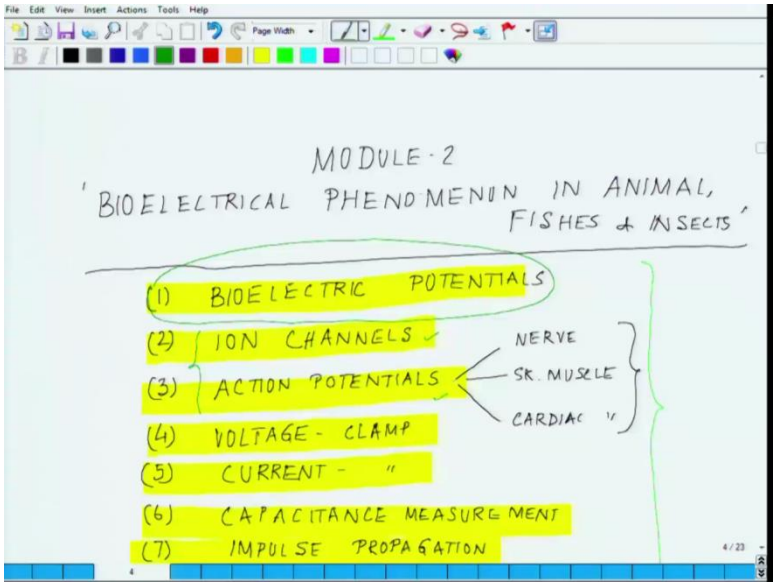
Bioelectricity
Prof. Mainak Das
Department of Biological Sciences and Bioengineering
Indian Institute of Technology, Kanpur

Lecture - 5

Welcome back to the NPTEL lecture series on Bioelectricity. So, we are in module two; and in module two, we have done our first class which is on bioelectric potentials. So, from here we will move on to the next two topics and if you go back and just please refer to the screen.

(Refer Slide Time: 00:34)

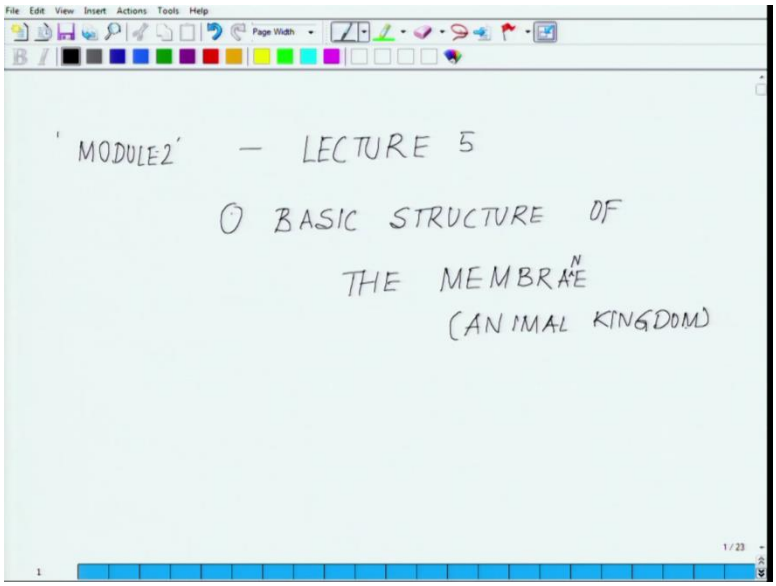


So, if you look back, so these are the two topics what we are going to deal with now - ion channels and action potentials. Let me just put here lecture five and this is module two this is sum total this is the fifth lecture. So these are the things essentially we are going to deal in this class. We will start with the basic structure of the membrane which we have not done yet. From basic structure of the membrane, we will move on to the different transport phenomenon taking place across the membrane, after that we will discuss about the Nernst equation. And from the nernst equation, I will give you little bit structural generic structural detail of the ion channels and we will talk about the different kind of ion channels from there we will move on to the action potential. In that process, while talking about the ion channels, initially I will just give you a generic introduction of the ion channels and then as we will progress we will talk about more and more about the

different kind of ion channel. There are sub type, the one which are voltage gated or which are open by the voltage difference, the one which are chemically gated, the one which are open after binding of a liken like where. There are series in a mechanical ((Refer Time: 02:21)) channel which are sense the mechanical change, a mechanical stimulation or the ones which are light sensitive ion channels so likewise and so on and so forth.

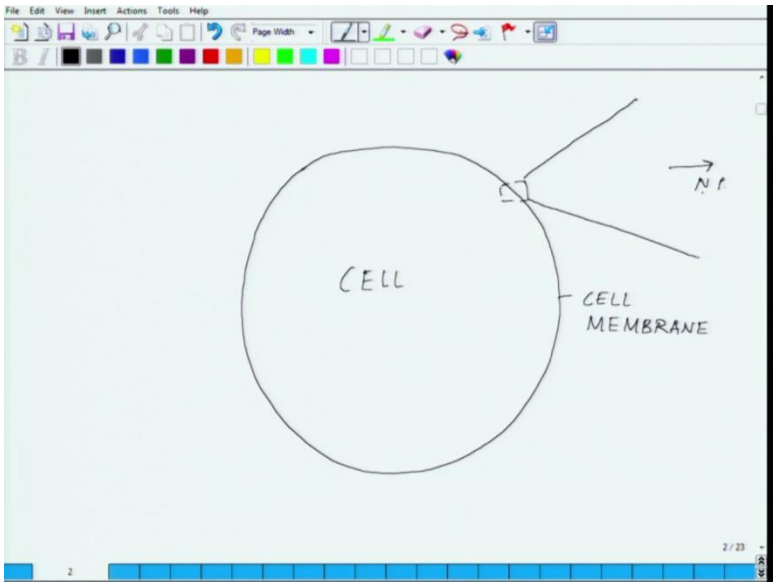
There are whole bunch of them and we will discuss one by one in different context. As we will be talking about vision, we will talk about light activated one, as we will talk about hearing we will talk about the mechano receptor one, as we will talk about different sensory circuit, there are ((Refer Time: 02:54)) channels we will be discussing. So, let us start with the basic structure of the membrane; very, very basic structure, I am not going to get into any in depth detail I will just give you an idea how ion channels are placed in those membranes and how the electrical properties of the individual ion channels are being studied. So, as we will progress in the course we will talk about it.

(Refer Slide Time: 03:24)



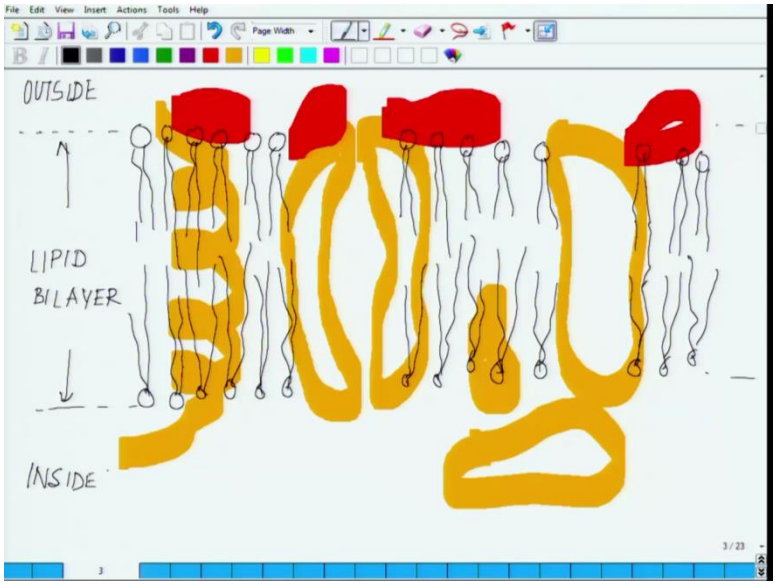
So, here is the section. So in today's lecture, we are dealing as mentioned the basic to start off with basic structure of the membrane. And this is the membrane we are talking about, we are only taking into account, in the animal kingdom. We are not talking about plant cell or any other cell and the generic structure.

(Refer Slide Time: 04:02)



So, if you look at the basic structure, if this is your cell, this is any kind of cell, it could be a neuron, it could be muscle whatsoever. So, if I take a cross section of this and blow it up, what I will essentially so this is basically your cell membrane or plasma membrane, sometime it is called plasma membrane also.

(Refer Slide Time: 04:36)

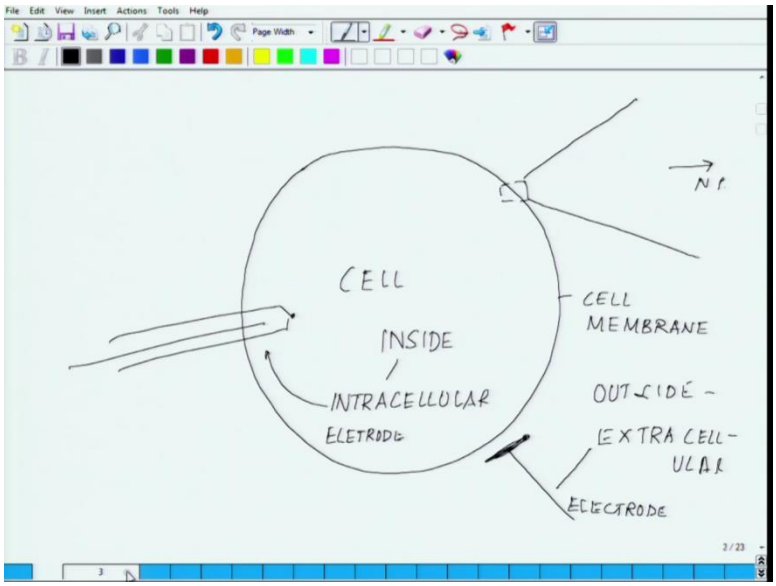


So, we go to the next page. So, essentially what you will receive see the membrane consist of by lipids likewise this is how the membrane looks like. And please refer to any standard textbook as I was mentioning in the last class that you can refer to Strier, you

can refer to Leninger or any other standard physiology textbook. You will get really very nice description about different kind of lipids which are constituting the membrane. Here I will just draw for your understanding sake. So, my objective here is not to have an extensive discussion about the membrane structure or anything, but only the electrical phenomenon. So, this is how it this is very tightly packed though the way I am drawing and there are gaps you are seeing.

So, here you will see at here, there are proteins which are in the different - yellow colour or like this. And there are proteins which are sitting single handed like this; there are proteins which are sitting out here, and there are proteins which are sitting like this. Again there are certain integral proteins which are moving through the membrane like this; and apart from it, you have whole bunch of carbohydrate molecules which are setting decorating the surface likewise. Let me label it that will make more sense to you people. So, coming back, this is the outside the cell, and this is the lipid by layer out here the lipid by layer.

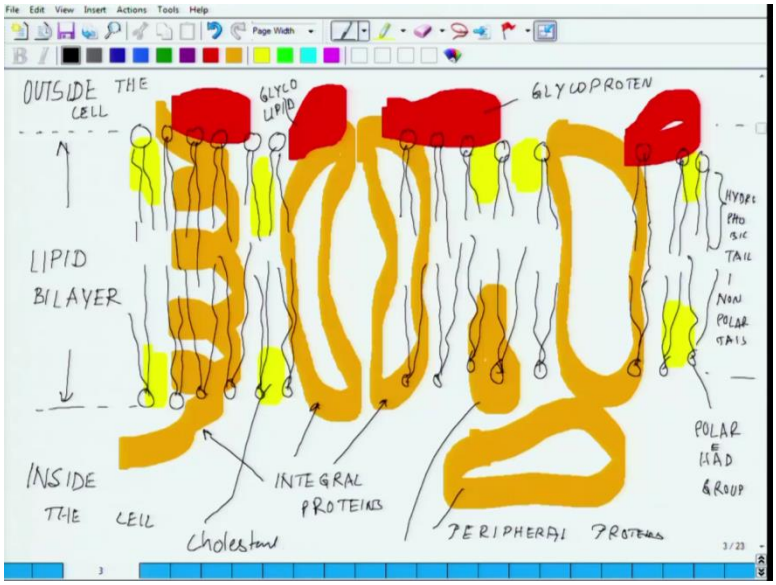
(Refer Slide Time: 07:18)



This is inside the cell as I was drawing here previously. So, this is inside or this is also called intracellular. This is outside, which is called extracellular. And here since I am showing it like that and let me introduce if a electrode is placed here like this, this is called intracellular electrode; and if an electrode is placed outside the cell like this, this is

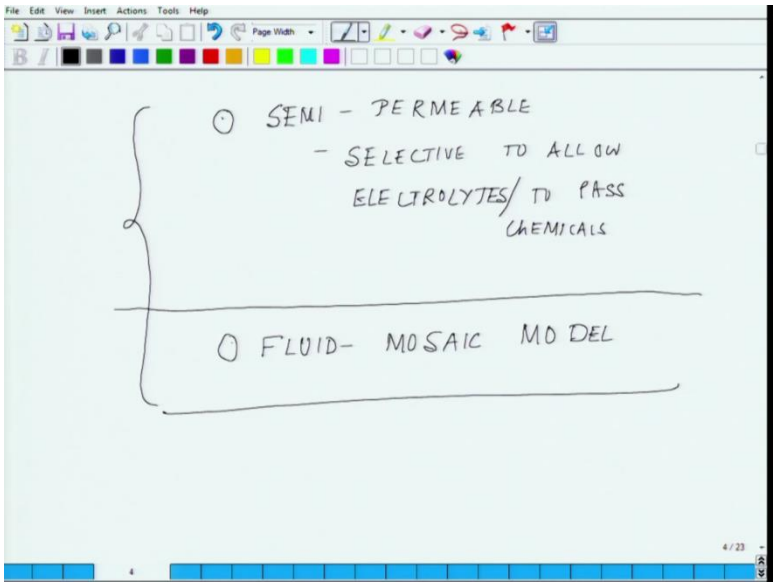
called extracellular electrode. Just in case, that come across which is will be coming across this pretty frequently. So, I just want to highlight that.

(Refer Slide Time: 08:09)



Coming back to the structure of the membrane. So, this is inside - outside the cell, and this is inside the cell, and these are the hydrophobic tails or non-polar tails. They are also called non-polar tails of the lipids, and these are polar head groups of the lipids. These are all the different integral proteins, spanning the membrane. This one, this one, this one, these are all integral proteins, spanning the membrane. And if there are certain proteins which does not span the membrane and those are called peripheral proteins. And the red ones that you see are the mostly carbohydrate glycoprotein, or some of them could be glycolipid; and in this membrane, within this membrane, you have there are whole bunch of cholesterols which are embedded all over the place in yellow they were, which enhances the fluidity of the membrane. In other word, the fluidity what I meant by fluidity here, so one second let me come back, these are cholesterol. So, what I essentially meant by the fluidity of the membrane means those cholesterols allows the membrane to be much more in a flexible and winding and all those kinds of things are being provided by the presence of cholesterols.

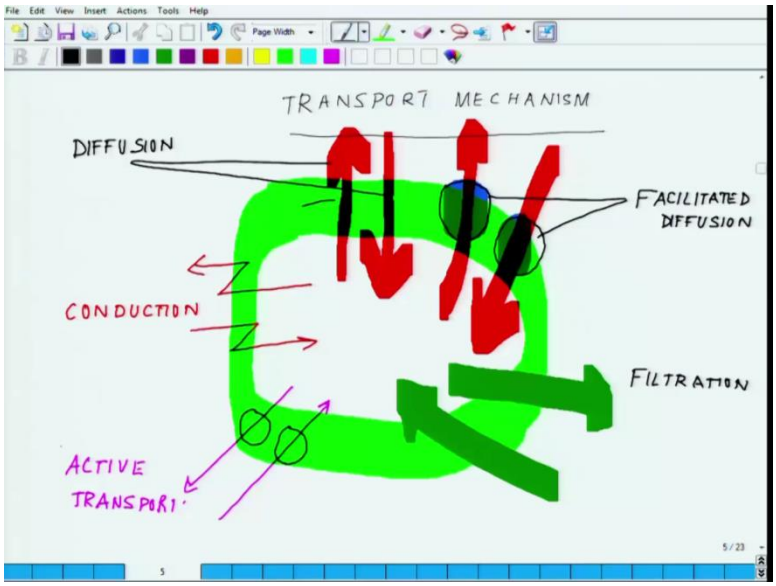
(Refer Slide Time: 10:25)



And apart from it, this is the membrane which is basically this is semi-permeable in nature as I was mentioning in one of the previous classes. Semi-permeable - it is selective about allowing things to pass through it; selective to allow electrolytes to pass, electrolytes or other chemicals to pass. And essentially, these kind of membranes are regulated by the whole series, if you see this structure, these embedded among this are the different integral proteins which forms ion channels and these membranes the model which is being currently used for this is called fluid mosaic model.

This is the very very basic fundamental which you people needed to understand, in order to understand the membrane. So, my request will be please go through any standard textbooks or go online, you will see the structure of the membrane even given in three dimensional that more beautifully, but this much basic is essential for me to kind of communicate with you further about you know what all the processes which are taking place. Now across this membrane, there are transport phenomenon of different kind of solute and solvents which are taking place. Next what we will do, we will enumerate all the transport phenomenon and then from there we will move on to the next part.

(Refer Slide Time: 12:31)

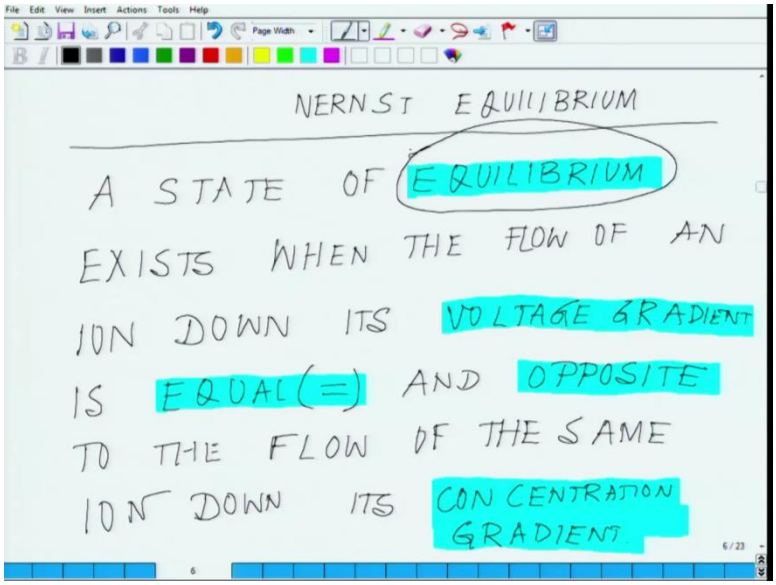


Let us talk about all the transport phenomenon, which are happening out here. So talking about the different transport mechanisms, which are being dealt out here. So, basic transport mechanisms, so if I consider, let me do it in slightly. So, if I make the membrane like this. So, this is the by lipid layer . So, there are essentially four different kind of transport phenomenon, which are taking place. One is the free diffusion inside of a molecule and outside the molecule. The other set of diffusions are like this, which has specific proteins which ensures, I will come to that. So, essentially what is happening out here in the first case, what you see is, what you essentially see out here, this is the case of free diffusion. Here in blue, what you see is what I have drawn out here, which I am circling now; these are the proteins, which allow a facilitated diffusion. Apart from it, you have the other process, which is called filtration.

So, this is showing the filtration; this is another transport phenomena. Then you have something called electrical conduction which is something like this; based on potential difference - conduction phenomenon. Then you have an energy driven process which are totally regulated by the availability of energy that is called active transport. So, this is in most brief manner, all the different transport phenomenon could be described. You have conduction, conduction is basically a function of the potential drop across the membrane which I have explained in terms of potential in the last class.

Then we have facilitated diffusion where basically there are proteins which ensures the moment of on the specific molecule electrolyte or organic molecule or whatsoever. Then you have filtration, then you need mesh through which it filters through and then you have the active transport which essentially depends on supply of energy. These are the four basic mechanism by which a membrane acts in order to maintain its bioelectric potential. And out here lies in this picture, out here lies, your whole series of ion channels and everything, everything is kind of you know lying all over this; this is the zone, where all these events are taking place.

(Refer Slide Time: 16:54)



So, now, based on all these things, I will come back to the Nernst equation which I initiated in the last class and now I will move on to the Nernst equation or Nernst equilibrium. So, before I explain Nernst equilibrium, let us try to understand two simple situations. So, let us assume the inside the cell and outside the cell. So, basically what he proposed is he derive the whole condition and proposed under what condition what will be the exact potential drop which will be maintain across a membrane where there will be a balancing act between the charges and inside charges outside and along with a different concentration and that is essentially called a Nernst equation.

So, let us formalize this thing in terms of in the just put it down in the slide, how the Nernst equation looks like, and how we give it a formal explanation of it. So, Nernst equation could be essentially could be written as this is a state. So, please be very careful

the state of equilibrium exists when the flow of an ion down its voltage gradient is equal and opposite to the flow of the same ion down its concentration gradient. So, if you read through this now carefully, since I have now put everything in word. A state of equilibrium, so your first keyword should be the word equilibrium, which exist between the flow of an ion and down its voltage gradient. The second keyword, which is equal and opposite to the flow of the same ion down its concentration gradient this is important. So, essentially you need to realize there are in between the line there are three important words; there is equilibrium which has to be established.

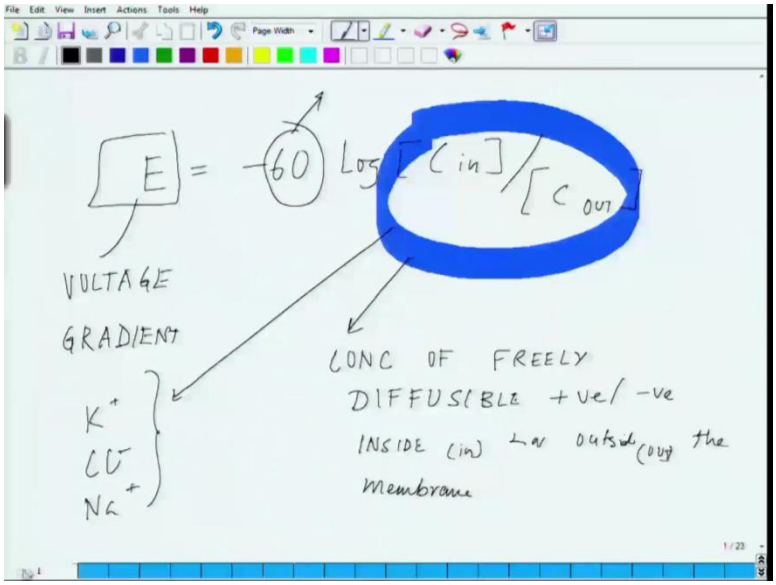
(Refer Slide Time: 22:50)

So, let us see what exactly that mean; that means, if this is the membrane which is separating one side to the other side and there are lot of positive charges likewise positive, negative and these different positives have different nature. I am just take care of that, it shows different nature. Say for example, this is sodium here, sodium here, sodium here, sodium here and say for example this is potassium; this is potassium and say this is chloride, chloride, chloride chloride. And then say for example, these are the n ions and proteins; whereas, we call this also called it n ions, there are lot of proteins inside.

So, let us label them. So, this is sodium, this is n ion a minus, this is chloride, this is potassium . So, now let us do the same thing again. So, we have to say this is the potassium, and then you have this lot of sodium outside. Then you have potassium out

here then you have this whole bunch of chlorides, which are present out there. This is the left, this is right. So, across this membrane, there has to be a electrical neutrality which has to be established in terms of the charge and in terms of concentration. So, the blue is basically telling you the concentration gradient and this is basically telling you the electrical charge.

(Refer Slide Time: 26:20)

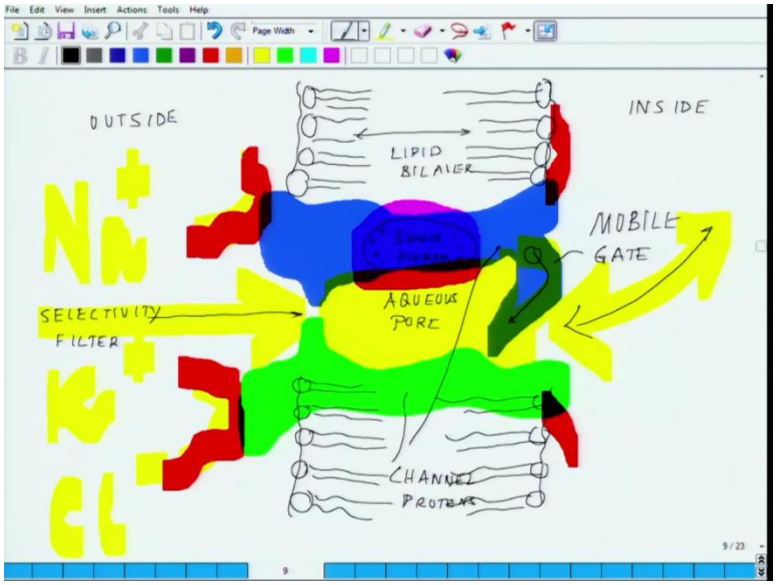


So, the balancing act between these two, so there has to be equality if you go through this diagram. So, there has to be equality between the voltage gradient and the concentration gradient and this is essentially expressed by a simple equation basically E is equal to and this is the most simplified form of it, you will see minus 60 log concentration inside upon concentration outside. So, where C in, C out represent concentration of, so this is the part which is representing the concentration of freely diffusible positives or negative ions from inside to outside from left or right to the membrane. From inside, which is represented by in or outside represented by our outside the membrane. And essentially E stands for the voltage gradient; and for individual ions, you could calculate the values for potassium, if you know inside and outside, you can calculate for chloride, you can calculate for sodium. Calculate for pretty much anything and everything out there across the cell as long as you know the fundamental, you know the values inside and outside.

So, this is the most fundamental equation which needed to be understand in order to understand membrane bioelectrical phenomena. So, from here, after giving you very

brief by the way minus sixty what you see is actually has come from minus r t l and f. And I will if say fairly straight forward thing I am not getting in depth into this. And you can really see any textbook, you will see the whole basically there is Fahrenheit constant involved in it in absolute temperature at which it takes place and that also takes into account the valency of the particular ion which is freely diffusing across the membrane.

(Refer Slide Time: 29:41)



So, here what we will do, I will based on my one of the slides come back where we talked about the membrane structure, I will introduce the structure of the membrane protein how it looks like. So, from here let us talk about the structure of the membrane protein that will give you help you to visualize it much better. So, if this is the lipid by layer we talking about. So, for example, this is the lipid by layer where, and here you have the polar head groups which are sitting there. Now the membranes kind of look like something like this, and if I use the other side that will be something like this. And top of this, you have and this is anchored and these are being anchored.

This is basically called the selectivity pore. So, you can call this inside the cell, and this is outside the cell, and this is the selectivity filter. This is aqueous pore, so this is all proteins. This is essentially is the gate out here, when we talk about the voltage gating and these things. You have a sensor element, which is sitting there. This is the sensor element, and this is lipid by layer and these are the channel proteins. Having introduce you to this structure, so this is the generic structure what I just now drew for a channel

protein or a membrane protein. It could be either voltage sensitive or ligen sensitive. If it is voltage sensitive, this sensor element what you see out here, this senses the voltage, this is the voltage sensor sitting out there which I have just now highlighted.

Then it has a gate element which is out here, now I am highlighting. This gate opens or closes. So, in other words, this gate has some kind of mobility - molecular mobility. Then you have the selectivity filter, this selectivity filter decides whether it will be sodium, whether it will be potassium, whether it will be chloride likewise. And then you have this aqueous pore which is out here, which is essentially this part of this through which it passes. So, and this is something we are talking about one of the most and of course, apart from it there are few other may be some kind of a glycol proteins which are sitting there here out here likewise. So, this is the overall geometry and this gate what you see out here is existing out here. This gate is a mobile gate or this is a movable gate, so this gate basically moves in both the direction. It can open according to the command it gets from the sensor. So, this whole structure, these are the most beautifully evolved structure of ion channels. And now what we will be essentially try to do from here is that options you have done Nernst equation, we will talk about in depth about sodium channel, potassium channel, and we will talk about the techniques which are being used to study these ion channels. But the very basic structure remains like this on top of that, there are lot of modifications which takes place.

So, I will close in here with this introduction, so introducing the membrane structure. So, what we essentially did today is we introduce ourselves to the structure of the membrane out here. From there, we moved onto talked about the characteristic of the membrane and then we talked about the different transport phenomenon which are involved across the membrane. Then we introduced ourselves to the Nernst equilibrium and here in Nernst equilibrium, i tried to help you to visualise the situation, how the Nernst equilibrium is being maintained. And from there, we moved onto formalising the Nernst equation and then we introduced you to the ion channels. So, I will close in here; and in the next class, we will go in depth with the different ion channels and immediately followed by the action potential.

Thanks a lot.