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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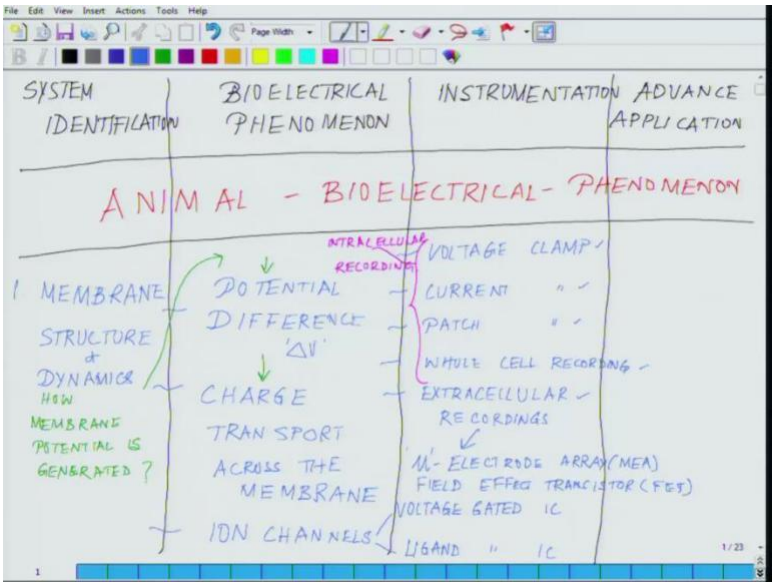

So, once again this coming back the way we started with the other once, so will make four columns, system identification. So, system identification we have first column identification, bioelectrical phenomenon, and instrumentation then we talked about the advanced application. And this we are holding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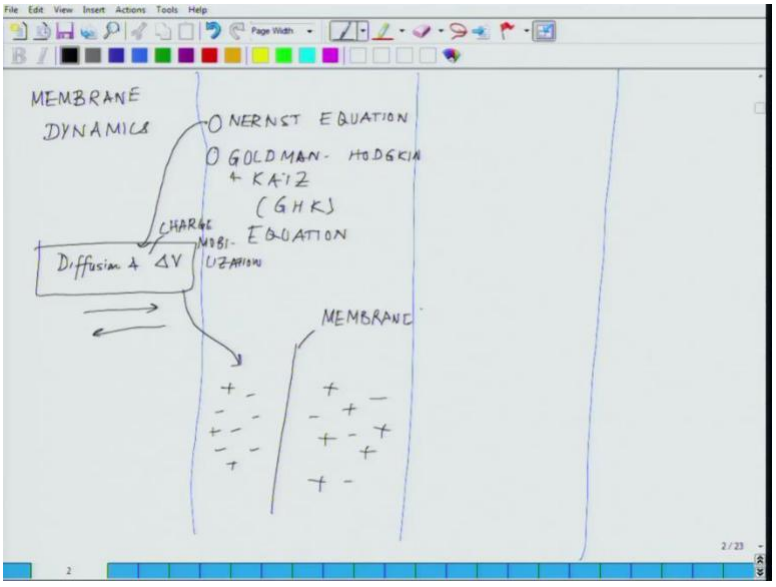

So, I will be talking about the membrane, so I to verify it ok. With the membrane structure, membrane dynamics will be talking about the Nernst equation then will be talking about

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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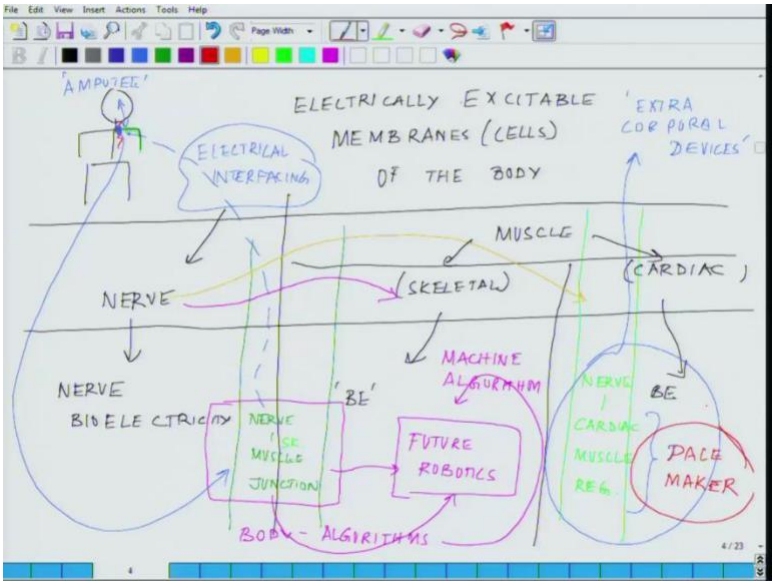

So, there this if the nerve cell, you have muscle mostly skeletal, which is more pronounce and you have other muscle, which is within the muscles in between this. Now, I am doing it write cardiac and skeletal, essentially we will be talking about nerve, bioelectricity, skeletal, bioelectricity, and cardiac 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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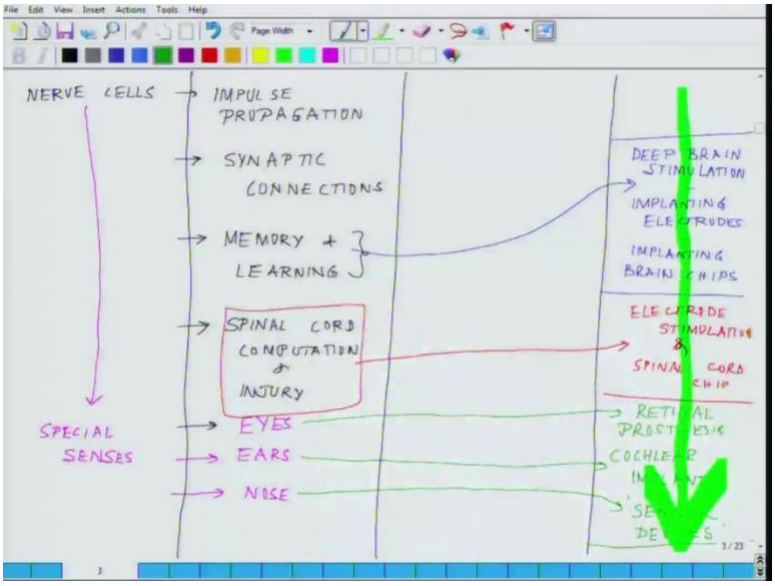

And then we talk about the yah, so in this classification what we are going to studying in the nerve cells. So, within the nerve cells, we will talk about impulse propagation, this is exceptionally important then we will talk about the one second, we will talk about the synaptic connections and in that 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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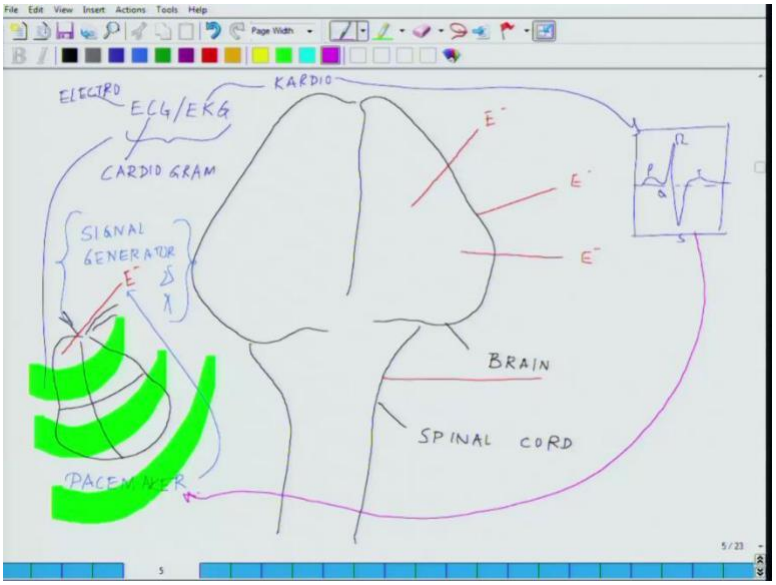

So, see for example, this think of it, if this is your brain and this is the spinal cord moving it. Now, we are introducing an electrode into the system like this, or say for example, electrodes are maybe a self as electrode like this. So, the very moments and these are I am just putting the sign E minus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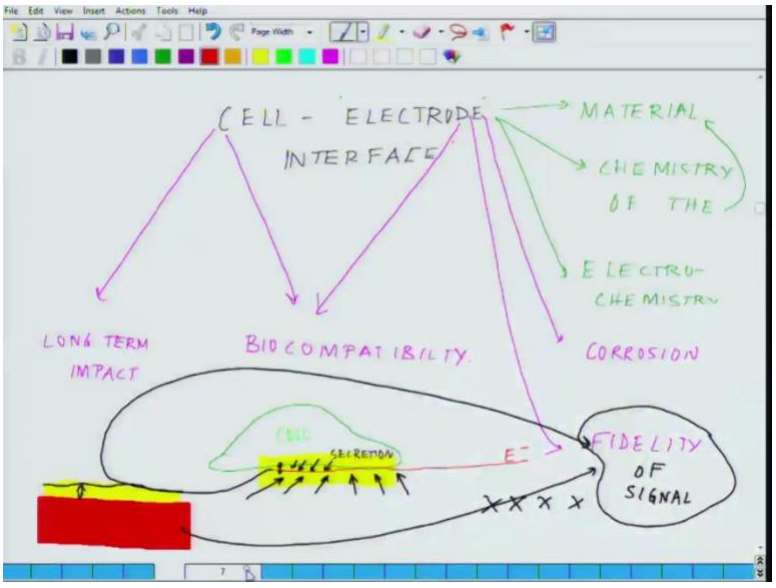

And that falls under them the feel of cell electrode interface, cell electrode one second, one second, cell electrode interface. This interface is extremely important because electrode this is the zone, where we look how diverts the feel becomes, this is the zone which needs your understanding of materials, 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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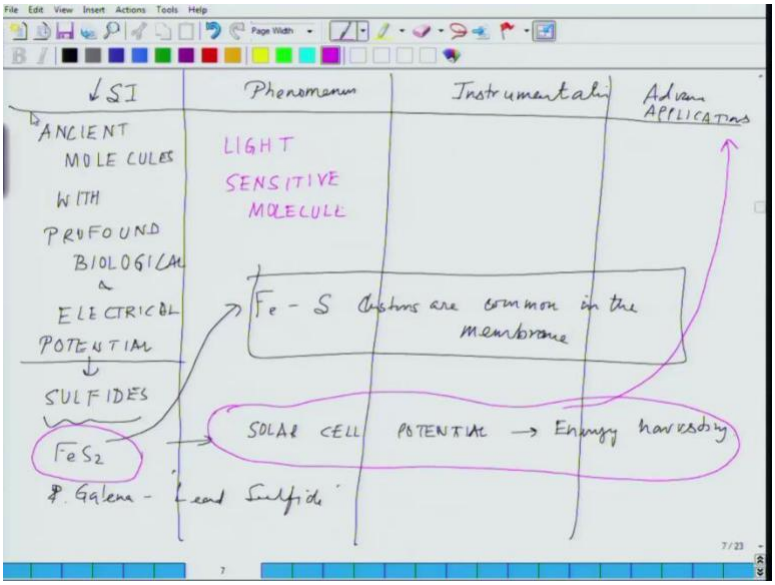

So, the scheme of things I told you that you know, I have these another four columns in the graphical representation. So, we will talk about in that in among the system identification some of the ancient molecules, some of the very ancient molecules with profound biological and electrical potential. 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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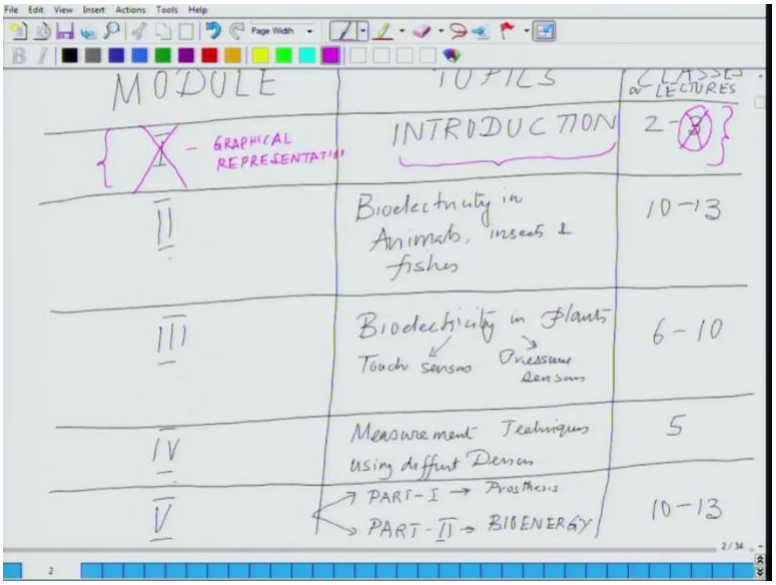

Now, we will move on to, so this part is all taken care of now. Now, we will pick up one by one, all this what you are seeing in section two and every time I will come back, I will just see, how far I have reached in this whole scheme of things what you seeing front view now, the first three lectures 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.