Bio-electrochemistry

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Lecture – 15
Bio-electrochemistry of Excitable Cells (nerve cells)

So, welcome back to the lecture series in bio electrochemistry. So, today we are into the fifth lecture of the third week, which is essentially our lecture 15th. So, last class; last two classes, we talked about the concentration cells, and I told you that how our concentration cell can be used or can be constructed, and in the last class, we talked about when you have a porous membrane which allows a selective ions to flow across it that leads to the generation of Nernst potential or membrane potential.

So, today our journey will start with a biological cell todays class is dedicated to electrically active cell mostly, the nerve cells, or the muscle cells, and if you see most of these cells those of you have done, I mean any biology class till class 10 which most of you have done I believe. You know that a membrane potential they say that a cell has a membrane potential of say minus 90 or minus 80 millivolts.

With respect to the outside the inside is negative. So, this is what we always say that inside the cell the negative charges are more, with respect to the outside, and the cell membrane is a semi permeable membrane. So, before I just go into the discussion, let us put it.

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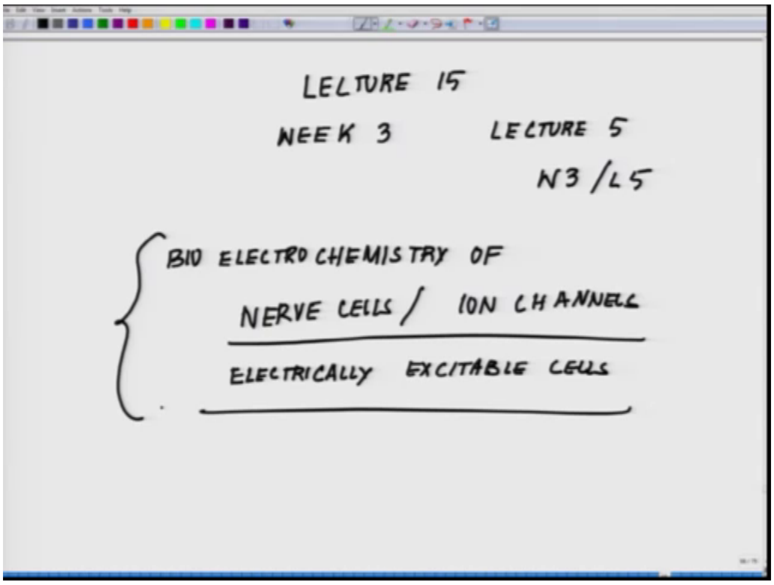

So, today is lecture 15 we are into week 3, lecture 5 W3 L5, and today what we are going to deal with is Bio Electro Chemistry of nerve cells slash ion channels or you can call it electrically excitable cells. So, this is what we are going to deal with. Now when we look at an electrically excitable cell.

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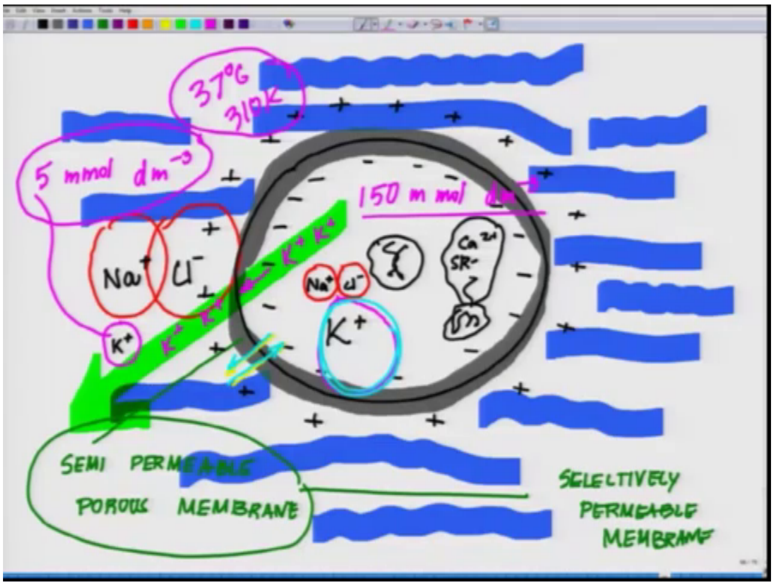

So, this is what we kind of see if this is a cell, this is the biological cell. Now I am not talking about electrochemical cell now. Now I am truly talking about a biological cell.

So, if you look at it I have a nucleus, and all those kind of stuff, but what is important for us to realize that inside it is more negative, and outside it is positive.

And the ions which dictate this negative, and positive situation are outside you have sodium inside you have sodium outside you have potassium, inside you have potassium of course, if sodium then you have chloride. So, at this point lets deal with only these 2 3 ions of course, inside you have inside a structure called sarcoplasmic reticulum SR you have calcium, but we are not dealing with it just for your knowledge sake ok.

Which is calcium is not freely moving around roaming around inside the cell. Now having drawn this, you must have seen I have drawn these alphabets at larger and smaller size there is a reason for it. So, outside the cell which is extracellular. So, this whole region, which is the extracellular region extracellular region is has a concentration with of solute similar to that of seawater.

So, in other word when we talk about seawater, we talk about a situation when concentration of sodium is fairly high. So, this concentration of sodium is fairly high along with the chloride concentration, chloride ion concentration. As compared to the sodium which is inside, and chloride inside vice on a reverse note inside the potassium ion concentration is very high as compared to potassium concentration.

Now, the third aspect what is important for you people to appreciate is this membrane what we talked about, the cell membrane what we are talking about semi permeable porous membrane, this membrane is selectively permeable, or semi permeable, this is also called selectively permeable membrane.

Now, having said this now if I say, if I take the liberty to tell that this semi permeable membrane on a normal condition only allows one particular kind of ion to freely move across it. In other word there is a free movement of only one particular kind of iron, barring aside it will not allow others to freely move.

Unless otherwise they utilize some other mechanism to flow across it; so if I say, if I take this liberty to tell the ion which can freely move across it is potassium. It can freely roam around across in and out. Now if I say so; that means, the potassium ion concentration inside is higher, as compared to the potassium ion concentration on outside if that is the situation, then what will happen is the potassium ion flow will be governed like this.

Because in that case potassium ion from here, from inside will try to leak outside. A situation which you could recollect back in the previous class, if I now just put in front of you the drawing what you drew here.

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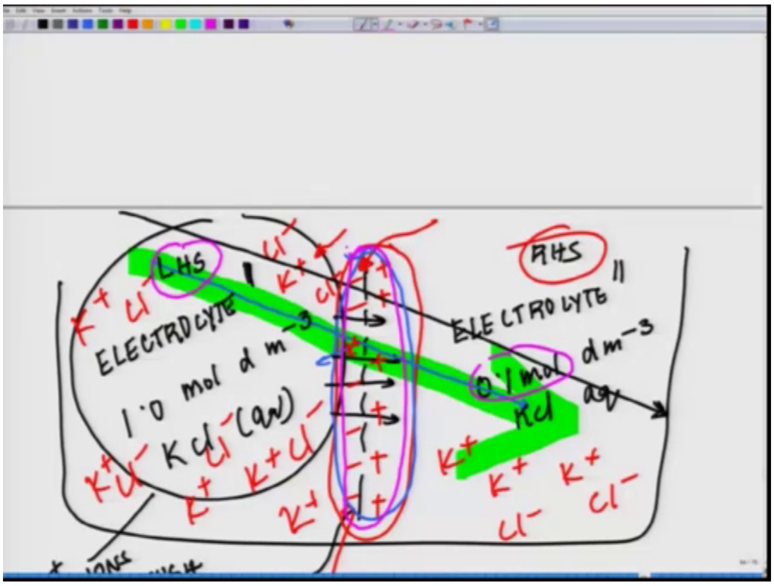

On your left hand side, you have higher potassium on your, right hand side, you have a lower, potassium chloride both side of course, you have potassium chloride on the left hand as well as right hand.

Only difference is that potassium chloride on the left hand side has a higher concentration as compared to the potassium chloride on the right hand side, and the membrane what we talked about is a semi permeable membrane, which only allows potassium to migrate in both sides. So, what it led to is what we call as the membrane potential.

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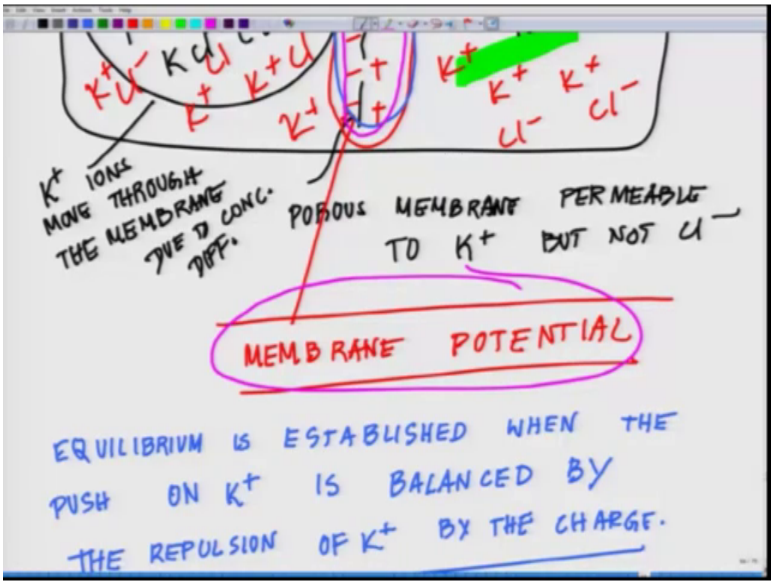

Now, if that holds true in that situation.

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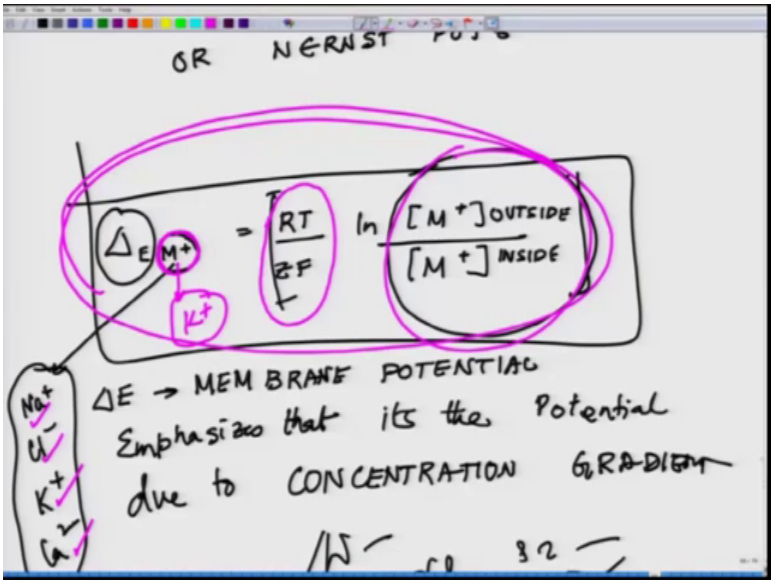

Exactly using the same situation, we are almost getting there, and we draw this expression where delta E which is your membrane potential, and we talked about any iron, it could be sodium, it could be chloride, it could be potassium, it could be calcium. So, in this situation now we are talking about potassium, if we use this analogy I already told you the E 0 will become 0, because on both sides it is the same E 0 we are dealing with .

So, in that situation this is the expression which is going to govern, the membrane potential. Now coming back to the situation. Now since I showed you this if now I plug in the values if I know the concentration. The concentration generally, the concentration a typical concentration of potassium inside the cell is 150 mill molar.

This is the typical concentration inside the cell as compared to outside; outside the potassium concentration is around 5 mole, this is the typical outside concentration. If these two are the concentration, and if we consider the body temperature to be 37 degree centigrade, which is 310 Kelvin.

Now, if I plug in the values now, with the expression which we developed out here. So, now, I am plugging the values.

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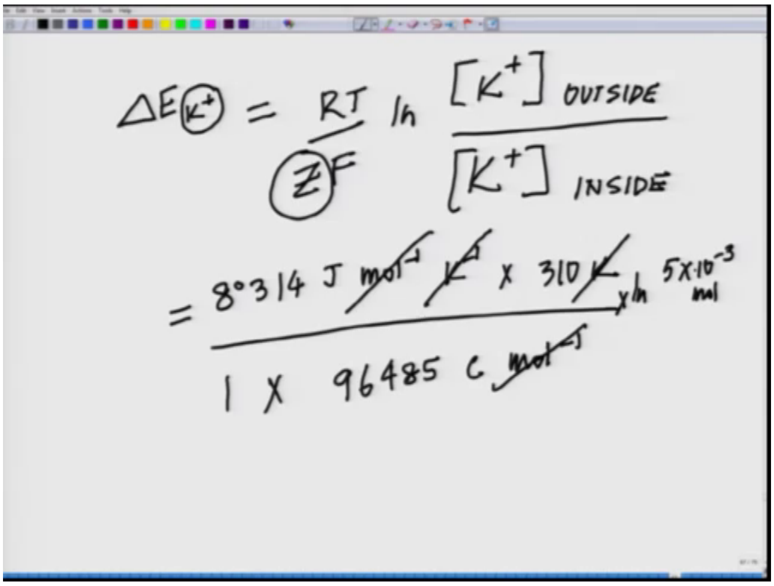

So, again let me put it across delta E k plus, now instead of m plus no I am just putting the comparison. So, that everything makes sense. So, M plus become K plus equals to RT upon ZF natural log K plus outside K plus inside.

So, that brings us to the point 8.314 joule mole multiplied by your Kelvin 310 Kelvin divided by 1 which is potassium ion, which is 1 electron transfer, which is happening multiplied by the valency actually essentially in this case, 96485 coulomb this too gets cancelled this one, this one gets cancelled.

Multiplied by natural log putting the value outside, which is 5 into 10 to the power minus 3 mole that was in mini mole, if we just do not get confused this is in mill moles.

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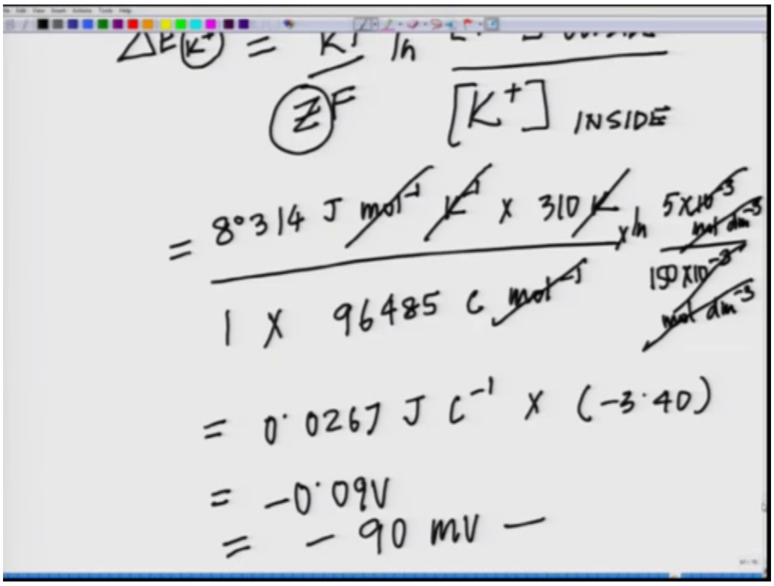

So, it is converted into moles its convert into mole 5 into 10 to the power 3 mole divided by 150 which is inside multiplied by 10 to the power minus 3.

This is cancelled, this is cancelled, 10 to the power 3 get cancelled 10 to the 10 to the power minus 3 gets cancelled sorry 10 to the power minus 3 get cancelled. So, eventually the expression almost boils down to 0.0267 coulomb multiplied by minus 3.40, and that brings us to 0.09 volt, and that further brings us to minus 90 milli volt.

Now, this is the reason the concentration of potassium ion which dictates the membrane potential, and this is the fundamental reason, why our cell sits at minus 90 millivolt, and this whole derivation, the whole journey of last 10 to 14 lectures you might be wondering that why I have to go through this whole rigor of understanding Nernst equation, why I am pushing upon that you know please go to the basics. Now in the light of all these things, if you understand the Nernst equation, if you understand the simple electrode reactions everything will make sense to you; otherwise nothing will ever make sense to you.

Now, in the light of this if you plug in the values y s l sets around. Now I told you in the beginning the cell sets around somewhere around.

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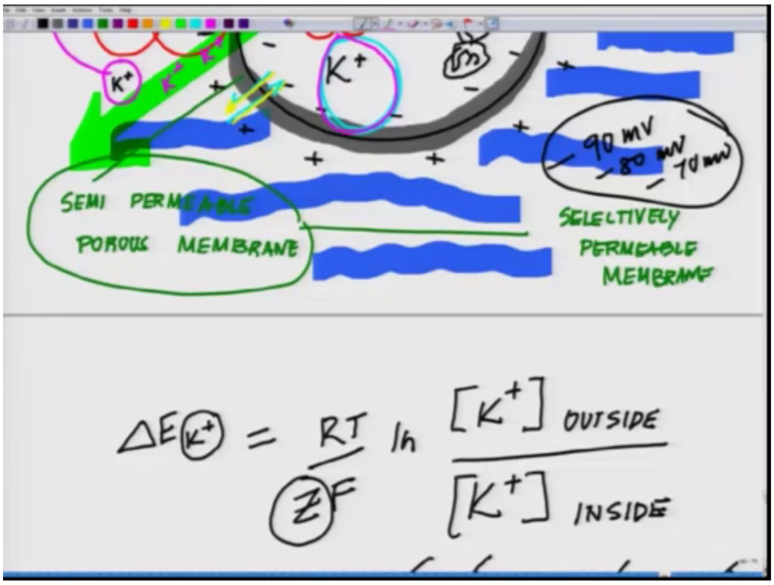

So, mostly a cell sits around whenever we talked about sits around either minus 90 millivolt or minus 80 millivolts or minus you know 70 millivolt this is there.

So, except barring aside certain cells. So, for those who are biologists; do not take into account at this point the pacemaker cells, which sets at minus 35 or minus 40 millivolt do not take those into account there is different reasons for it, but the basic logics are the same, the membrane potentials are determined by a different kind of permeability. So, we are not getting into that for the time being ok.

Now, coming back; so, that is the fundamental reason why a cell sets at minus 90 millivolts. Now if we plug in another value say for example, we talk about I will talk to talk about say for example, when we talk about. So, thus the potential across the membrane due to the difference of potassium concentration is minus 90 millivolt.

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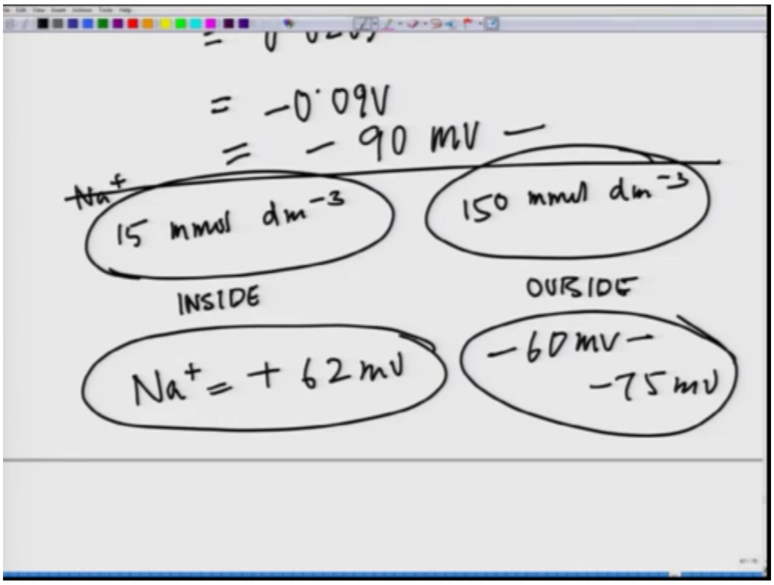

For sodium ion, the intracellular and extracellular concentration are for if I talk about the sodium ion, it is around 15 millimole, this is inside whereas, outside at it is 150 this is outside.

If this is the situation, and for the sodium if you do the calculation you will find the membrane potential of sodium is plus 62 millivolt, I will leave it for you to do this exercise all by yourself. So, am giving you the value you can look at it. So, all the various ions that exist in and around the nerve cell contribute to the overall membrane potential, which when cell is at rest and not transmitting any information it is around that is why I told you minus 60 millivolt to minus 75 millivolt, this is where most of the values lies because there are other ions which are involved in it. The exact ionic concentration depends on the situation of the cell, and the ambient condition.

So, these are the values which are very typical values. So, when a nerve cell is stimulated. Now this is a different kind of situation, when a nerve cell is stimulated the sodium channels at the start of the axon, they allow the sodium ions to move inside, making the potential inside less negative.

And as more sodium enters the cell the potential increases around plus 20 to plus 40 millivolt, at this point the sodium channel closes and separate the potassium channels open. So, that potassium ion leave the cells changing the potential back towards the resting value, when the resting value is reached the potassium channel closes, and the normal balance of ion is restored by ionic pumps, proteins that can transport particular ions against the concentration gradient which of course, requires a lot of energy.

And this change in potential is what we call as an action potential, which is being governed by the presence of ion channels, and restored by ATP dependent pumps. Otherwise a cell is a very similar entity as what we discussed out here, a concentration cell. So, you look at it where we started on our 13 lecture this is where we started.

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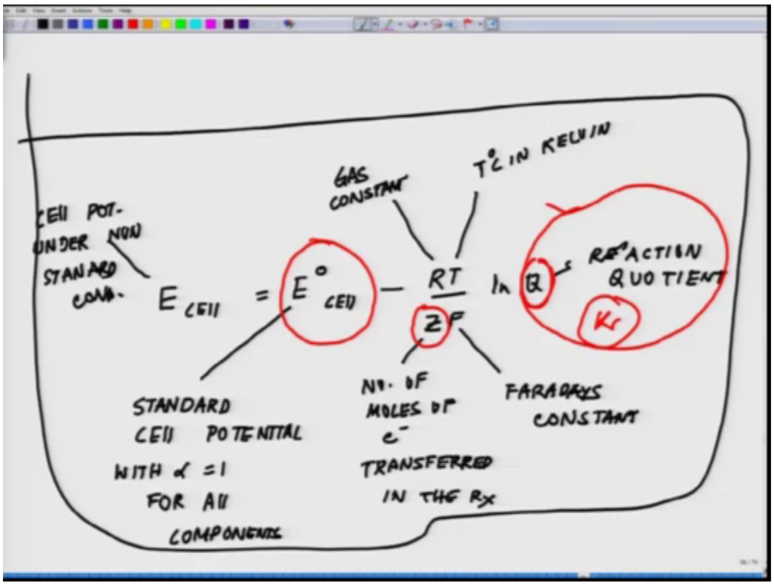

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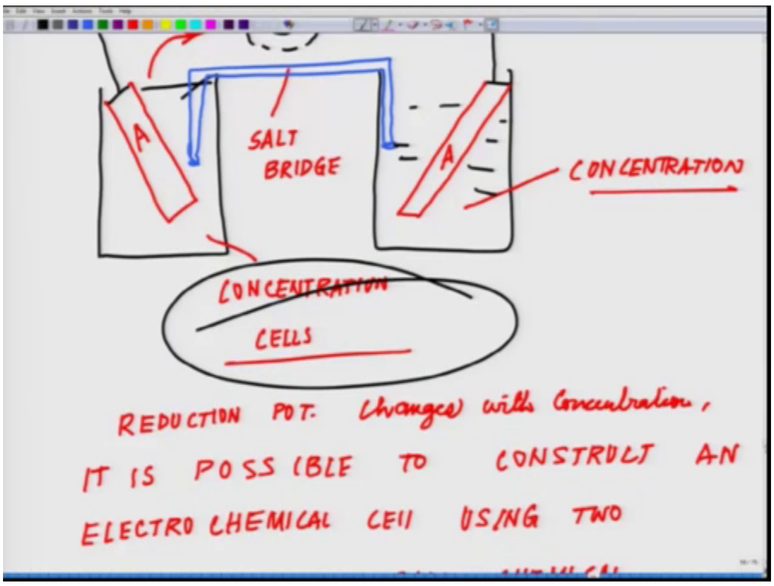

With that simple equation in front of us, from there, we moved on to the concentration cell, which was our first cut from concentration cell, we gave an example in the inorganic system, where you have silver as on both sides you have silver in the aqueous environment with a different concentration.

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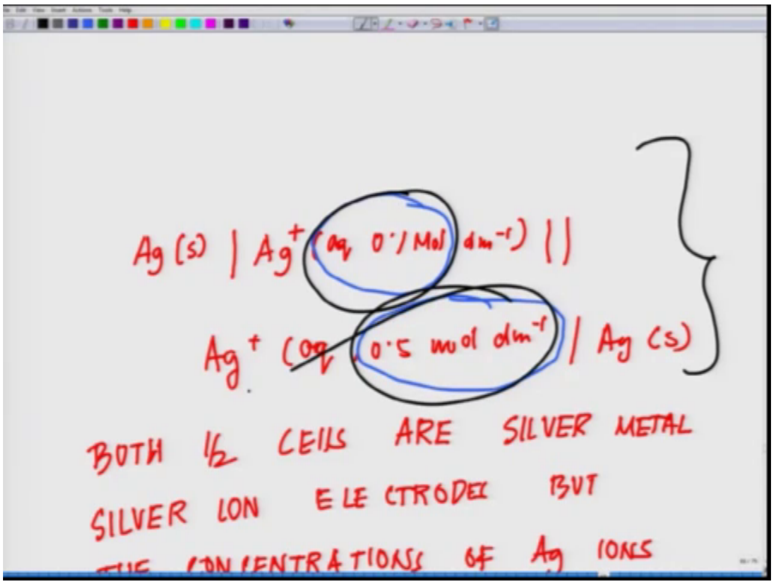

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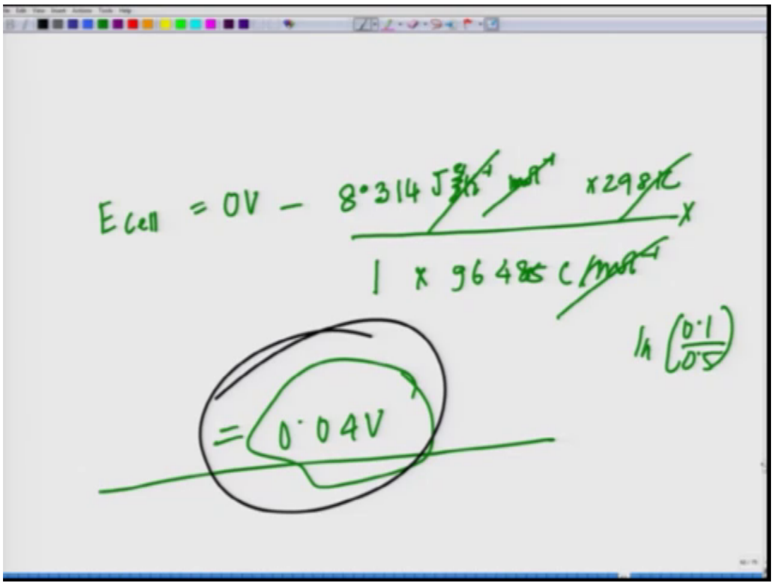

Then from there we moved on and we made the calculation what we got as 0.04 yeah 0.04 volt, and from there we moved on to an another example of a concentration cell where we took into account a semi permeable membrane, and we introduced the concept of membrane potential.

This is where we introduce the concept of membrane potential, and from our journey to membrane potential, we entered into the world of biological cells. That brings us the complete circle of realizing Nernst potential, how different electrodes on left hand, and right hand side, same electrode on left hand right hand side.

How you can vary the concentration, how you can vary the electro motive force how you can really you can have different reduction potentials think of it. I have a E 0 of a different E 0 on one side, another E 0 on another side, two different E 0s let us do the flow keep the concentration same. I could have different concentration having the same E 0, E0, E 0 as we talked about silver.

E 0, E 0 so, E 0 gets cancelled because e 0 you remember E is equal to E 0 plus minus e 0 minus right. So, the E 0, E 0 gets cancelled, but still you the concentration which is different. So, this requires a lot of rigorous thinking process, it is not you have to you know mug up the things.

You just have to realize that you have to think over it, churn over it, realize that you know these are very simple equations, but these expression which won Nobel prizes, you know they hold something amazing in, in their own beauty. So, try to appreciate these simple things, and try to correlate things. So, that is our journey as of now from simple electrochemistry, to the bio electrochemistry, of biological cells.

Thank you.