Bioelectricity

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Lecture – 39

Let us resume our lecture series on Bioelectricity. So now we are into the last two lectures thirty-ninetieth, and the fortieth one; as of now in all our up to the thirty-fourth or of thirty-fifth lecture, we have talked about the overall animal electricity. Then we talked about the plant electricity in the form of photosynthesis, where the electron transfer takes place;, then we talked about the movement of the plants form venus fly trap, and touch me not plants, then we talked about desensitized solar cells. Followed by this, we had a brief exposure about some of the very ancient molecule iron pyrite, and iron disulfide, and their electrical properties.

So, we will close in this section or this course with some of the lesser known electrical phenomenon, which are observed in nature;, and one such material or biomaterial which is getting very huge prominence in last two decades, although more than that is silk. Silk as such, the way it has been understood, when it is dry, does not have certain like does not really carry charges, but it behaves in a different way. So, what we will do today is will devote two lectures now, talking about the silk what is really silk is, and how it has evolved, and what are the different forms of silk, and what we know about its bioelectrical properties, and how this could be used for some useful applications, and what are their implications in nature.

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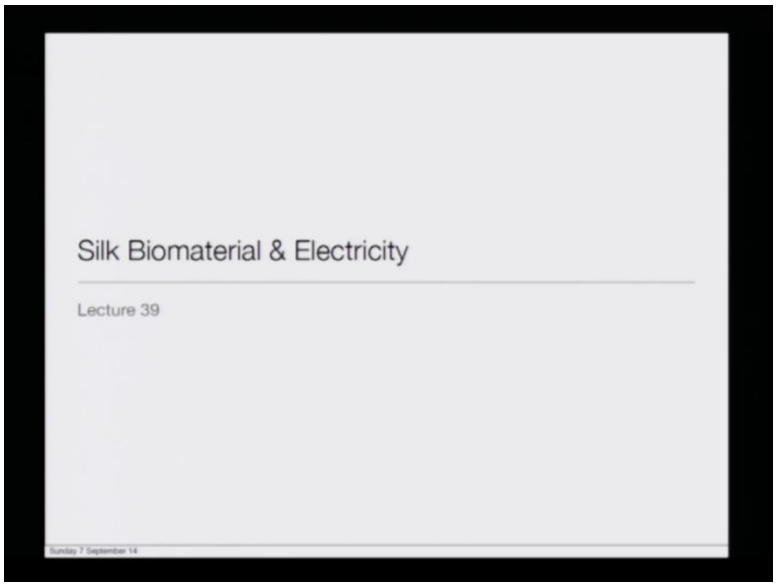

So, let us start the thirty-ninth lecture, under the broad heading of Silk Biomaterial, and Electricity.

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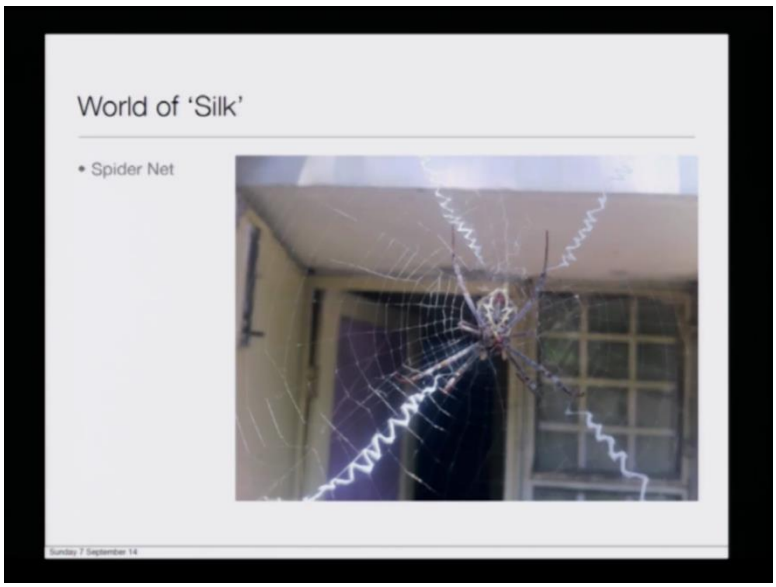

Talking about silk, what really is silk. So, whenever we think about silk, there are what the first thing you get is about silk sarees or silk clothes or you know silk garments nothing else really comes in your mind, but this is a kind of misconception among the general audience that is not really silk. Silk is a broad name for all those insects, which excrete certain thing from their mouth, and form a protein or network, or mesh of protein

or proteinaceous network that is called silk. And as a matter of fact you really go through the plethora of different silk, we will be talking about the spider silk, which is also a silk; we are talking about hornet nest that is also a silk, we will talk about bombyx, and tussar silk which is also a silk. So, just give you a kind of feel what silk is. So, if you look at this slide, which shows a spider net. You are seeing this wonderful net. So, this material of net, which is forming that specific net is a silk.

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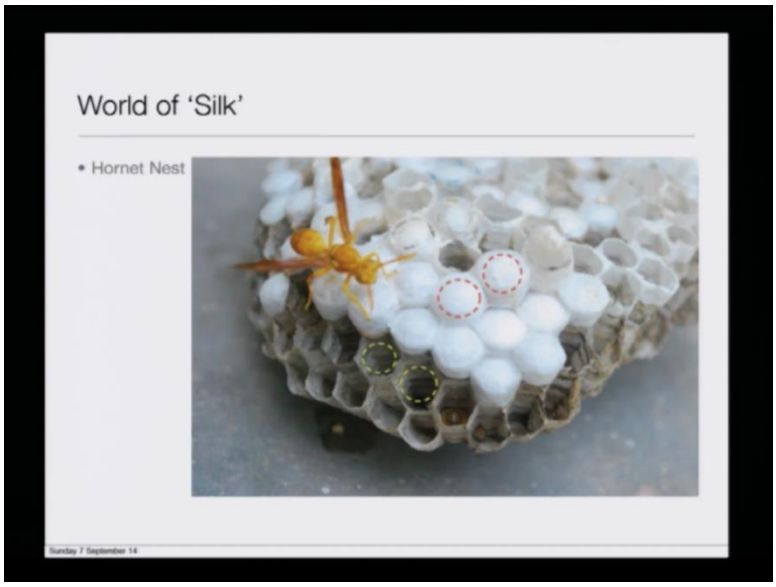

Now give you a second example, hornet nest. All of you have seen this kind of nest either honey bees or hornet nest. You see this nest some of the see this nest, some of these nest. If you see this picture, you see some of the nest are closed with the white cottony coating or a cap, and where as the other ones without any cap this cotton cap what you are seeing is also silk, and then the most traditional ones which most of us understand is a silk cocoon a bombyx, and tred just I have given such examples these are also silk now coming back to the word of silk. You know if I have to come back. So, how really what how this silk is produces first of all let us answer this question. So, there are series of insects which goes through a four stage life cycle. So, the adults lays the eggs these eggs like just put it on board to make more sense.

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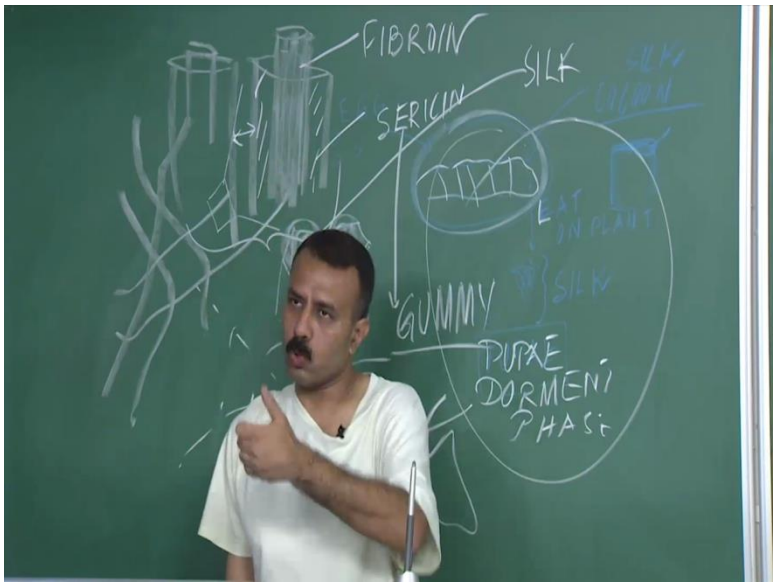

So, so these insects adults lays the eggs, and these eggs hatch on something called a larvae all of you must have seen this kind of you know these larvae's very gregariously they eat on plant material, and and upon eating plant material from their mouth from this part they secrete a series of kind of you know sticky material and these materials is essentially what we know as silk, and there are almost four thousand to five thousand such species which produces silk we only know handful of them, and eventually this larvae goes into a dormant phase called pupae, and this pupae is an inactive phase of their life, and this pupae has to be protected from the surrounding. So, that protection is offered by this material, because what it does essentially it covers around this larvae something like this which leads to the formation of called as cocoon or silk cocoon or you know in the case of hornet nest you see that white covering on the hornet nest like this that hornet nest covering that is also a silk material.

So, this is the coating what we talked about the silk cocoon in the hornet nest if you look at the hornet nest hornet nest there is something like you know those hexagonal things, and you see that white coating on top of it those white coating is also silk, and then you have seen those spider net something like this this is also silk. So, this is the basic thing what I wanted to clarify those insects which goes through this four stage life cycle the egg followed by a larvae which I have shown here followed by formation of the pupae which is also called the domain phase of their life, and then this emerges out as a butterfly.

So, this four stage life cycle during their four stage life cycle during this stage they secrete the silk material, and this material is nothing, but a rich matrix of proteins embedded with lot of elements, and few other organic molecules depending on where they have been grown if they are raised under a specific kind of tree is a continental areal, but if they are they are you know evolving in the wild depending on what tree they are feeding the protein quality changes not only the protein quality the quality of the silk changes, and as of now why the silk become.

So, prominent with garments is there are two or maybe you know there are four or five species which has been which has been domesticated very thoroughly one of them is bombyx mori, and from there we get the pure silk apart from it most of the other species whether they are found in africa or in a subcontinental of india or asia likewise whatever they all are partly wild or you know semi domesticated species like anthereaea myllata which are from the tussar silk, then you have panthereaea paranie there are bunch of such species which are they are still in the wild, and still considered as a wild or semi wild species, but they are also silk likewise the spider silk, but now again revisit this.

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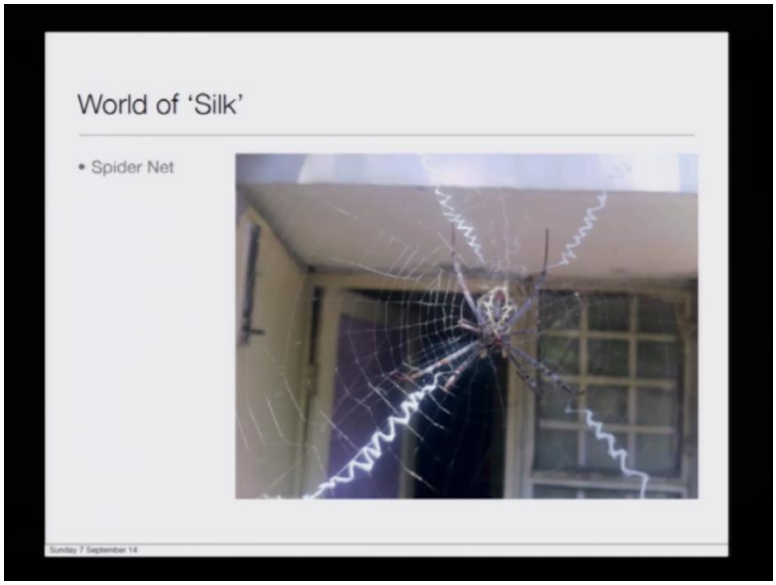

So, this is also silk if you look at the slide this is also silk this is also silk this is also silk, then what is the difference between these silks there must be a structural difference. So, that is what we are going to come first what is the basic difference between these silk. So, I told you silk is nothing but a protein mesh work, and these proteins are something

like this it forms a mesh work proteins. So, these proteins consists of two different kind of proteins if you really take a cross section of silk cocoon silk, and you will see these protein is made up of something like this inside one chamber.

You see inside one big cylinder there is another cylinder, and this big the big cylinder which is inside is called fibroin protein f I b r o I n, and outside where I am putting a hatch line this is called sericin this sericin protein is a gummy protein kind of a gum, and sticky protein. So, whenever one such… So, these two can stick with each other, because of the gummy nature of it. So, this is what we talked about the regular protein fibers are. So, they were fibroin proteins which forms the core, and then they have a outer shell which forms the sticky protein called sericin.

So, there by several of these fibroin cylinders are attached to each other, and form the very complex structure of a silk cocoon something like this what you see out here, but if you see here this is also same thing it is a fibroin, and sericin coating which is forming, but here story is slightly different in the case of a spider silk in case of spider silk they do not have this sericin sericin is missing instead they have only fibrin they do not have any sticky thing that is why you see those thread fibers they are separated from each other they are separated from each other, because there is no sticky material, and the protein what is forming in the core or fibroin core, and putting the air this protein is a beta sheet protein extreme beta sheet protein.

So, that much you needed to understand about basic structure of silk, but, then why we are interested in this problem there are, and where these whole electricity comes into place this basic introduction was very essential for you to understand let us summarize this what we have talked just now. So, silk is a broad class of protein which is essentially secreted by a at least five to seven thousand or eight thousand species of insects doing at a specific stage of their life, and most of these insects are four stage say life cycle insects they have egg larvae, and the dormant phase called pupae, and after the dormancy is over they become an adult butterfly. And this dormancy phase last from ten to twenty days to even eight or nine months depending on the species, and the kind, and where they are there are species found in united states where the dolmency phase goes all the way up to you know eight or nine months where as in most of the species which are found in the tropical, and sub tropical belts in, and around india china, and all these places they last you know twenty twenty one days likewise. So, this thing varies third thing what we

talked about is the difference between the different silk in terms of their fibroin, and the sericin the silk what we understand ra really from which the clothes are being made its basically originally the silk consists of two proteins there is a fibroin core.

There is a gummy coating called sericin, and these fibroin cores are attached to each other side by side or cress cross what is ever we, because of the gummy coating which is present outside them. So, this is what we discuss now why we are getting into this problem. Now in order to understand this. Let us get into this slide. This is the first silk what we are discussed today the hornet nest the whole idea about you know trying to understand the properties or electrical properties of silk comes from a very fundamental question which has been raised by the entomologists for a long period of time.

How most of these insect nests which are present in an environment could regulate their temperature they indeed have a thermo regulation, because these hornet nests are living at a temperature say fifty degree centigrade. So, if the fifty degree centigrade remains in this small structure what you see the pupae would not develop there will be defects. So, there is a way by which the temperature inside these nests are being regulated, and this is the genesis of these asking this question, then who is helping it, because in the case of hornet nest if you see this hornet nest see this slide very carefully.

You will see there is this hexagonal structures which are formed here they are made up of clay where as that upper coating is made up of your silk. So, who is really taking care of it. So, since nineteen twenties, and thirties this remain in a very interesting question, and till date this is an very interesting question, and people started to you know address this question.

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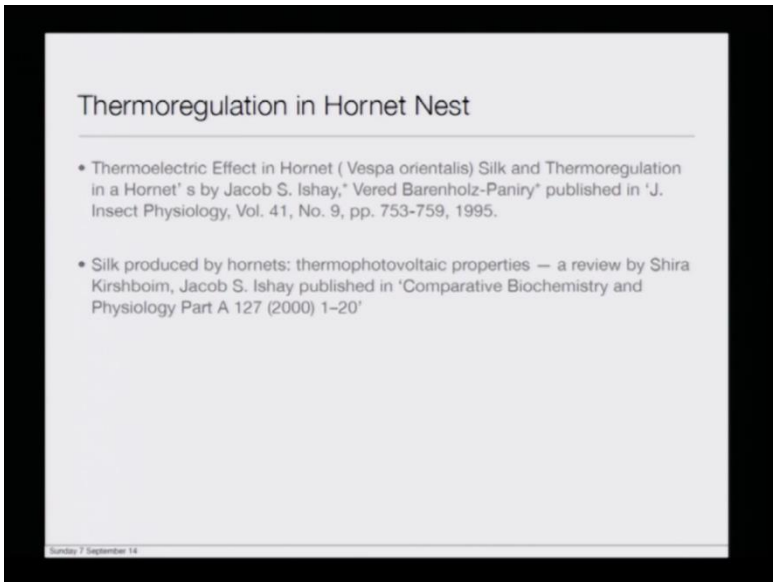

So, today we will be talking about some of those pioneer discoveries or first attempts, and I will be referring to these two speakers which are which were published by jacob jacob ishay he was working in israel he was in teleview university. So, he was working on understanding how the thermoregulation takes place in hornet nest this was his basic idea there were two very nice papers which he published one of them is thermoelectric effect in hornets that is vespo orientale silk, and thermoregulation is a hornet, and the second one is the review paper of all his work what you can see here silk produced by hornets thermo photovoltaic properties.

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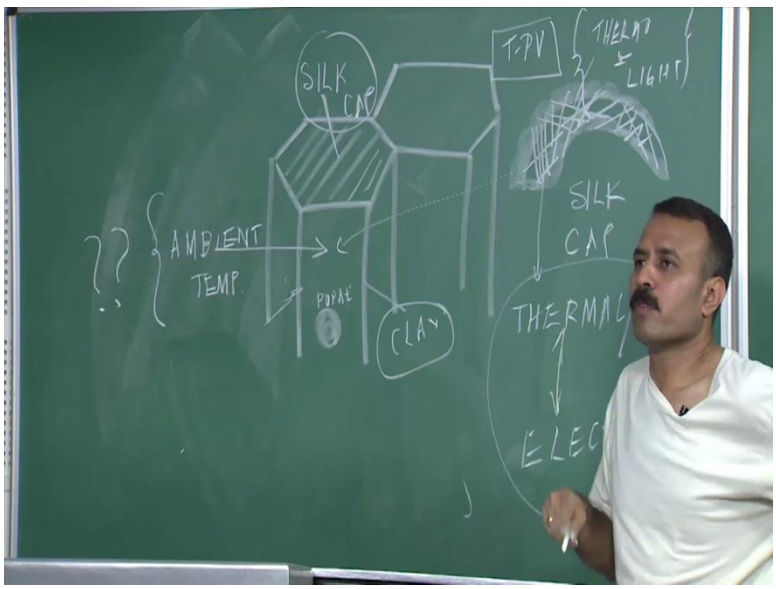

So, the basic idea of was about these papers even before you even get into it is silk membrane has certain thermoelectric properties. So, let me just get on the board for this to get you an idea what is the basic premise to start these kind of studies is… So, you see the hornet nest something like kind of structure side by side you know , and on top of this you have this, and the pupae is growing out here for this pupae to grow there has to be an ambient temperature how this ambient temperature is being maintained this was the fundamental question there are two possibilities some way or the other this membrane this structure this clay is helping it or the silk cap which is covering it is helping it or both of them are helping together the both the silk cap this one, and this clay both are them are helping both the silk cap, and clay both are playing the role.

So, the hunch was that it is a silk cap which is playing the role. So, how to study it. So, one of the basic idea which was kind of tinkered by ishay, and his colleagues was this silk cap. So, if I kind of you know put this it is a cap like structure which is nothing, but a mesh work of silk protein out here. So, this structure somewhere or the other has a ability to you know change these two things thermal to electrical vice versa, and they added one more thing say based on the light they respond. So, what was the kind of beginning of this of this kind of study was this membrane is thermo sensitive membrane this is light sensitive membrane.

In other word, it is almost like a t p v thermo photovoltaic membrane will come across this one more thing I wish to express is go to the slide I wish you guys please download these papers or I will try to add these papers at the end. So, go through these papers. So, this membrane is acting as a thermo photovoltaic membrane which is helping this structure to maintain the ambient temperature. So, this was the premise with which all these things have started how to study this this is very challenging problem this is not something. So, easy you know first of all you have to collect these hornet nest. So, professor ishay collected all these things from in the mediterranean region, and after collecting. So, the hornet nest the silk top comes like this.

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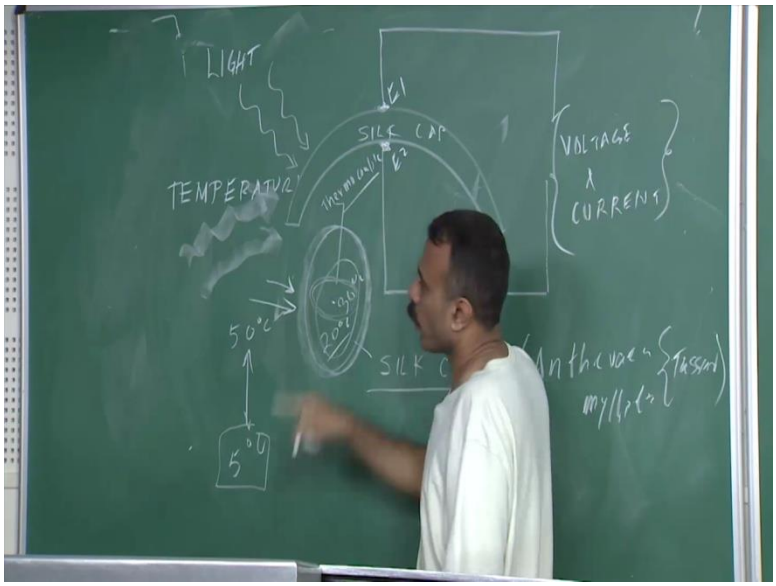

So, then what he has to do is in order to understand this he has to connect a electrode like this, and a electrode like this across across this particular membrane just is having this silk cap like this, and a electrode is connect this side, and a electrode is connected this side now this is exposed to different kind of light, because you are studding the photo effect as well as different kind of temperature, and what you are monitoring is depending on the temperature, and the light on this silk cap this is electrode one this is electrode two you are monitoring the voltage and the current this is the basic premise what they wanted to do now think of it. Now if I show you the picture again. So, this is what you are doing you are removing this white part what you see in the slide, and on either side of it you are connecting those electrodes. Now I will show you a real picture. So, this was the whole idea was this thermoregulation is regulated by charge transfer. So, it has been observed hornet nest maintain a temperature.

So, if you see a middle line twenty eight degree centigrade irrespective of anything whether their temperature is changing it may go up it may go down across the day, but the hornet nest temperature remains at around twenty eight to thirty degree centigrade there is no shift in it and as a matter of fact is the same thing which is being observed in the silk cocoon, and I will give you the reference the silk cocoon they could also do the same thing, and we will talk about talk later about that experiment. So, it means as a matter I will just let me just take the liberty to explain that experiment. So, this experiment was done like this. So, here is a silk cocoon. So, this is a pure cocoon now it

is completely there is no, and this was done with anthereaea myllata or or this is also called tussar cocoon. So, what was being done was you kept a thermocouple inside it. So, here is this thermocouple…

Now, you are just changing the temperature. So, you keep this cocoon for example, at a temperature of say fifty degree centigrade, and vary it all to say five degree centigrade, but what you will observe inside the cocoon is without by the way when you are doing these kind of experiments in real you have to remove the dead animal you have to kill it, and you have to remove the dead animal, because you are only studding the property of the membrane now if you measure the temperature inside it you will see at the fifty degree this this will maintain at around thirty degree centigrade, and if yu are keeping for long period for at five degree it will maintain around twenty degree centigrade.

So, from starting from these two I was showing a these two pictures whether it is a silk cocoon or whether it is a hornet nest the temperatures are being regulated they all have certain thermo regulatory mechanism, and this refers I will add this reference for you people at the end you can go through that paper this is a much more resent paper this was published in twenty twelve.

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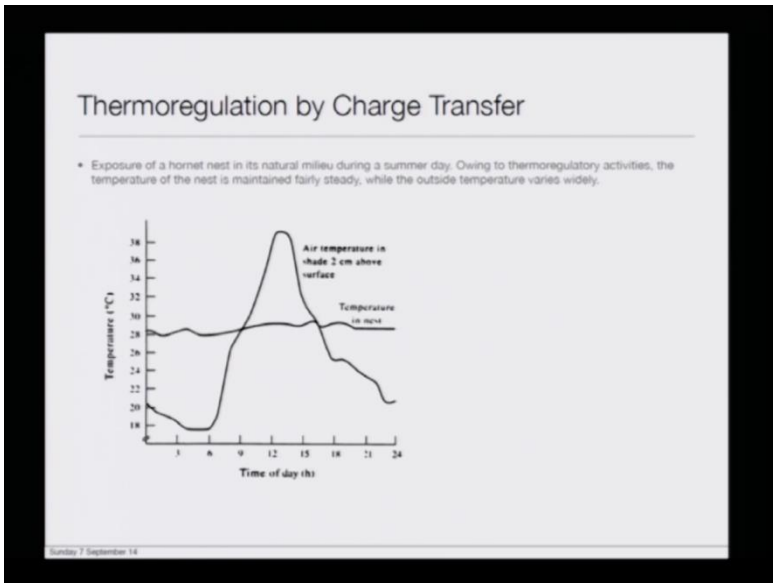

So, coming back this is what inspired ishay at the point of time this was a slide which this was from ishay's paper itself that it maintain the temperature inside it, and how it does.

So, what ishay pretty much clamed is that this particular membrane translate transform the electrical energy into thermal energy, and thermal energy into electrical energy, and same with the light light to electricity likewise which essentially is a photo voltaic property now we will see what are the results you obtained, and how far we have understood about this process. So, now, if you look at the ultra structure I will show you the ultra structure this is how the ultra structure of the silk looks like it is a mesh work. So, basically what you see here is a mesh work, and this is basically taken a scanning electron microscopic picture which will give you an idea.

It is almost like a porous membrane in the right hand side of the picture you will see the hornest nest in black, and white, and those white what you have done is you have taken those white caps, and these sections were made, and this pictures were taken this is how the ultra structure looks like, and this ultra structure consists of both fibroin, and the sericin protein. Now if you look at the photo properties of hornet nest exactly the same experiment. So, the experimental set up is in front of your eyes.

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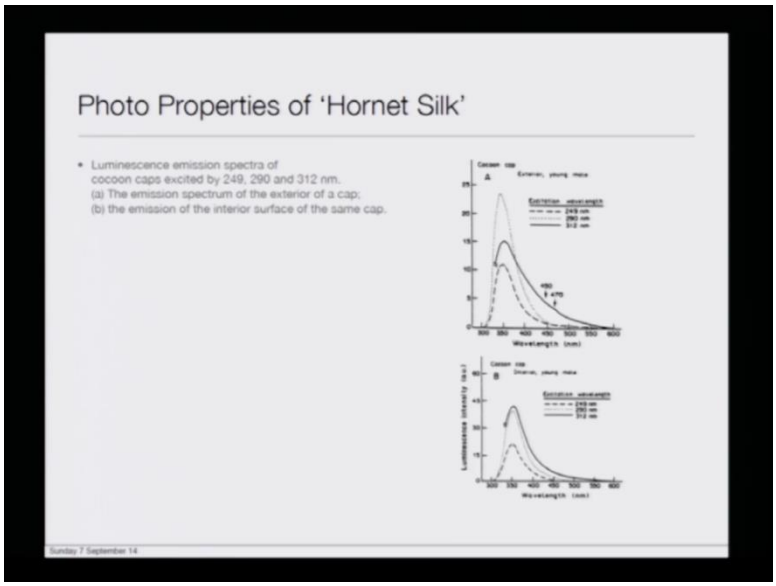

So, if you look at the photo properties of hornet nest. So, this is what you will see is if the cocoons are exited at around two forty nine or two ninety or three hundred twelve nano miter you will see the emission spectrum. So, emission spectrum is coming at you know at around depending on what you are if if you are exciting at two ninety nano meter you are seeing an an emission spectrum for at around you know near to three fifty,

and with a slight shift at two hundred forty nine nano meter there is a slight shift. So, it is pretty much it is all concentrated around three fifty, when you see the emission there is something very interesting depending on which side is exposed whether the inner side.

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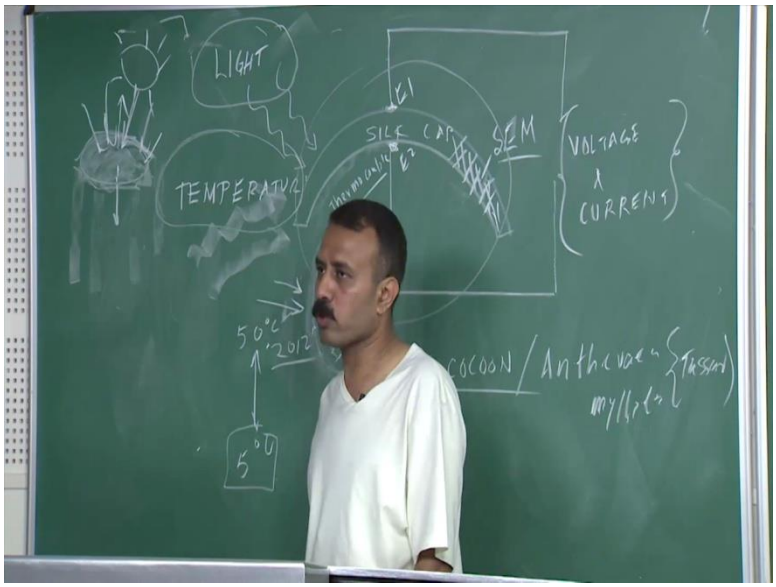

Say for example, what I mean by the inner, and outer side, and you have to again go back to the structure. So, this is how it is covered fine. So, it has one face which is facing down wards another face which is facing upward. So, if you take the downward face the one which is facing inside the nest it has different luminescence property as compared to the face which is outside. So, this is the surface which is exposed to the direct exposure to the sun or to the light the other one is kind of underneath it is something like this this is the one getting exposed to the sun the other one is different if you see these two plots now on the slide you will realize that they show a different kind of intensities in terms of it.

But in terms of their emission spectra they pretty much remain constant. Now moving on to the next slide this is how I was trying to explain you people through this diagram. So, here if you go through the slide, you will see how these connections in the real life connections are made again these are all from the eshay's paper what I have already described you people, and if you see this. So, you will see this is the cap like structure what has been removed from from a hornet nest after anesthetizing it.

So, all the life insects are not biting you or not. So, ever, and then you connect using colloidal silver you are connecting a wire on either side of the membrane.

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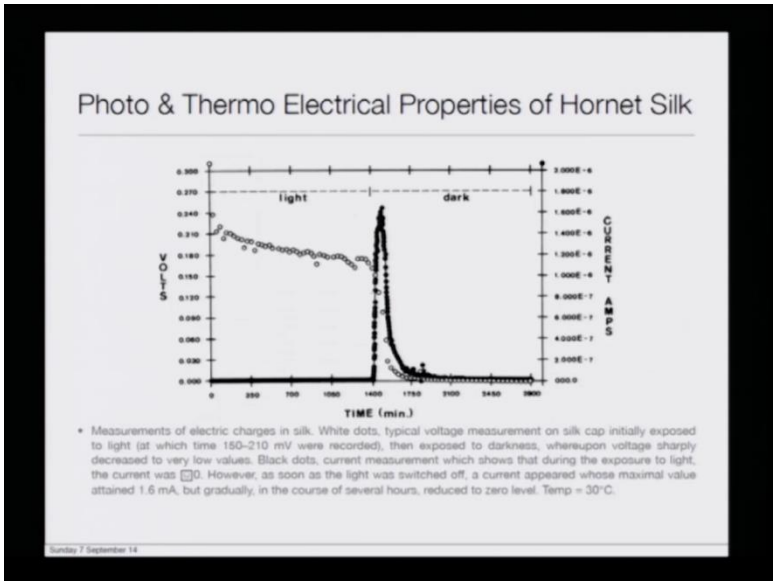

now let us see how the electrical properties are changing. So, we talked about the photo, and thermal electrical properties of hornet nest. So, if you look at this slide this this is a this you really have to look at it very carefully. So, look at light, and dark situation while there was light. So, there are two symbols here one are the filled circles what you see here, and another ones are the empty circles the empty circles are the one which is indicating the voltage, which is on the left hand left left hand side on the left hand side left hand axis. So, there are two y axis here on the right hand you are seeing the current on the left hand side you are seeing the voltage. Now if you see it during the light the voltage was very high as it dark as you are moving.

So, its diurnal its during the day there is a light phase, and it is a dark face, because it is day, and night during the night the voltage drops down, and in between while the voltage drops down there is a spike of current which you see there is a spike in the center there is a sharp spike, and then it falls down. So, if you go through it is measurement electrical charge in silk the white dots typically voltage measurement of the silk cap initially exposed to light at which time one fifty milli meter is recorded now when exposed to darkness, then the voltage sharply decrease to a very low valley that you could see here at it has fallen down where as the black dots which is the current measurement which

shows that during the exposure to light the current was almost zero; however, as soon as the light was switched off a current appeared was maximum value at in one point six milli ampere, but gradually in the course of several hour reduced to zero, and this all this measurement was done at thirty degree centigrade. So, now, what we are talking about these natural materials what you see out here responds to temperature oh sorry responds to light.

As well as temperature coming to the temperature definitely they respond to light as we are dark as the dark approaches as darkness approaches day to night the voltage changes. So, it means what it looks like as as if you know they are just a inert cover they are not inert cover they are electrically active cover, and this is the picture which is taken from all those two references what I give given you this is from the second the review paper by late jacob ishay. So, for his time these were some of the very very seminal studies what he conducted like you know this was never done before. So, this material has some very interesting thermo voltaic property.

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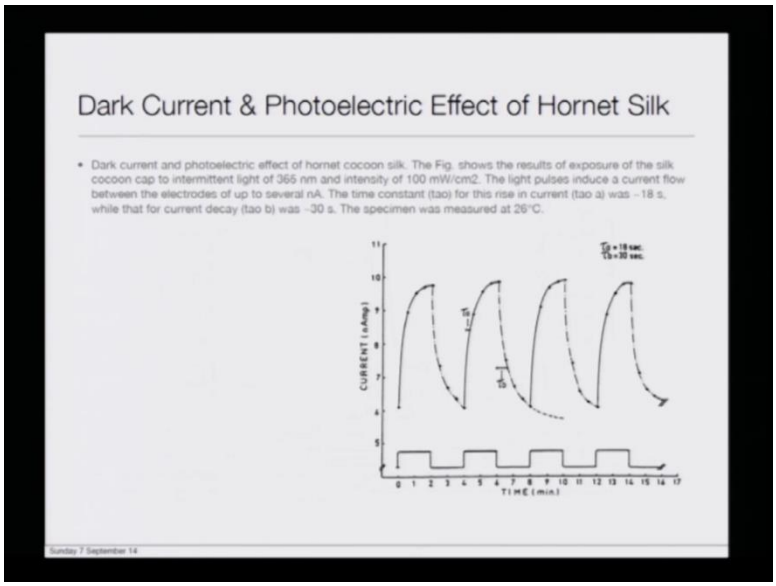

Now, next we come about the dark current, and photo electric effect look at this trace very interesting study the dark current, and photo electric. So, what you see out here look at carefully there are spikes there are you you see these underneath line what you see. So, shows the result of the exposure of the light cocoon cap intermittent light three sixty five nano meter with a intensity of hundred mega voltage inter scova at the light percent uses

a current flow between the two electrodes up to several nano amperes, and if you use the time constant which is shown by tau tau a, and tau b you see eighteen second, and nineteen second.

So, you see when you are exposing you are giving a light the… So, if you if you remember previous slide when there is light there is there is no current, and whenever there is a darkness there is a spikiness of current. So, light dark light dark light dark, and you will see whenever there is dark there is a spike of current whenever there is light the current will fall down. So, this shows that this membrane what you are what we are talking about membrane is a light sensitive membrane it has photo properties, because we saw about the photo characteristics about its absorption, and emission now we are seeing the functional properties that it indeed shifts it is there is a charged movement based on the exposure to light.

Now, let us move onto the next slide which is the thermo current. So, as of now we talked about the light we haven't talked about the thermo current now let us talk about the thermo current. So, if you see the membrane has been vary from a temperature of say twenty degree to thirty degrees. So, here there are thirty three degree look at the slide twenty to thirty three degree. So, if you are if you observe it carefully you will see as you are going to three degree centigrade there is increase in the current as you are bringing down the current falls down again there is a increase it falls down again there is a increase it falls down there is a increase you see there is a cyclic fashion.

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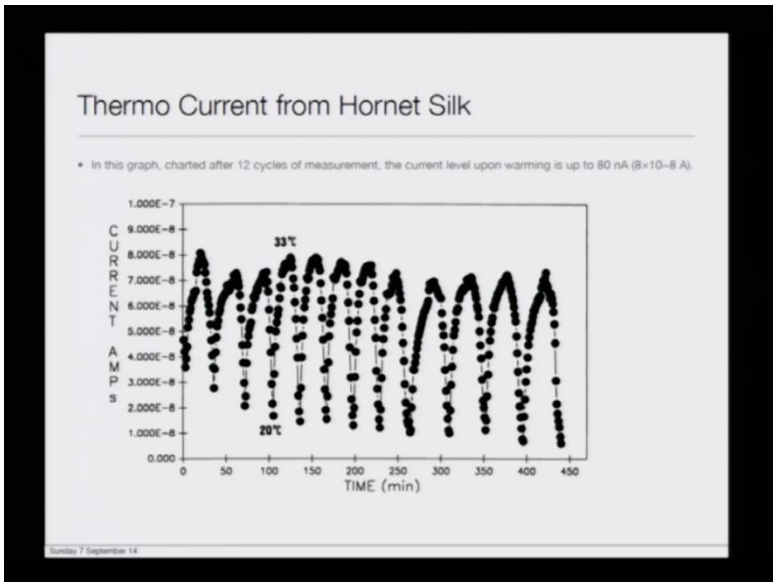

So, it means just like light light if you see the previous slide just take the light as the light increases current falls down as there is a dark the current rises same way as a temperature goes up there is uralic as you know shift it as it falls down you see. So, this is how there is a cyclic fashion this is happening. So, this is very subject they have another thermo electric property which is fairly unique, but you have to keep on shifting this temperature there should be a shifting temperature without if you do not shift the temperature this you would not be able see this kind of effect .

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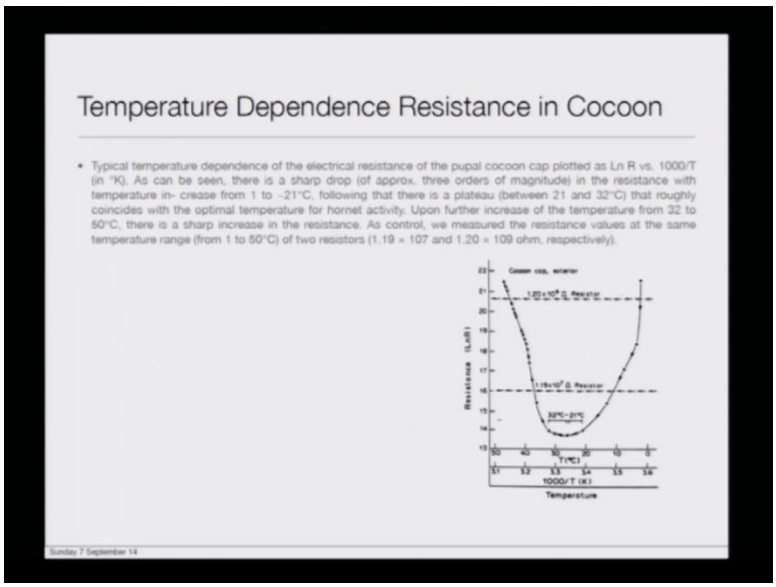

So, now moving on there is a temperature dependence resistant in silk cocoon. So, this is what is being shown here. So, if see follow this graph very carefully. So, see at the y axis sorry in the x axis you are seeing the temperature. So, if you see the temperature very carefully at around twenty, and thirty degree centigrade there is some the whole resistance goes down. So, the typical temperature dependence, and electrical resistance of the pupae silk cap plotted verses the absolute temperature can be seen there is a sharp drop approximately three or to some magnitude in the resistance with temperature in case of between one to one twenty degree centigrade following that there is a plato between twenty eight to thirty two degree centigrade at roughly coincide with the optimal temperature of the hornet activity.

If you remember if I go back to this slide the optimal activity could be seen at around twenty eight to near about twenty eight to thirty. Now if I follow this one that is exactly what you are seeing at around twenty to thirty near about thirty you see an optimal temperatures. So, there is a temperature dependence. So, the membrane itself changes its property it is thermo active membrane it is a light active membrane, and there are lot of things to understand that you know how with the temperature current is changing how with light along with temperature the properties are varying.

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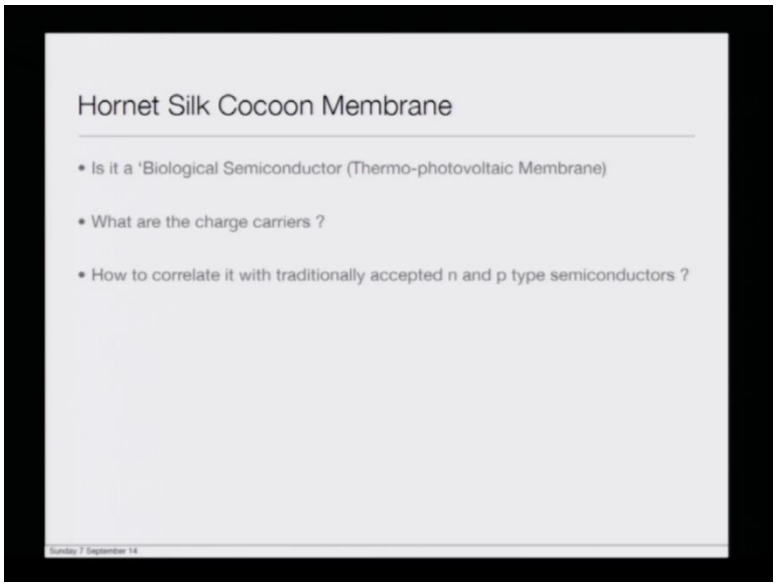

Now get there are several things which it is believed that this is what is regulating this kind of temperature region. But what we do not know, because of now is it what we are

seeing is a biological semiconductor thermo photo voltaic membrane or what are the charge carriers really do not know how to correlate it with traditionally accepted n, and p type of semiconductors we know this part that it indeed shows a thermo photo voltaic membrane it acts like that, but what we do not know what are the charge carriers that needs a much more better understanding. So, in order to summarize this. So, we talked about today we started with the basic problem of thermo regulation how thermo regulation is conducted, and you saw the ultra structure of the hornet silk.

Then we talked about the photo properties of the hornet silk followed by the electrical properties, and the electrical properties we talked about in the presence of light the current is less, but as you take it to the darkness the current increases. So, there is a light, and dark situation, but in case of temperature what you see as it as you increase the temperature to certain optimal value the temperature kind of goes a the current goes up, and then it falls down. So, there is an optimal range for this kind of material to function, and that is why I told you that, and then we talked about the temperature dependent resistance in cocoon, and at a specific temperature twenty to thirty degree centigrade.

You see there is a significant fall in the resistance of the membrane, and there is a sharp rise in the current followed by these some of these interesting questions which in future will be able to answer is this a biological semiconductor what are the charge carriers how to correlate it with traditionally accepted n, and p type semiconductors.

So, I will close in here, and we will go to the part two of this where we will be talking about the other membrane, what we haven't talked about yet is this membrane will be talking about the bombyx, and the anthereaea mylleta, which we have not talked yet. We have only talked about a wild species, which is this one. So, I will close in here; in the fortieth lecture, we will talk about this section.

Thank you.