Bioelectricity

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Lecture – 1

Welcome to the NPTEL lecture series. So today, we are introducing a new course on Bioelectricity. So the course consists of forty lectures and the course has been divided into five different modules and each module is purely independent of each other. I will try to treat each module as an independent cluster so that at one point which one module you want to really go through first, may help you, (( )) site very fundamental basics. The basic requirement that I kind of expect from this that up to your high school, you have gone through some of the very very basics of electricity, that the charges been carried in different forms. It could be an ionic charge; it could be a flow of electrons. So the way, and this much fundamental understanding of Ohms law – V is equal to I R, any point of time voltage is equal to the product of current and resistance. As long as these simple concept or concept of a capacitor, what is a capacitor and what is an amplifier, there is good enough for you to you know to appreciate this course.

What is the philosophy of this course? Today, what I will do, I will give you some basic ideas about the philosophy of this course, and then I will move on to the overall layout of this course. Why bioelectricity? There is electricity all over the place. So all of you are aware of that your, I am talking because sound energy is converted into electrical signals and electrical impulses. I am standing in this room, this completely lighted, because there is a source of electricity which is taking care of it. So, what is the origin of the electricity? Electricity is very much a part and parcel((Refer Time: 02:14)) of the biological system. If you look all around you, say, for example, think of the nerve impulses, those are nothing electrical impulses, which are flowing in your body. The way your cardiac beat, cardiac cells beat, the way your heart beats that is nothing but the flow of electrical impulses, which regulates the flow of blood all over your body.

The memory acquisition phenomenon, it is an electrical phenomenon. The moderation, the propagation of nerve impulse, the way your muscles respond to some kind of a stretch, some kind of a strain, there is a translation of mechanical energy into electrical signals. Or say for example, in the case of touch me not leaf, you touch the leaf, it folds. It's electrical phenomena, it is a bioelectrical phenomenon. Think of the situation of Venus

flytrap, which catches the insects ok. These are the plants, which catch the insects. So, basically, the insects come, touches on certain surfaces of the flower and the flower starts closing. It is another electrical phenomenon. So they are some touch sensors, which senses that impulse and translate that impulse into electrical signals, and in a result is the trap gets closed and the insects get trapped inside that whole flower. And it is being finally digested and used for food. So these are the carnivorous plants.

Similarly, there are several inanimate ((Refer Time: 04:21)) objects, which exhibit electrical phenomena something like back in the hornet nest, this is back in the nineteen seventies, there was significant research which was done. It is in the hornet nest, it has been observed that hornet nest has a thermoregulatory property and that thermoregulation is driven by the hornet cell cap, which is present there. In other words, the hornet cap is a thermoelectric membrane, those of you from your basics high school if you remember something like Peltier effect, Seebeck effect, where which are thermoelectric. So you give thermal energy, it is translated into electrical energy or vice versa. If you give electrical energy to a material, it is converted into thermal energy. So these kinds of thermoelectric materials are being seen across nature.

Apart from it, you will see examples of fireflies… Or think of the situation of photosynthesis, where solar energy is leading to the emission of an electron and that electron eventually, basically a photon is being absorbed and an electron is being emitted and that electrons hop through inside the plant cells and leads to the generation of food, which is under photosynthesis. Photo means light, synthesis is a process by which bigger molecules are being synthesized. So all these phenomena that you look across nature are bioelectrical phenomena. And they have been exploited or they have been understood from a different perspective. So, bioelectricity is a very very broad term first to start off with.

The whole body is governed by bioelectrical phenomena and understanding of this individual bioelectrical phenomena has profound implications in understanding our whole existence. So if you look the way it has progressed in the last two centuries, I would say definitely one and half centuries, the progress in the measurement of charges, electrical impulses leads to the development of the whole field of bioelectricity. Look back at the time of Volta, look back at the time of when the impulse was recorded from the frog's muscle, the twitch which was recorded. So these are long back Volta, galvanic – these

are some of the like the stalwarts ((Refer Time: 07:13)) or you can say the founder, father of the whole field of electricity.

So it is, it deeds back to that time, from the time actually as a matter of fact ((Refer Time: 07:24)) electricity was initially being very correctly observed in biological systems. It is long back. And then of course, the whole field of electrical engineering develop, and parallelly the progress of bioelectrical phenomena or understanding bioelectricity became a function of the different devices we have developed in the domain of electricity and electronics. Especially in the later ((Refer Time: 07:49)), of the last century, post the nineteen fifties with the discovery of silicon-based electronics, there happened tremendous improvement in the development of amplifier circuits, or in the development of different electronics electrometer, which could major current on the nano ampere level with a decent amount of accuracy. So if we look at one side is all these phenomena, which is taken place.

There is another side, where we are talking about all the different measurement techniques, because whenever we talk about biological systems essentially we are measuring currents of pico ampere, nano ampere, Femto likewise very low currents, we are talking about. We are not talking about a grid where a huge huge amount of currents are flowing through. We are talking about something which is a fairly look, in order to major such currents you need different kinds of devices. You cannot afford to use your regular multimeter to do those recordings. So you need very high impedance devices, which can measure those.

So if you look back since nineteen or from seventeen hundred, I would say, the field has taken quantum jumps with the discovery of newer and newer measuring techniques. And currently with the advancement of amplifiers, high-end amplifiers we can measure extremely low electrical potentials in all different forms of systems or different systems which are existing in nature. So a part of the course, will concentrate on all these different kinds of devices that will be dealing with. Then we will be dealing with any electrical phenomena has a direct link then this could be used for energy harvesting. So we will talk in detail of different energy harvesting modules which are being currently under in developments, especially you have to realize that more and more we are heading for sustainable energy. And our biggest hope is learning from biology, the sustainable root to harvest energy.

So we will be talking in-depth about different modules like an artificial leaf, how from the leaf there are people who are trying to emulate the photosynthetic power of the leaf to harvest energy, one of the topics which will be going to go through extensively. Apart from it will be talking about the examples where the different dyes, different color dyes of nature are being used like Hibiscus, which are being used to develop dye sensitize solar cells. So, these are the molecules that are all across nature. And they have a tendency to absorb light and eject an electron and that electron could be funneled and could be used for running any kind of low power electronics devices at this stage.

So we will be talking about those small dye sensitized solar cells, will be talking about back-back based systems, where mechanical energy is being translated into electrical energy which has been, is in progress for a long time. Because those of you grandfather or you know great grandfather riding a bicycle which has a dynamo attached it. So basically while the bicycle they are riding, so the mechanical energy which is generated well the bicycle is moving is translated into electrical energy using the dynamo. And you could see that without any source of battery or anything, the light is glowing in the night. So if you look back and go online or ask your great grandfather or grandfather, they will tell on that is how they used to travel with a bicycle when in the evenings. When there is no street light or something like that. So there are several examples where electrical phenomena have been extensively used for harvesting energy.

Apart from it, we will be talking about the man-machine interface, where we will be talking about how the, say for example a person is having a blindness. So basically that means the image plate or the retina of the individual is not functioning. Is there a way, we could implant and synthetic or electronic camera in front of the eyes so that the image which is formed in eyes could be interfaced with the brain. So we totally bypass the sensory mortality, because this has been successful in cochlear ((Refer Time: 13:31)) implant in the ears. So those are cannot hear, they put a synthetic cochlear or bioelectronic cochlear or basically an electronic gadget, which could sense, in other words, you are essentially (( )) putting a mike out in your ear. In that mike is being connected to your brain, so what is your hearing is bypassing your ear, because your eardrum is, your eardrum and the cochlear structure is no more rarely fractural, so you bypass everything and you interface it with the brain, so that is possibly another way. Or say for example, is there a way for spinal cord injury patient, we could implant some electronic devices with at the zone or at the

site of injury which could help this person to you know get back some of the lost degrees of freedom in terms of movement, is it possible?

We will be talking about here some of these seminal experiments, which have been done by people or scientists across the world, where they could dictate a monkey using a computer or vice versa. So basically, in other words, how man is interacting with a machine, so that is another area that would be highlighting. So this course encompasses a wide range of different topics, which has been put under five different headings. And the goal is to give you aflare of bioelectricity and inspire you to exploit the subject for the future because the future lies in all forms of sustainable growth, sustainable development, sustainable energy because we cannot rampantly misuse the natural resources for our good. We have to very careful and critical

because you have seen places like Tokushima or you know places like Chernobyl a kind of a nuclear disaster have taken place or several other places which are not really reported that.

So we need different other sources of energy and some of our hopes are lying in using the biological system for energy harvesting, in the field of solar energy where we are pretty much heading the roof with the silicon-based crystalline, silicon-based electronics. Because, currently in the lab conditions, the maximum efficiency you could get it is around seventeen percent. And the cost recovery is a very challenging problem because the amount of intense investment, which is being done in developing a silicon-based electronic system, silicon manufacturing system is enormous, could we really you know bypass that could they have to be newer and newer material. So we will talk about some of these newer and newer materials, which are there in the dark but needs a lot more research from your people.

Apart from it, another area, which people are trying to explore is the way biological system which is a byproduct of photosynthesis. How they are splitting water because this is a way how hydrogen can be generated and eventually hydrogen could be used as the source of energy. So what are the different techniques by which water could be split, what are the different molecules which could be developed very cheap? So in the case of biology, the leaves contain, something called a manganese cluster. It is the cluster of manganese which remain indifferent oxidation state and the water molecules get strapped, it is mean stripped off and you get the oxygen and as a byproduct and this

whole process people are trying to emulate using different kind of complexes which will emulate the manganese cluster.

So this is the wide range of bioelectrical phenomena and the other side is where people are developing different kinds of a supercapacitor, biological materials. We will be talking about some of the most recent advances where people have developed supercapacitors from biological systems. People are trying to develop bio batteries using different kinds of sources. So these are, these all like whenever you pick up a textbook on this, there is hardly any textbooks, which exclusively deal with all these things. So it is a very broad subject. So, this forty brief forty lectures is basically to give you aflare of the broadness of the field and the beauty of this whole field, its a standalone subject, and its a very passionate subject, if you look at it. I mean there are so many things, what you can do, so many products which can develop so many fundamental studies which could be done, but it needs a different kind of flare to appreciate all these things.

So with this introduction what I will do, I will give you the outline of this, what are the different modules I do, I have pretty much talked it out, but I have given you on the systematic layout that how will be dealing with this different modules and what are the different things will be dealing with. So let me give you an overall outline of the different modules, and from there, we will talk about how we are going to deal with these individual modules.

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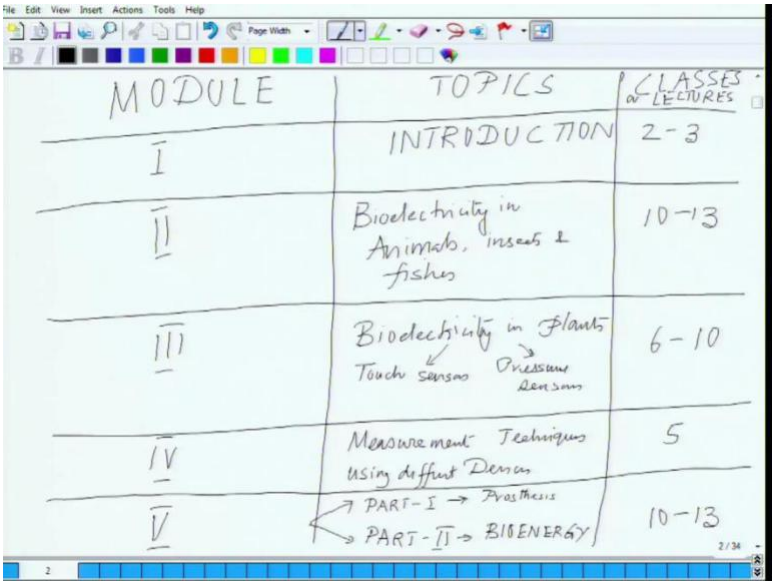


So welcome again, so the course title is Bioelectricity. So, I told you there are five different modules we are dealing with. So let me, the module, and for the topics. What are the different topics we are dealing with? So module one that is an essential introduction to the subject, so coming to a module one, coming back to one, so here basically what we will do, in module one we will have three lectures, two or three lectures, you know this kind of flexible. I will introduce you with some of the different examples of nature, what is happening in a diagrammatic manner. And based on what I am drawing now ok, and we will try to get a formal definition of bioelectricity and from there we will lay the course, how we are going to follow in the subject and section.

So coming back, so let me put another column here, which is classes or lectures. So there will be two to three lectures out here in module one, which is the introduction. Module two will be dealing with bioelectricity in animals, insects, and fishes; so pretty much all in the animal kingdom. So here, I am keeping it very broad, we will talk about the, we will introduce ourselves with the membrane potential in the animal world. Then we will talk about the nerve propagation, which is taking place in the animal world. After that will be talking about the action potentials, we will talk about memory acquisition processes, then we will talk about the reflux circuits; we will talk about vision, how the image is being formed. Then we will talk about the hearing, and mind it all this will again come back. So parallel what I will do, what are the cochlear implant, and all these things I will include, both of them simultaneously. And will be talking about the different situations how spinal cord

injury situations could be you know could be bypassed. So this is all about the bioelectrical phenomena, so you will have approximately ten to thirteen lectures devoted to this area.

And from here, we will move onto the bioelectricity in plants. So here we will talk about some of the plants like you know touch sensors or pressure sensors likewise; especially plants like mimosa pudica, touch me not, and the insectivorous plants like you know those which traps the insects and will partly introduce you to the whole photosynthetic machinery here. How the photosynthesis taking place, how the electrical events within the plant lead to the generation of energy. So this is where we will be devoting around six to ten lectures.

So then from there, we will move onto module four. Module four is measurements of electrical impulse, measurement techniques using different devices. This is the section that will cover approximately five lectures. So in this section, we will be talking about electrometers, those of you remember during your school days may be standard seventh or eighth, we introduced to ((Refer Time: 25:12)) golden electrometer. If you remember, there is a charge if you wrap something, and you see the charge moment; so currently those old electrometers have become electronic devices, now it has translated into electronic kind of ion. They are very high-end devices in terms of their measuring capacity, they can measure around you know nano ampere, pico ampere currents with the highest fidelity.

So will talk about the electrometers, will talk about the high gain amplifiers; will talk about the patch-clamp setup, where which are used for measuring the electrical impulses or the flow of current through a single channel. So in that context will talk about the single-channel recording, will talk about the development of different fluorescent molecules, which could help to image electrical phenomena something like calcium imaging or there are molecule, which has been

developed. And some really very intense research has been done in developing some of these fluorescent molecules, which changes their color with the change in the potential. So we will talk about some of those techniques. Apart from it, we will talk about the voltage clamp and current clamp under the patch-clamp. And then we will talk about if the time premise will talk about a little bit about the electrochemical measurement techniques, which helps in the bioelectrical process. So this is our module four.

So from here, we will move onto module five. Module five is a very interesting module, this module will take you from one end to the other end. This is the module where we will be talking about the man-machine interface; we will talk about prosthetic retina in terms of putting a camera in front of the eyes and interfacing it with the brain. We will talk about a cochlear implant, here we will talk about the different electronic gadgets, which are been used for deep brain stimulation and the idea of brain chip, idea of spinal cord chip, what is the current status of research. And here I will introduce you to some really very good materials and I will introduce you to some of the stalwarts in this field whose work you can read and kind of get an idea about how the progresses are been made in this phenomenally beautiful area. And a very very challenging area, because the very moment we talk about, so here I will highlight something.

The very moment we talk about the man-machine interface; in other words, we are talking about, you have to engage an electrode inside your system. An electrode is a foreign material, so that needs an intense understanding of material properties of the material, which you are introducing into the body and that is the whole field in its own authority. Because when we talk about like you know, you put a deep brain stimulator or electron inside your brain, it is a totally foreign material which is entering. How do you handle that it is not easy, it is not easy really even to think in that way like you know what a big deal? It is really challenging. And that's where lies the major challenge of prosthetic bioelectronics. The prosthetic area of bioelectronics where people are really is developing, so there is one there are groups that are developing newer and newer by compatible electrode materials, which would be put inside the body without much immune reaction. Because you have to realize that you cannot pull that out electrode or gadget from time to time, and you know clean it up and put it back; it is there, and it has to be there for a while, its just like you are putting a pacemaker.

It is another area, which will be dealing with. A pacemaker out here, so ((Refer Time: 29:58)) ensures the pacemaker does not have an immune reaction or something of that sort. So, these are the things we will be talking about in this section part one of it.

So essentially, I can divide this into two parts; here is part one. This part one will be dealing with prosthesis mostly and mostly in the animal kingdom. I will be dealing with another part, so part two will be dealing with, how energy could be harvested from the biological systems that fall under bio-energy and that is where will be talking

about as I was mentioning in the earlier half of this lecture. In that, there will be talking about the dye-sensitized solar cells, artificial leaves, bat back energies, and deriving energy from inanimate objects. And if possible we will talk about the fireflies and will talk about other different dyes that are found all across nature, which has the potential to be exploited for electronics applications. So that will be essentially our part two, where we will be talking about bio-energy. And this is the part which will be dealing in another ten to thirteen lectures.

So this is in as a summary I could say how the course will progress will talk about, I have partly introduced due to the subject. I will probably take one more class to introduce in the depth of these different aspects, how you are going to move on. The whole graphical understanding of it that how all these things are happening, then I will be moving onto the individual module and as I have told you already, you can study the individual module as a standalone module, I will try to keep it as independent as possible so that you do not need to follow a sequence really. If you know the introduction, and the broad outline of the course, you can pick up any of the modules and do a complete in-depth study of it without any problem.

So apart from it, what I will request you, people, that in every class, I will try to give you some of the references which because of course because of copyright reasons and everything, I cannot really handout like that, but you people can independently download them. I will give the link and will try to go through those ok that will be extremely essential. If you invest a little bit of your time to go through them, so that will help you to understand some of these processes and that is the reason why I am not even giving you some of these handouts, because there are copyright ((Refer Time: 33:17)), and I don't want to do that.

So there will be materials, which I will be providing, I will be providing the link we will have to go online and search or download. If the link is functions with your system and definitely you will be downloading some of these materials, which will be really helpful in this course. And just while concluding this first lecture, I will tell you just brush-up some of the basics of electricity that will help you to appreciate this course in greater detail. And you have to be a bit more imaginative for this course, this is not really an information-based course that. There is information I have you know transferring information to you, its more of an imagination. This course needs a bit of a, so high imaginative power

to think from a very global perspective that how things are going to change in the next hundred years; thinks are in the phase of changing. It is just we are not seeing them, but things are changing across the world. So I will expect you to be slightly more imaginative you know visualize the changes that are coming on our way, so the way we see life, it is going to change in the next hundred years – big time. So with this whole, different five modules of the course how you are going to progress so I will be closing here, and we will come back with our second lecture, which is part of the introduction and there will be talking about the graphical layout of the course.

Thank you.