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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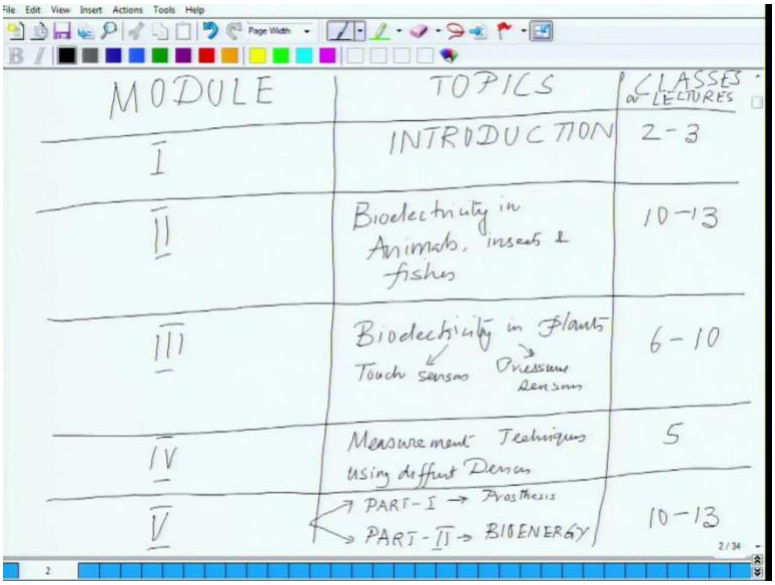

So welcome again, so the course title is Bioelectricity. So, I told you there are five different modules we are dealing with. So let me, the module, and for the topics. What are the different topics we are dealing with? So module one that is an essential introduction to the subject, so coming to a module 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.

Bioelectricity

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Lecture - 2

Welcome back to the NPTEL lectures on Bioelectricity. So in the last class, I introduced to the curriculum what I am going to follow, and I talked to you about the five modules under this course to be dealt with, and I also highlighted the fact that each of the modules will be standalone. So you really can pick up any module and go through it. So today what we will do is, I will give you a graphical outline of the way the course will progress, so that will kind of giving an idea where everything fits in because whenever we do a course, kind of you lose track like what is the central theme, how this whole course in its structure.

And especially in a field like bioelectricity which is so diverse from inanimate objects to animate objects, the insect world, the world of plants, and everything. So, where all these things kind of converged, where really why we devote time. So today's class will be kind of giving you an overall outline, the flow diagram – how you are going to progress; of course, your five modules will remain there. Those are the five modules, we will going to follow, but all those five modules can be put under one graphical representation, and that graphical representation is extremely essential for you people to kind of appreciate all other integral theme or I should say the central theme behind this whole exercise of forty lectures. You should be able to correlate each and every component of nature and either you can go on very fundamental research, fundamental studies about it or based on the fundamental findings, you can think of how this could be used for different kind of applications like biosensors or you know prosthetic devices or bio-energy, ((Refer Time: 02:19) application all over the place.

So the way I am going to put the graphical representation just let me give you a verbal idea about it. So first of all, it would be in a tabular fashion depicted. So in the left-most column, we will talk about the system which will be starting, it could be an inanimate system, it could be an insect system, it could be the systems of animals, it could be a plant system then will talk about the examples under those headings. Then will talk about the exact physiology or the exact bioelectrical aspect we are going to study in that aspect and what are the techniques which

involved in those kinds of studies. And the result of those studies where we can take it ok, so overall starting from the basic, identifying the system, characterize the system, understanding the mechanism of the system, and the tools employing into the system, and last but not the least is where we can take it from there.

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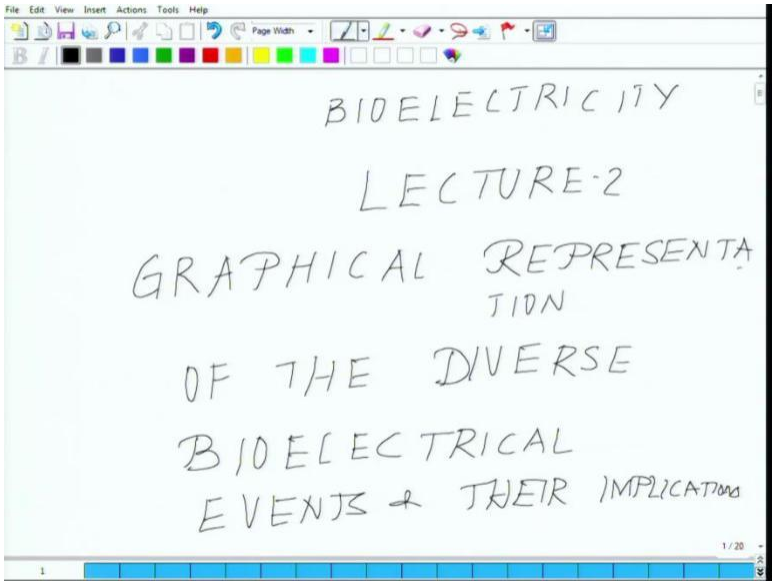

So let me start by slowly drawing the chart with you, at every quarter I will stop, and I will give you my opinion on it and let us get the whole graphical sketch of the whole course. So coming back to the so this is where we are Bioelectricity, this is lecture two and the title of this class will be the Graphical Representation of the Diverse Bioelectrical Events and Their Implications.

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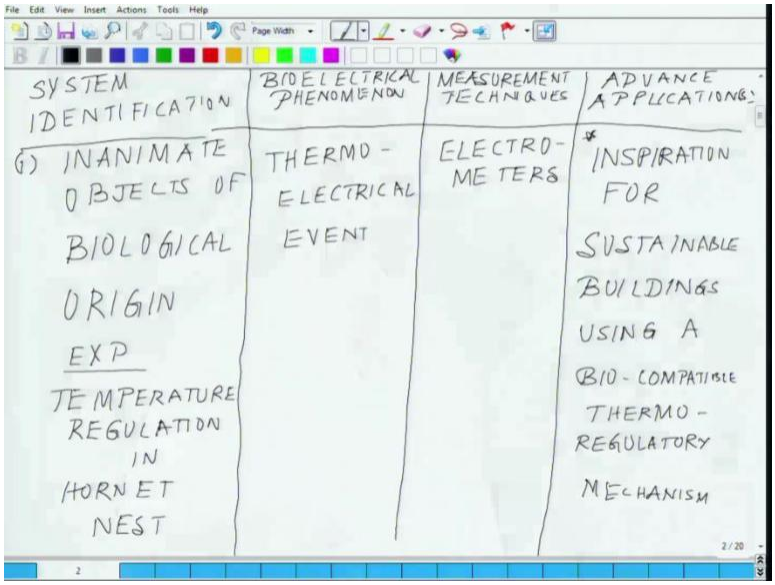

So to start off with as I told you so will be, the system identification that will be our first system identification this is the first step. After the system identification, we will move onto the bioelectrical phenomena of that system. Next, we will talk about the measurement techniques; how we are you know, measurement techniques. And then we will talk about the advanced applications. And I expect you people, to kind of keep this, so what I expect is that I want this to be an act as a guiding principle or should be part of your brain map.

So whatever in the next rest of the classes what I will be teaching, the rest of the course, you should always try to correlate with where exactly all those small pieces of information or puzzles are fitting. So at the end of it, you should have a very holistic picture of nature how nature is surrounded or pretty much bioelectrical phenomena is should say an integral part of the evolution of nature itself. And whatever we studying in basic physics they are all over the place in biology, all over the place. It is just we have to identify the system and kind of you know, quantify the system and establish a link with the existing laws of nature which has been governed in the physical world.

So coming back to the first, system identification part; this is our system one. So, basically, we will be talking about an inanimate object as the first one, inanimate objects of biological origin. So in this context, I will take you back to some of the most fundamental studies which were done

almost I should say forty to forty-five years back, while there are some people who studying the thermal regulation behavior in the hornet nest. So all of you must have seen the hornet nest at someplace or other, you know the hornet nest, it is kind of in the corner of the building or somewhere. And a very intensive study was taking up somewhere in Mediterranean in his rail by Jacob Ishee and other coworkers to figure out, how these different nests of nature maintain regulate their temperature. And in that journeying of last forty years, what all has been discovered, what are the different bioelectrical phenomena.

So in this, the example will be, the first example out here will be, temperature regulation in hornet nest. So the bioelectrical phenomena are out here is the thermo-electrical event, so talking about the thermo-electrical event, so we will be talking about some of the very basic events of nature like sea beck effect, Peltier effect. So these are some of the most fundamental properties where thermal energy is being translated or transforming to electrical energy and vice versa, electrical energy is dissipated in the form of thermal energy. And there are materials which show

such behavior and those kinds of materials are been utilize for refrigeration, for active cooling and likewise. There are several other applications of such devices.

Nature indeed has such an interesting mechanism to regulate temperature. So the bioelectrical phenomena which will be dealing in the hornet nest are relevant to that what are the different current and voltage are, how they are regulating temperature and all those things. And one of the instrumentation what will be involved in it basically will be, we talking about the electrometers, which has the ability to so talking about the electrometers. So electrometers are devices, we can measure the current of very very low amplitude, very low magnitude like pico ampere, nano ampere with high-end fidelity ((Refer Time: 11:11)) they can measure it. So we will be talking about electrometers.

So now if you look at it in perspective, so if you look at it that section one falls under all the different phenomena, section two falls under the different events, and section three is about the instrumentation because they are all interlinked with each other. And advanced applications of it, so advance the application of it is one of the applications is an inspiration for sustainable buildings. So this is one of the major inspirations using the bio-compatible thermo-regulatory mechanism. So here I wish to highlight something, so most of us whole eleven ((Refer Time: 12:30)) tropic countries, during

the summer, we are totally dependent on an air conditioner, so which basically essentially does only one thing. It pulls out the air molecules and reduces the collision and between the air molecules within a room using a very strong pump. The sucking out air, and thereby reducing the collision and making the room cooler, that is what an A.C does.

So think of a situation and this process of pulling out air from a room needs an enormous amount of energy, these are all high-powered devices. Now think of a situation, if you can replace an amount of energy which it needs could be replaced by something which is which can maintain the temperature of a room within a very comfortable biological regime. How that room will be, how our life will be, so these are some of the inspiration which we derive from nature and they intensely involved a whole lot of biological phenomena. So this is, this will be our first topic what will be dealing with under the heading of system identification, bioelectrical phenomena, measurement techniques, and the advanced applications – the imaginations. Tomorrow what will happen we do not know, but if we keep on doing this intense research one day the world may be a very different place.

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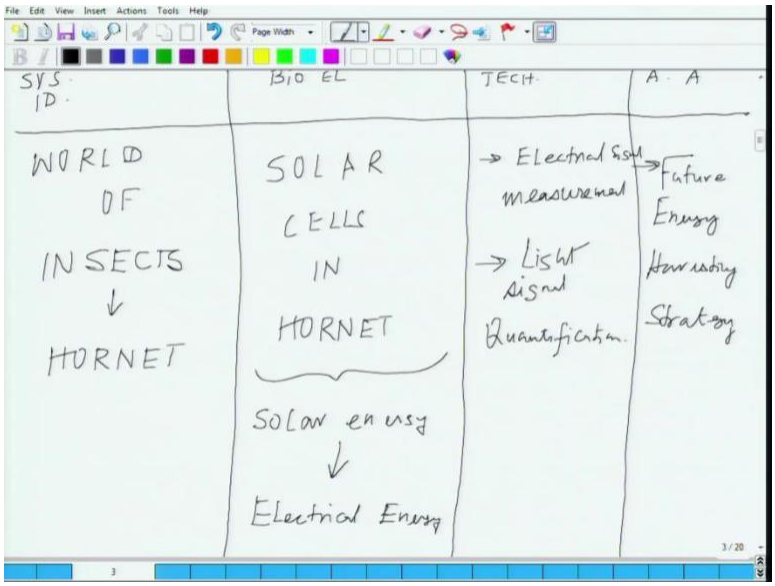

So let us move onto the next one, exactly under the same heading. Again the system identification, I will just put system ID in the first column, then bioelectrical phenomena are the second column, then techniques - I'm just putting the short form and advance application A A. So the second

the thing will be dealing with will be the world of insects. What we learn from them, so talking about insects. Insects have evolved or probably one of the most evolved species on the floor of earth, they have survived millions of years of turbulent weather, turbulent climatic conditions, geological changes, and they still survive. And they have adopted several mechanisms of energy conservation, energy harvesting, and several innumerable known and unknown survival strategies. In order to ensure that they survive on a slot of time, the changing time; so in that process, some of these insects, especially some of the hornets have developed a certain mechanism by which they can ((Refer Time: 15:59)) grab sunlight and convert it into energy. It exactly the same way a plant does.

So in other words, within their body especially in their wings and abdomen, they have certain specific molecules, which functions as solar energy draper. They can drape the solar energy and they can covert that; and in other words, essentially what we are talking about they are living mobile solar cells. So we will be talking about these kinds of solar materials, which are found in nature, which has the ability to convert light energy into electrical energy. So especially will be talking about in hornet and will talking about solar cells in hornet. So in other words here we will be talking about the phenomena that will be solar energy to electrical energy. And of course, the different techniques which would be used will be mostly electrical signal measurement sorry. And apart from it, it will have light signal quantification.

And among that advance application, future energy harvesting to energy harvesting I should say strategy. So will pick up one example from the insect kingdom and we will talk about how the insect harvest the energy from nature. And this is something which could be a big inspiration further future, whereas all of you have seen in that silicon industry is almost hitting the roof, crystalline silicon efficiency around seventeen percent, and seventeen to twenty percent, maybe maximum in the lab conditions. So there is intern search from molecules, which are much easily available, synthesizable, greener, and more biodegradable ((Refer Time: 18:52)). It does not need the extensive cost of processing silicon. So in that line, one approach I inspiration from nature is what I just now explained is in the lies in the cuticle of the hornets. And if we could synthetically develop those compounds, they may have immense potential to look forward.

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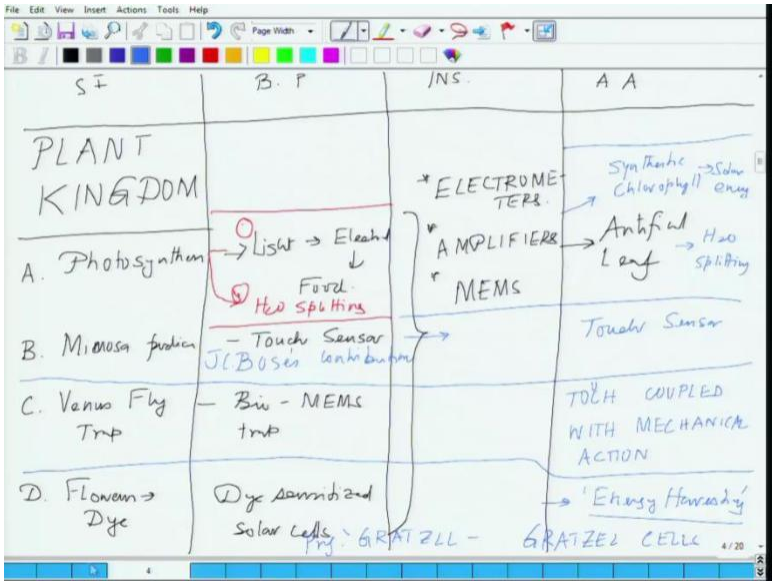

So let us identify the third system from here. Again there are four columns this time again the same thing system identification – the column one, SI – system identification, the biological or bioelectrical phenomena, the instrumentation, and advance applications. So here we will be talking about the world of plants. Another very very diverse kingdom and the only known biological system, which with its fullest ability could harvest sunlight; get the lights, converted into electrical energy in terms of the flow of electron, and helps us to synthesize, helps to synthesize food. In the food chain, they are the autotroph, auto means self, troph means they have the ability to synthesize food and we all depend on these autotrophs for our livelihood.

So they are kind of the pillars of the ecosystem. Based on those pillars, all our the whole food chain is dependent upon. So that is one of their most fundamental contributions. Apart from it, they have a wide range of sensors in their body. They have touch sensors in the form of mimosa pudica, they have touch sensor as well as mechanical you can say touch sensor coordinated with the mechanical door, in terms of Venus Fly Trap, where they could you know to trap an insect. But that whole mechanism, by which biology ensures a fantastic microelectromechanical system, which all of you come in the name of MEMS. Biology already has this kind of MEMS inbuilt in their system, so that's an inspiration for those who are working in the domain of MEMS or miniaturization or mesoscopic devices, it's a big inspiration, so that is the third thing we will be dealing with.

Apart from it, the whole world is so beautiful because of the beautiful flowers all over the place. And these beautiful flowers, there is something very amazing actually. They are the inspiration for dye sensitizes solar cells. Those of you heard ((Refer Time: 22:17)) of the name of grid cells, who has done pioneering work in the field of dye sensitizes solar cells. So what are those different should say different components of nature which contribute to developing a different kind of desensitize solar cells, because that is as I was telling on the previous slide that silicon is silicon technology is hitting the roof. So, we all are looking forward to the next generation. So desensitize solar cells is another one in that line. So different ruthenium dyes, different floral dyes, and all those things, which are derived from nature, basically which is an inspiration to develop the next generation of high-end dyes. So talking about the plant kingdom now.

Let us what I just narrated you, so plant kingdom. So within the plant kingdom, we will have A, we will be talking about photosynthesis. Then we will be talking about the mimosa pudica or touch me not or touch sensor. This is for light to electrical to food. Then you have Venus flytrap, which is basically a Bio-MEMS trap. And then will be talking about dye sensitize, so the flowers – flower dyeing or dye-sensitized solar cells. So the instruments here, there are multiple instruments, which are being used, which are fairly common' of course, you need electrometers, amplifiers. You need a whole lot of biochemical techniques to study photosynthesis and you need a high-end MEMS – microelectromechanical systems, and likewise several other instrumentations, which is needed. And among the advance application, in terms of photosynthesis, we are talking about artificial leaves, I am coming to this, what does it does that means.

So say for example, we talked about photosynthesis. Essentially what is happening, on the leaf surface light is falling, and this light energy ejects an electron, a photon is remaining absorbed, ejects an electron and this electron through the cascade of to the pathway along the chloroplast leads to the formation of glucose molecules, which is being consumed by our body. And of course, it goes for system one, for system two and the output of this is you are splitting a water molecule to oxygen as a byproduct, and you are evolving hydrogen. So there is two inspiration, the first inspiration is that making synthetic chlorophyll molecules, which could be used for trapping solar energy and ejecting an electron, that is one approach.

The second approach is that so coming back, let me the second approach is that whatever we get inspiration in terms of the manganese cluster for splitting water. So let me talk about at this line let me make one correction here, and this is one aspect of it, this is another aspect of it, which is water splitting. And this is all taking place within the domain of photosynthesis. And artificial leaf or we can add something else here also synthetic chlorophyll for solar energy. Artificial leaf for water splitting. So understanding photosynthesis and emanating photosynthesis could have a

profound impact on our understanding of nature. And this is one of the most fundamental reactions of energy conservation, which is being followed by nature. So we will go in-depth in photosynthesis and we will talk about it, and from there we will move onto the water splitting cluster which is part of the photosynthetic machinery.

So, then we talked about mimosa pudica or the touch sensors. So these touch sensors, have been a study for almost the last hundred years, and some of the pioneering studies were done by Sir J. C Bose. – Jagadesh Chandra bose. And he made some very very pioneering contribution and we will talk about his contribution where he talked about with the plants have nervous system or not, as [FL] matter of fact in some of his fellow's tropical transactions he has kind of hinted upon the these are rudimentary nervous systems of plants, which could sense touch. And we will talk in-depth and what are the different devices which are being used, and what is the current status of the field, and which could be an inspiration for developing touch sensor for the future.

So we will talk about J. C Bose's contribution and talking about touch sensors. And while talking about the touch sensors, I wish to highlight one more point that he is among those very first people, Bose is among those first people who could show a functional semiconductor device in the form of galvanic. We'll talk about it a little bit more. So now coming back to the Venus flytrap ok, Venus flytrap is a kind of a device where which has an inbuilt touch sensor as well as a mechanical event. So, whenever insects come and sit there, it stimulates some part of the flower, and there is a hood that closes in like this. So in other words, these touch sensors coupled with a mechanical door, touch to the mechanical door, and this whole connection are could be a big inspiration feature for developing MEMS-based devices, and which is purely an electrical and mechanical phenomenon.

So we talking about clear touch coupled with mechanical action, this is what Venus flytrap will be starting. Then we will be talking about some of the contributions made by Professor Gratzell who among the pioneer in developing dye-sensitized solar cells or Gratzel cells which is commonly known. So we will be talking about some of those dye-sensitized solar cells and basically talking about some of the contributions of Professor Gratzell and his Gratzel cells one second sorry and will be talking about energy harvesting.

And in the previous slide, while I was talking previously to the previous slide where we are talking about inanimate objects of biological origin. I will have one more column which I have mentioned, so if this one is the first one, so we talk about this will the second one which is the world of insects. And we talk about the third one, plant kingdom.

So there are two more which are left actually, I have not talked to about the kingdom of an animal, which will be anywhere I will be talking in the next class. There will be one more section, which I will be introducing which is not very clearly highlighted in the course part is about some of the very primitive inorganic molecules, which has some amazing electrical characteristic which has a wide range of implication in biological process and we will talk about those. So I will close in here today, we will continue here with the same graphical scheme of things in the next class and then we will move onto different steps of the course.

Thanks a lot.

Bioelectricity

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Lecture – 3

Welcome back to the lecture series in NPTEL on Bioelectricity. So, we have introduced the course in the first lecture and in the second lecture we went ahead and started with the graphical representation of the course the way it will progress. So, in that process we started with the inanimate object or inanimate object from a biological origin, we talk about how the thermal regulation is being done will be discussing it can be the following heads like you know the system identification the biological or electro bioelectrical phenomenon.

And then we will talk about the instrumentation needed and that advanced applications. In that process we finished with that inanimate world what will be dealing in the course, we talked about the insect world, we talked about the plant world, what we haven't talked yet is about the animal bioelectricity the world, which is most explored among all these where there are a lot of applications for by medical perspective as well as for the different form of prostheses and everything. So, today we will start with the graphical representations of animal electricity or animal bioelectricity that will be dealing.

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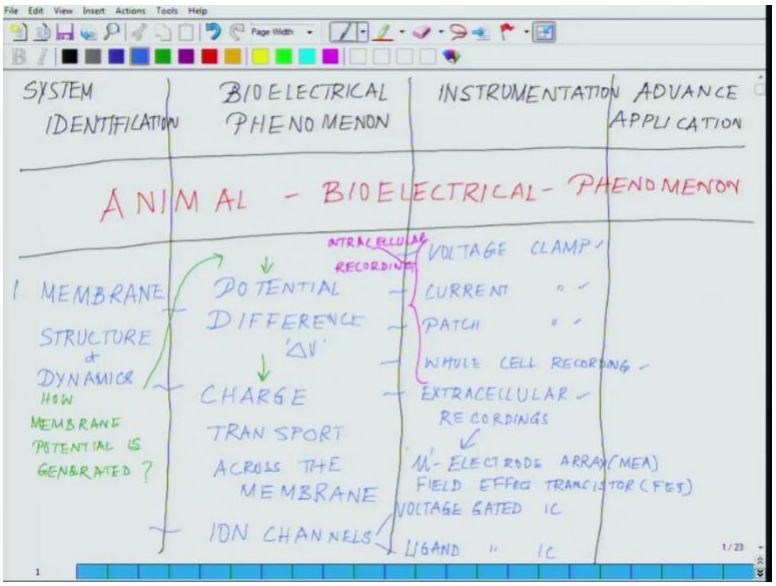

So, once again this coming back the way we started with the other once, so will make four columns, system identification. So, system identification we have first column identification, bioelectrical phenomenon, and instrumentation then we talked about the advanced application. And this we are holding under the title of the animal bioelectrical phenomenon.

So, again following the same scheme of things, so we will identify the system, we will talk about the phenomenon, we talk about the instrumentation and we will talk about the advanced applications. So, the first question which we will attempt to answer here is the origin of the bioelectrical phenomenon in other words the cellular electricity at the cellular level how electricity is being generated. So, that needs to go in-depth with the membrane, structure of the membrane, membrane potential, and the flow of charges across the membrane, which leads to the generation of electricity.

So, start off with we will study about membrane, and please ensure to keep this chart in mind all the time. Membrane structure, which leads to potential difference or delta-v charge transfer or charge transport across the membrane, and the kind of instrumentation, so here there are few more things. So, whenever we talk about the membrane structure and the charge transport across the membrane, we realize that these are semi-permeable membrane we are talking about. And they regulate the flow of charges especially or exclusively these are ionic charges, which are flowing and they are gated through the membranes using the smallest unit, which helps in the gating that is the ion channels. So, it will be starting about the ion channels, which is the smallest known entity that helps in or which regulates the flow of ion across the membrane ok.

So, will be talking about the membrane structure, we talk about the structure of the ion channels and within the ion channels will talk about voltage-gated ion channels, I am just putting ion channels as I C and ligand-gated I C, I just got in other columns do not worry, we will. So, the membrane is the most I should say the most primary level where the electrical impulses get generated and from there it keeps on traveling through from one membrane to another to the third to the fourth likewise ok.

And the major techniques, which have evolved in the study of membranes include voltage-clamp studies, current-clamp studies, patch-clamp studies, single-channel current measurements. So, talking about that instrumentations out here will talk about voltage

clamp and I will come to the exact meaning of all those things, voltage clamp, current clamp, patch-clamp within the patch-clamp we have the whole-cell recording, we will be talking about.

So, this of all classification, which all be coming to this whole electrochemical or electrophysiological measurements extracellular, intracellular, within intracellular, we have the whole series of patch-clamp, voltage clamp, current clamp, whereas in the extracellular also you could have those things, but using extracellular electrodes ok.

So, then we talking about extracellular recordings, which will include your micro this is just the sign of micro, microelectrode array MEA or field-effect transistors FET ok.

So, there is a, so this section what you see? The voltage clamp, current clamp, patch-clamp, whole-cell recording extracellular recordings by the way all these others fall under the, most of them fall under the intracellular recording. So, within the membrane structure we will talk about the potential difference and most importantly will apt to talk about is start off with actually will have to talk about them out here, how membrane potential is actually generated? This is the first and foremost question which we need get to answer. And from their so now, have a potential difference this potential difference leads to a charge transport across the membrane and in this whole game of understanding the membrane structure and I should put it more correctly membrane structure and dynamics, because their other event, which is taking place that moves on to the next slide, we will be talking about one of the other events, which are involved in this process.

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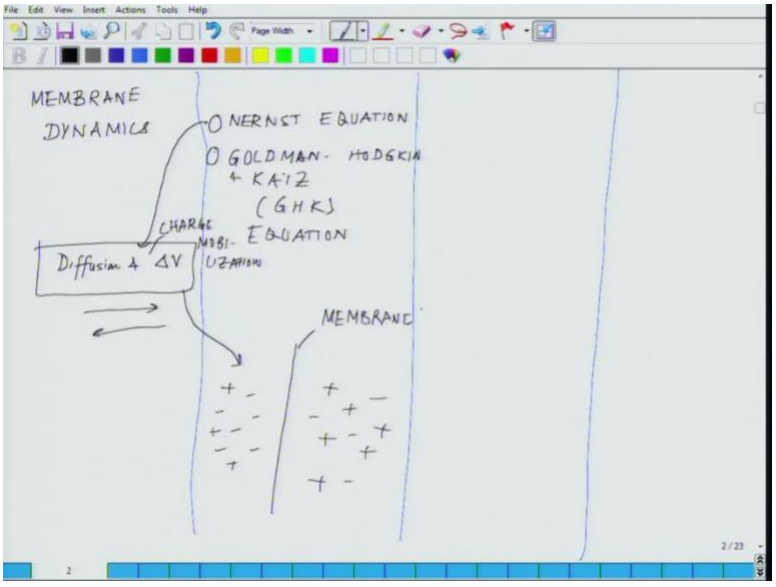

So, I will be talking about the membrane, so I to verify it ok. With the membrane structure, membrane dynamics will be talking about the Nernst equation then will be talking about

Goldman, Hodgkin, and Katz that also called the GHK equation, which is nothing but an extension of the Nernst equation. So, here will be talking about the counter forces of diffusion and delta-v. The potential difference and the diffusion, how that you know, how these forces are regulating, or other we can say the charge mobilization. In other words what you want, what we wanted to say what, what I want to highlight here is that, say, for example, you have across the membrane something like this positive charges negative charges. So, and this is the membrane ok.

So, essentially what we are trying to highlight here is that under the normal deficiency say, for example, you have a hundred molecules of NaCl sodium chloride on one side, if ten molecules of sodium chloride of one another side and if you allow the free diffusion, eventually what we happen? Hundred on this side, ten on this side, a hundred plus ten makes hundred and ten, hundred and ten divided by two, which makes it fifty-five, fifty-five one both sides. There will be fifty-five, fifty-five molecules, but think of a situation where you have a hundred and ten molecules of NaCl, so which dissociates into Na plus, cl minus charges, on the other side also Na plus cl minus charges. And apart from it, they are few other charge molecules and the membrane, which is their every semi-permeable it would not allow everything to pass through, then how the membrane will balance itself, across it two sides? That is what we will be talking

about the dynamics part of the membrane and because that those are the governing process is which regulates the flow of ions across the semi-permeable membrane and here I will go back to the previous slide.

So, whenever we talked about these kinds of biological membranes essentially, we are talking about the semi-permeable membrane. So, we will talk about the membrane dynamics and then we will talk about the once second with respect to individual cells, we will have to come and there will be talking about. We will talk about the nerve cells, which are excitable cells, in the body there are three kinds of excitable cells; nerve cells, cardiac cells, and few other cells on of course, that see the excitable cells are electrically excitable cells of the body. Electrically excitable membranes are it called the cells, of its membrane is covering the cells of the body ok.

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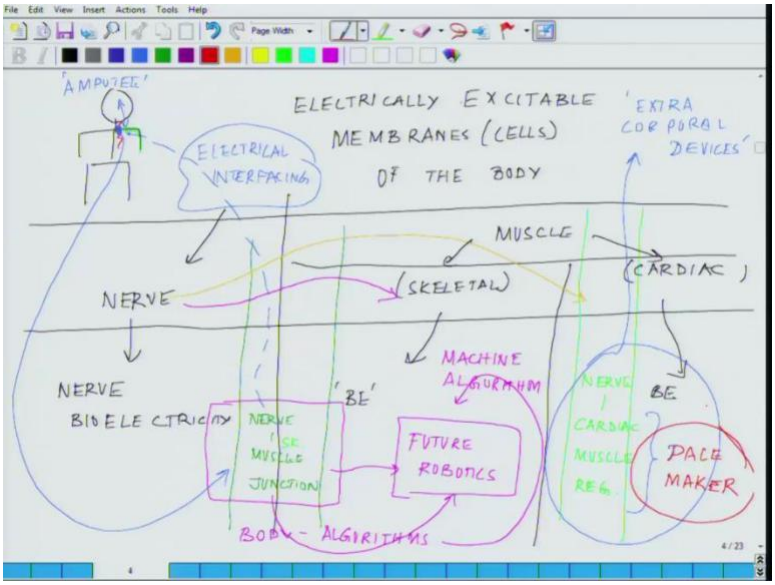

So, there this if the nerve cell, you have muscle mostly skeletal, which is more pronounce and you have other muscle, which is within the muscles in between this. Now, I am doing it write cardiac and skeletal, essentially we will be talking about nerve, bioelectricity, skeletal, bioelectricity, and cardiac bioelectricity. So, these are on the left-most columns. If I have to talk about the identification of the system so this is the broad identification of this system. And mind it, these systems are all interlink. So, for example, this nerve is regulating. So, there is an interaction that falls under the interface zone of this, where we will be talking about nerve, muscle, junction, and how to study that.

Or say for example, we pick this up the way nerve regulating cardiac muscles and in this situation we are talking about this skeletal muscle of course ok, cardiac muscle regulation. So, while will start with the structure of the membrane that will be organic structure, while we talk about this is how the membrane looks this is how the potential difference across being maintained and these are the different smallest in it ion channels which are regulating and from that generic introduction we will move on to the specialize cell types, which is nerve cells, take all the three excitable cells, muscle, skeletal muscle to the cardiac muscle.

So, coming back to the previous slide where we were. So, we were actually started. So, within, so one second within, so this is the overall outline to start off with this thing and then we talked about the membrane dynamics, what will be the starting in the dynamics part.

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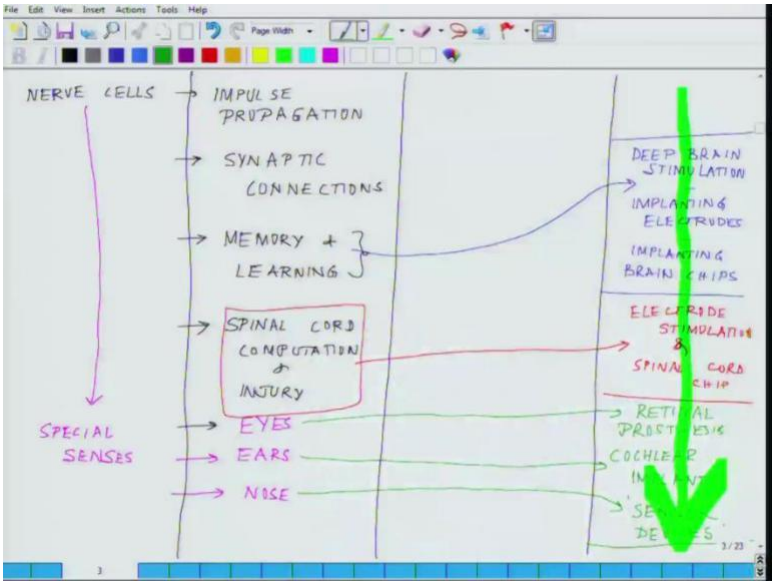

And then we talk about the yah, so in this classification what we are going to studying in the nerve cells. So, within the nerve cells, we will talk about impulse propagation, this is exceptionally important then we will talk about the one second, we will talk about the synaptic connections and in that whole process with the nerve system, we will talk about memory and learning. Because these are some of the most important bioelectrical phenomena; here we will talk about the spinal card computation and injury. Then we will among these nerve cells will talk about some of the special senses, becomes a special

senses, we will talk about the eyes, the ears then the nose and these have very straight output. Whenever we talk about the eyes, ears, and nose, because these are the organs, which has opened up the, should say opened up the scope for the prostheses right, because the first prostheses which were done were the cochlear implant.

So, from here will move one to essentially to from here will talk about that among the advanced applications about a cochlear implant, which is an eight electrode system than among the eyes will talk about retinal prostheses. This is in the case of the nose in the human being that is not as strong as on-road ends, it is more of a research interest of understanding what are the different odors and they have of course, the profound implication in perfume industries and all other places. So, they are more like an inspiration for an odor and sensors. So, for the sensor devices

and within this parts spinal cord injury, we will talk about among that advanced application, we will talk about different electrode stimulation or and sorry, spinal cord chip likewise. Then in the case of memory and learning this is one of the most challenging frontiers, where we will talk about different debrain stimulation techniques different research is currently going on to replace a part of the brain with a chip to you know to handle situations of like Alzheimer's or some other Neurodegenerative diseases or we will talk about how a brain can cross-talk with the robot now those kinds of things.

So, it will start with stimulation is one of the areas then implanting electrodes then you have this implanting brain chips. These are the futuristic dream of mankind. So, what essentially transfer out of all these things is this that, we have to understand the very basic fundamental ideas first, especially in terms of you go back to the previous slide have to understand the membrane potential, we have to understand the charge transport across the membrane, we have to understand the dynamics of the ion channels. And we have to understand how the Nernst equation, Goldman Hodgkin and Katz equation, and all other things regulating the whole process, but then the next phase, which is the most challenging phase of all these games is something if you look here. So, if, you look very concentrate on this side right, if you really look very carefully to this side, this whole part is taking us to a different zone that basically what we talking about is your implanting or you are introducing something inside your body in the form of an electrode or in the form of a chip, but mostly at the form of an electrode ok.

So, that requires a different kind of explicit. So, we will just numerate bit of it. So, let you appreciate why these areas are so very challenging. So, I will do it. So, I will try to do it more in a diagrammatic position.

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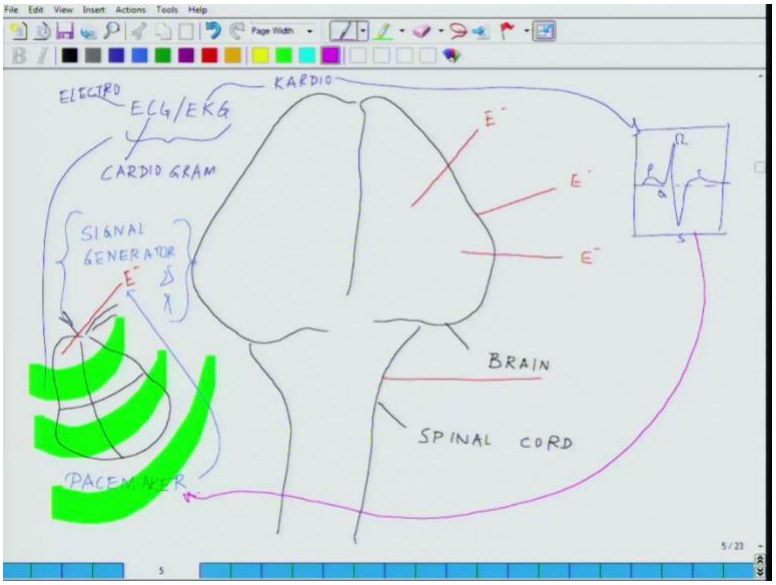

So, see for example, this think of it, if this is your brain and this is the spinal cord moving it. Now, we are introducing an electrode into the system like this, or say for example, electrodes are maybe a self as electrode like this. So, the very moments and these are I am just putting the sign E minus as the electrode and this is of course, the brain and the spinal cord ok.

So, the very moment, you're introducing something into the brain or into the spinal card you're introducing a foreign object into the system. And essentially how these individual cells are going to interact with that foreign object is the most fundamental challenging problem.

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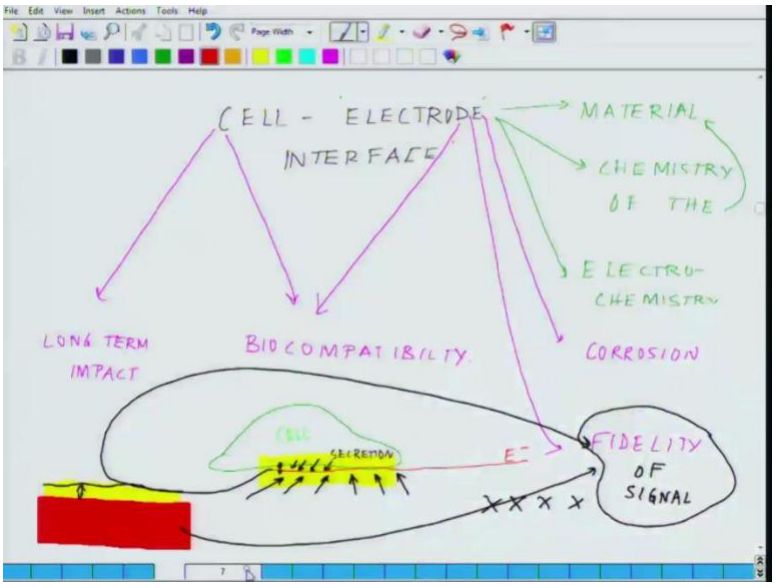

And that falls under them the feel of cell electrode interface, cell electrode one second, one second, cell electrode interface. This interface is extremely important because electrode this is the zone, where we look how diverts the feel becomes, this is the zone which needs your understanding of materials, the chemistry of the material then we have to understand the electrochemistry then we have to understand the, which is the interface area out here, that interaction which is the biocompatibility and then long term impact. So, this whole feel of cell electrode interface is exceptionally challenging and that's where lies the catch what are the newer and newer electro materials, which mankind could develop which could help us in progressing into the feel of the man-machine interface or Neuro prostheses and Neuro electric interface much more easily it should, it should be seen in very easily without any problem.

So, that is a whole feel in its own merit and that needs a different kind of training to understand. So, this is one thing which will be highlighting as we will be talking about microelectrode daring is we will talking about different electro material that are been used. So, that is the part where we will be talking about the whole instrumentation in everything. And talking about its implication if you look at it we have already talked about if you will go back or out here one second yah, so deep brain stimulation implanting. So, these are all material things, electrode stimulation, spinal cord, retinal, prosthesis, cochlear implant, sensor devices. So, if you look at all of them they all need electrode materials. So, on the one hand, we are dealing with the biological system, but on

another hand you need a deep in-depth understanding of material science otherwise it is exceptionally challenging even to handle a single problem in this field.

So, now what we will do will talk about a few more other areas. So, this zone, so talking about nerve-muscle junction, understanding nerve-muscle junction. So, this could have a profound impact in understanding the field of robotics could you have a robot, which makes the movement of the arms, so gently it could do like this, it could walls through, it could move through, it could do like this all these different degrees of freedom. This privilege we have because we are under the continuous control of the nervous system which helps us.

So, this is the area, the nerve-muscle junction that I try to highlight out here has a profound impact on future robotics. Future robots may use some of the algorithms what are been. So, basically first of all you have to understand translate these algorithms of body, body algorithms have to translate into for a machine algorithm to execute the job. So, this is how the understanding of nerve-muscle junction could be a big help, other than that there is another side of this whole field that is the case of a patient with amputation, say, for example, a person has to say amputate hand or amputate legs could we, so say for example, here is the situation here is a human being ok.

This is an intake human being. Now, there is an amputation, this is gone. Now, we can put an artificial, artificial limb, but how this limb will cross-talk with the brain, what will be the signals which will be put here, that all falls under understanding these algorithms how nerves are controlling the muscles, could we have could we translate this in terms of some kind of electrical gadgeteer. After understanding the algorithms are electrical interfacing could you do that for an amputee patient. So, these are some of the fundamental things, which we needed to understand, while we will be talking about the nerve-muscle interaction from a very application-oriented point of view.

We will do the very little bit biology, but will more concerned about how those signals could be translated in terms of a computer algorithm that we could design something, which could execute, if not to the level of fishing so fee normal human being, but you know to some degree, so that the life of this individual, but comes much easier. So, there is one re area we will be kind of highlighting here is an advanced application, while

talking about this part of the story nerve cardiac muscles. So, these are some of the understanding, which has a profound impact on extra corporal devices for those of you are not aware of the extracorporal devices these are devices to check the spelling from thus spelling is wrong here. These are the devices, which are used outside the body. So, for example, somebody the best example is this, somebody is having kidney, kidney problem fine, the kidney is unable to purify the blood. So, what they do they put an artificial kidney outside the body and they bypass the fluid which moves through that devices and purifies the blood input in back in your body. So, it pretty much carries the devices with you or when you are lying down. So, it depends on how fast it has to be taking care of.

So, this extracorporal device, devices are fairly prominent in before even we have a very ready prosthesis out here. So, this is one of the routes. So, these nerve cardiac interaction could have such scope apart from it understanding it could help us to develop the zenith artificial heart, which currently only app course, only one company in the world which is doing, so but there is a lot of room lot of understanding apart from it. There is another area which is the most prominent area currently is, the area of pacemakers, one second where basically, so the pacemakers, pacemakers is nothing but the heart has a rhythm, by we the electrical impulses are been transmitted from one part like from one side of the heart to the other end from one I should say from corner to other corners ok.

So, that pace is set by the specific cells or the specific circuit within the heart and those are called pacemaker cells. So, say for example, for some reason or than the pacemaker cells goes, they were, they were bad, they were not functioning. So, what to do? How to bypass the problem? The only way to bypass the problem is that input as a synthetic pacemaker on the surface of skin out here, which said the tone for the conduction to take place and there is the technical term though for it. So, basically, the heart is divided into two systems, which functions in complement in each other one is called the conduction system, which is basically the pacemaker system and other one is called the contraction system, which actually executes all this you know the heartbeat and all those kind of things ok.

So, is the conduction system goes bad how do you know to ensure that we are doing fine? So, that where comes the whole field of pacemaker and pacemaker implantation is the very common process currently, but there is a lot of room for an improvement of a pacemaker,

because this is another thing, which is very similar to what I drew for you something like this. So, where your putting electrode like this. So, here essentially what you are doing, if this is your, this is the heart with four chambers. So, essentially what you are doing at the surface of the skin you are putting and something like this. So, this is essentially is the story of pacemakers, which is nothing, but a signal generator. So, here the electrode is not really picking up the signal it is generating a signal at a certain frequency and a certain wavelength. So, that is the other area where there is the enormous scope of understanding an apart from it, the way this rhythm is moving across the heart the way these waves are moving out here the propagation of the wave.

So, this propagation could be delt in the field of ECG or EKG. So, I will talk more on this on C stands for cardio, electrocardiogram, or K is the original cardiogram. So, this is something, which all of you must have seen that this is the kind of traces. Whenever you see a screen and that based on that there are intervals like you know p q r s t likewise you know. So, we will be talking about those electrocardiograms and all those electrocardiograms are being interpreted, and what is the significance and how that helps the doctor to decide with it this individual needs a pacemaker or not.

So, these are the things, which will be studying in the cardiac system. So, we have talked about it, so the way we started is to go back. So, we talked about they will be talking about the membrane structure and dynamics and how the potential is generated the potential difference leading to the charge transport across the membrane, we talk about the voltage-gated ion channels, will talk about the ligand-gated ion channels and in this whole section of techniques will talk about all the major techniques will be dealing out here. I will thus I told you that we have a section on the techniques one second yah, then we will be talking about the dynamics part where I highlighted that will be talking mostly about Nernst equation and how this is being the governing, the governing dynamics for this whole process. Then will be talking about the nerve, when in the nerve cells will talk about the nerve propagation, synaptic connection, learning and memory, spinal cord computation and injury and the special sensors, which are exceptionally important for our survival the eyes, ears and nose and simultaneously Retinal prostheses this cochlear implant and then sensory devices respectively.

From here we will talk about the electrical within this classification we have this nerve cells out here this skeletal muscles into cardiac and we will talk about individually and

how those could be used for amputation patient amputee patients and or in robotics. And then will talk about the electrode implant and especially within the cardiac and how the EKG traces could be used to understand the pacemaker with it the person needs the pacemaker or not.

And here I highlighted that how the cell electrode interface demands your understanding of material its biocompatibility, its long term impact and the electrochemistry of the material and in that same line there is something called the corrosion and then they are the fidelity of signal how long the signal they are because the thing is that whenever there. So, it does realize here in this diagram whenever this electrode is inside. So, essentially what is happening to redraw the situations it is like this? So, if I representing the cell by a green color like this, we have the electrode as red color like this. So, this is an electrode and this is your cell. So, at this interface zone, at this interface zone its a very dynamic zone, this is the zone where this cell what you see out here is secreting a lot of things. And the surrounding fluid is acting with this electrode and because of this gap, first of all, there is a gap you could see there is a gap this gap influences the signal the fidelity of signal is one thing this gap is very good at doing.

Apart from it what happens over a period of time this cell is secreting as these arrows are saying the secretion this secretion could if you kind of makeup slightly bigger image of this it will be like this that this is the electrode over a period of time what will see is out here what will essentially see that they will be a coating of something like this. And still the cell is out here and this gap may keep on increasing and that definitely reduces the fidelity of the signal what is reaching to the electrode. So, these are some of the stuff that we are going to deal with in the cell electrode interface, which is exclusively its a very challenging area and continuously there is research going on I will try to give you the feel of the different research, which has been done. Apart from it we will talk about some of them, so I told you that we will be talking about the lot about the bioenergy. So, what we will do this is one area which I haven't really highlighted well showing in the scheme of things.

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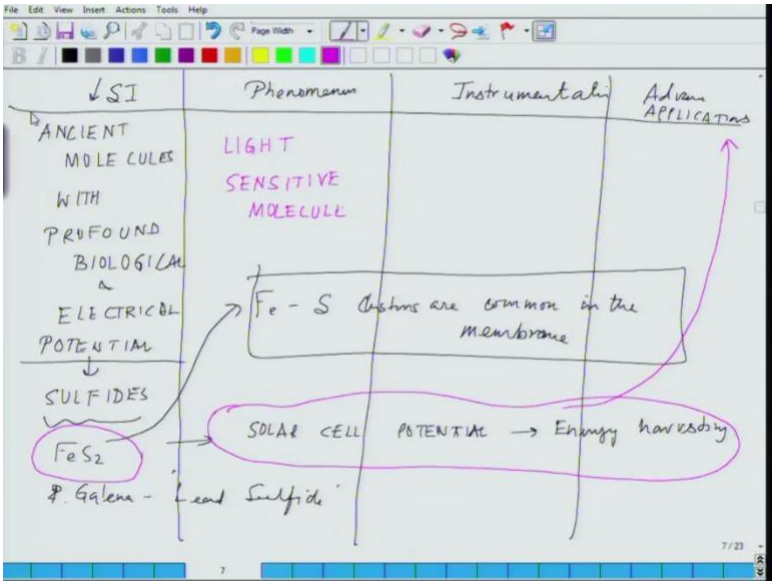

So, the scheme of things I told you that you know, I have these another four columns in the graphical representation. So, we will talk about in that in among the system identification some of the ancient molecules, some of the very ancient molecules with profound biological and electrical potential. So, some of the molecules will be dealing here will be some of the semiconductor molecules like sulfides. So, we will talk about them, we will pick up one different section something like will talk about to FeS2 and one of the major ones will be talking about its solar cell potential. And the reason while picking up FeS2, because these are iron-sulfur clusters are common in the membrane, they are pretty much an integral part of the membrane. And we will talk in-depth about what will that advancement, which has been made because the mind is among the first semiconductor material, which was developed, which was kind of discovered was galena, which was nothing but lead sulfide.

So, sulfide has remained very much an integral part of our development. So, this is one section, which will be separate out, so here of course, again another same classification we will talk about system identification the phenomenon and instrumentation what will be needed for that will remain between the same instrumentation and advanced application. And within the advanced application is our this section, which I actually denote, this is passing part which will be in that advanced application and phenomenon is, of course, the light-sensitive molecules. And as will moves through this you realize that why I picked

up this particular molecule, it has some very unique, unique properties, which is far better than the silicon-based electronics that we are currently so much involved in it.

So, this is the overall layout of the first three classes that I told you that all been you introducing you to the intro to the course. So, these are the first one minute yet to let me just, just like do you are favor let me open up my first lecture to hear yah. So, this is what I wanted to show you guys here yeah, so this is the introductory part of the module, which I just now finished with you people that first three-class two to three class what I devoted to introducing you to the whole subject. So, this is where all those three graphical representations in everything comes introduction and graphical representation of the subject.

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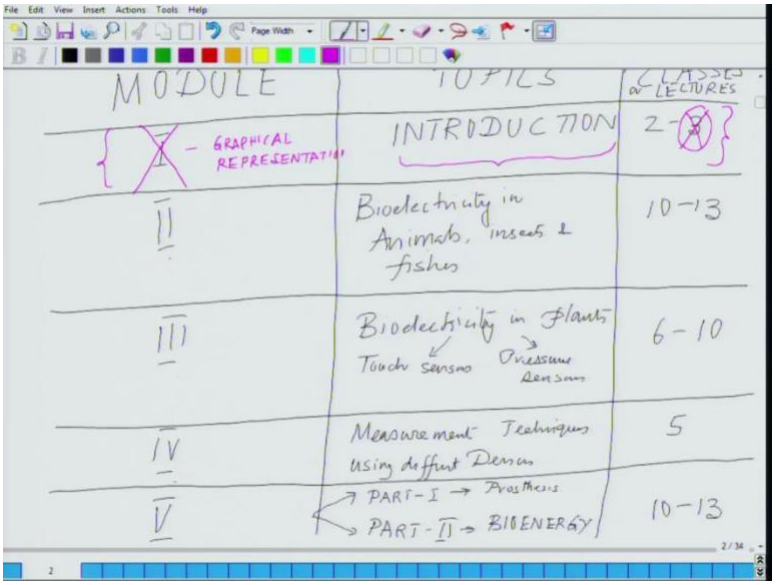

Now, we will move on to, so this part is all taken care of now. Now, we will pick up one by one, all this what you are seeing in section two and every time I will come back, I will just see, how far I have reached in this whole scheme of things what you seeing front view now, the first three lectures are gone. So, now, you move on to, so will make call weather we moving to sections because as I have told you, we can pick up this, this, this, this, anything at any point, we can again come back. So, we will keep it very lose it, very simple and my expectation is very clear here.

Just your basic high school or whatever it is and we will stick them, we will not go anywhere beyond it, because the whole idea is to appreciate electricity across nature. It

is not about you know knowing high-end equations out here or you know the very intricate phenomenon, it is about first of all what is needed is that we have to love the subject you have to appreciate and once you start loving the subject then you get in-depth into it you like this part ok. You will get into it.

So, the whole philosophy of this course is appreciated, appreciate all over nature they are so many beautiful things, which are happening, easiest you have to try to look at it ok. So, now I will end my module one, where I basically introduce you to a wide range of bioelectrical phenomenon. And now I will pick up one by one and I will expose you to the different events.

Thanks a lot.