength and the red drop graph is something like this.

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So, here you have the wavelength 400, 520, 600, 680 and here you have the quantum yield of photosynthesis in terms of oxygen evolved for photon, which is called quantum yield or photosynthesis. The quantum yield of photosynthesis is something very interesting to look at if you look at the graph it is something like this, this is that red drop.

So, if you add the 700 then something like that this drop you would not see. This quantum yield of photosynthesis drops abruptly when the excitation wavelength is greater than 680 nanometer ok. So, this is something very interesting which was observed once again, which was once (Refer Time: 23:23) something like this slightly more out here once again let me. Just redraw this again for you. So, it is something like this on and something like this red drop ok..

So, Emerson again I am repeating it Emerson proposed that photosynthesis requires, the interaction of two light reactions both of them can be driven by light of wavelength less than 680 nanometer, but , but only one of them by light of longer wavelength. So, this is where if you use only one and this is what is going to happen there will be a drop, both of them are together you will see a higher efficiency.

So, I will close in here in the next class we will move on to the actual light reaction photosystem 1 and photosystem 2.

Thank you.