Neural Science for Engineers
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Module - 02
Lecture - 06
Synaptic Potential

Ok so, revising something from the previous class we looked at in great detail about the action potential, I mentioned the necessity of knowing the details of the action potential because there are a lot of jumps which is happening at that stage. So, we were looking at very dumb biological processes which suddenly show a lot of maturity in its computational status, we looked at how proteins can act as logic gates.

So, protein channels not only act as logic gates, but also as time gates, so there is a lot of computation built into that step and we also looked at the phenomenon of action potential which is a remarkable entity in itself.

So, we have one single method of communication for all neurons, it is so standardized, that it is standardized for billions of years across various kinds of organisms, same method of communication for the nervous system and with similar potential changes also conveyed about how potential changes remain the same across various neurons of the body, there as some things which we will be discussing now, which are exceptions to this, but which only adds to the beauty of the whole process.

So, that is about the action potential, we also discussed how the action potential is a wave form and how being a wave form it can be a propagated wave and by propagated wave, we also convey that there is information which is transferred from one part of the membrane to another part of the membrane.

We have not discussed about the origins or the destinations of this action potentials and what subsequently happens downstream or may be upstream. So, how the stimulus is generated, how the action potential goes on to produce something else is something we have to discuss subsequently.

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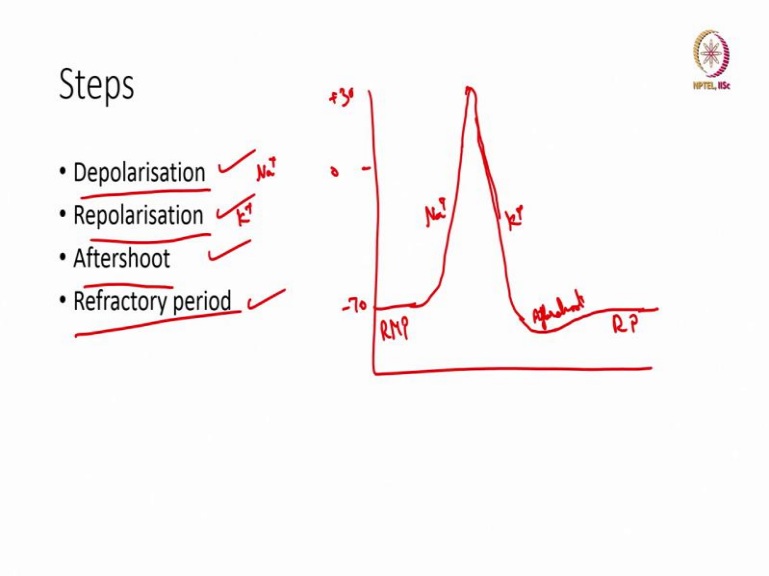

So far, I have been discussing in very non biological terms, we just discussed potentials we discussed something called proteins and we discussed wave forms. Properties of the wave form, how amplitude remains the same and the frequency. What are the bounds of frequency generation vis a vis stimulus?

So, stimulus frequency to output frequency; output frequency is a function of the membrane, as such simulation frequency beyond a certain level can synchronize with output frequency because of the properties of the membrane or you can call it resonating frequency.

So, you have a stimulus which can exactly output the membrane because of the same properties of the membrane. So, you have a particular frequency beyond which output frequency matches the input frequency ok.

So, some terminology is necessary because people who are in various domains of engineering physics, biophysics, it may not be sufficient enough to have this bland explanation and understanding of the whole process. So, that is why I thought I should highlight what these things are and what parts of it is.

So, we go back to the potentials -70, 0 and +30. So, we start with the baseline which is the resting membrane potential then this is called the phase of depolarization.

So, depolarization as sodium based then this is the phase of repolarization which is slightly exaggerated a bit too much. So, repolarization is this phase in which this is sodium, this is potassium, this is potassium also used for questions which I have to set for all of you.

So, then there is this after shoot; after shoot which is the restoration. So, this is the after shoot and then there is the refractory period. So, this constitutes a conventional classic action potential the properties of which we have discussed so far this is the medical terminal.

So, you have depolarizing phase, repolarizing phase, the after shoot and then the refractory period each of with the implications and relevance in various contexts, I will try to discuss it as much as possible in wave form context and these are important things to be remembered because especially when you are looking at more complex wave form such as EGMG the same stuff works, but you should understand the difference between the two and how each of those signals have unique properties and they all have the AP as the fundamental entity.

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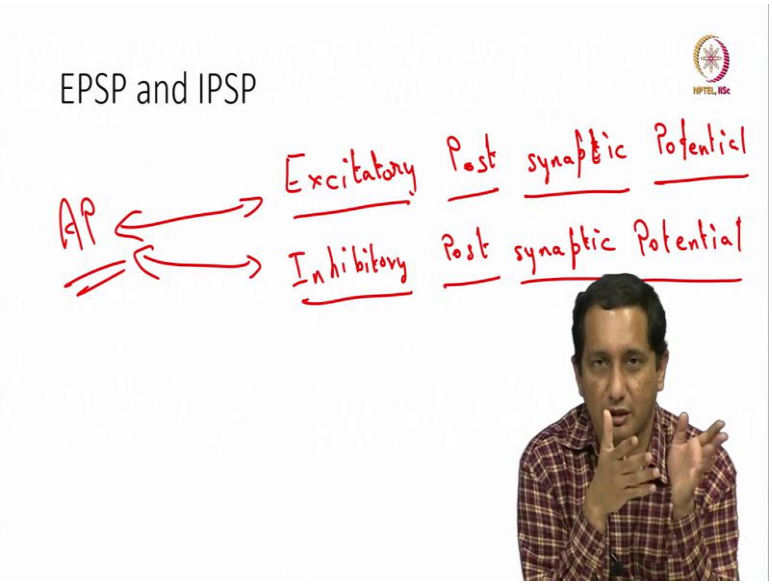

So, we now discuss something else. So, we now discuss something called as EPSP's and IPSP's. So, EPSP is Excitatory Post Synaptic Potential and Inhibitory Post Synaptic Potential. So, there is a jump which is happening here. So, we were discussing only in terms of membrane, I never use the term neuron or the nervous system or anything. So,

we had intelligent cells, alive cells, then we had excitable cells and then we had a cylindrical membrane through which we discussed the entire story so far.

So, there is a particular jump which is happening because I have not described a synapse so far and it becomes worse because we are discussing postsynaptic, and it also is different because we have two entities. So, these are very different from an AP which we have discussed so far.

So, how an AP differs from each of this and why it is relevant? I think we will discuss this before going into the structures of the nervous system. See, so I am going in a particular way as I told you we are not dealing with it in a medical curriculum fashion where we discuss all of this in very compartmentalized entities. So, you would have the anatomy of the nervous system, have the physiology of the nervous system and then of course, pathology and stuff like that which is much later.

So, there is a blend which I am trying to convey, and it has a particular reason. So, I am trying to link up a lot more from the engineering side. So, physics side where what should be very basic material for you starting from semi conductor theory to wave functions and then go on to the structural part of the story instead of the way in which we are taught in the medical side where we look at a structure first and then function or rather maybe of course, it is not so discrete, but I have not included any structure so far.

So, in the same way I will discuss these potentials and then we will see how to take it forward in way we use these two to incorporate it to the structure and once the structure comes into play I think neural networks and so many other things make a lot more sense. It also would show how poorly designed the most sophisticated neural networks are even by today's standards, you have fantastic outputs coming from several kinds of neural networks.

But even looking at stuff which we have discussed so far, they are far behind. Either in terms of the genetic complexity or in terms of consistency of proteins, consistency of the action potential, consistency of the frequencies. So, they are conserved, they have been conserved for millions of years.

It is such a beauty that you know you have a protein which acts as a logic gate. We have proteins which change the shape to time and how about two or three sets of proteins is

sufficient enough to produce a propagated wave across a lipid bilayer which is basically a capacitor ok.

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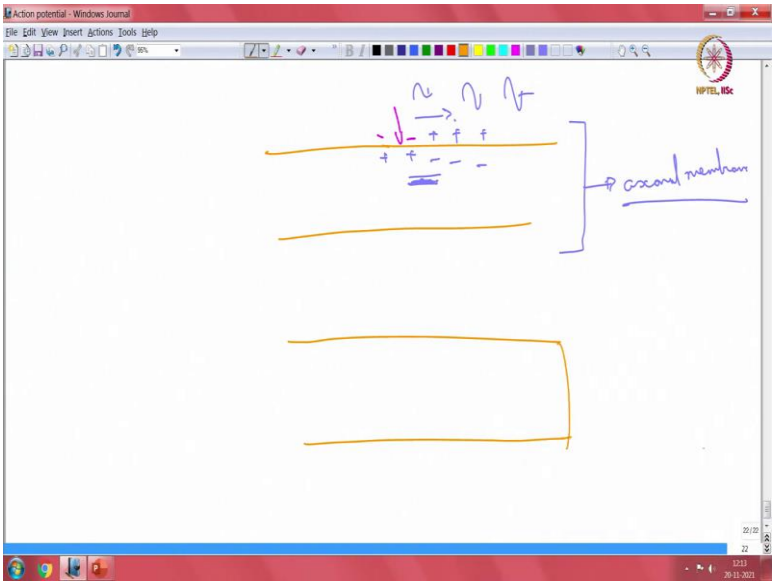

So, we go on to EPSP's and IPSP's. So far we have been discussing that when there is a membrane and when there is a what you call stimulus and you have stimulus on the outside which is producing change on the inside, that causes and it propagates.

Now, this is because the nature of the membrane is such that this is allowed. So, when we speak about this thing we are generally speaking about an axonal membrane. We will look at this in a slightly greater detail at later class, but for the time being we understand that this is an example of an axonal membrane in which this particular sequence of things happens.

But suppose that this catching business does not happen. So, you know you have such a density of cells that you know what is the wave function that gets transmitted along the membrane, but it does not happen that way. So, we look at a different cases in which you have a membrane and ok I think it is time to take up a new.

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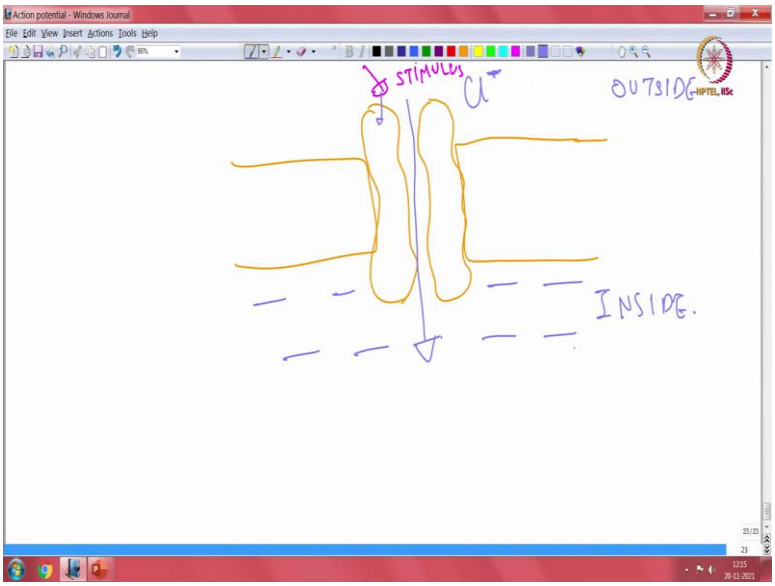

Suppose we have a different kind of membrane with a different kind of channel. I will not specify the channel and the stimulus in this case is again you know we put in negative charge. So, we have a stimulus so outside and the inside.

So, we put in a stimulus and then there is a particular ion which goes in and which although it is negative it allows for a negative ion. So, say for example, chlorine; chlorine moves across its gradient because this channel is open because of the stimulus.

So, stimulus actually acts on the membrane and then there is chloride which goes across a concentration gradient which actually causes increase in the membrane increase in the membrane negativity. So, you have got more negative channel across here, so this is one of the scenarios.

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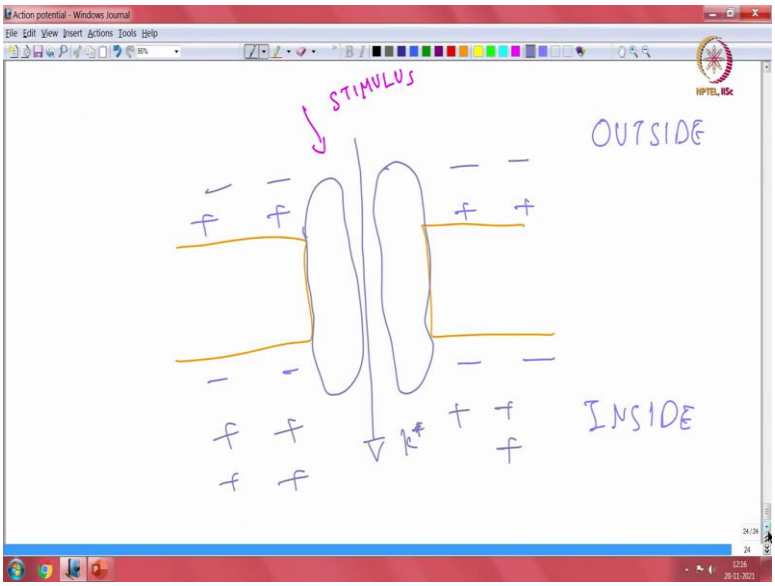

You look at the opposite scenario, same membrane different channel and we have charges positive and negative positive and negative, positive, positive, negative, negative outside inside. So, what goes through here with a stimulus is potassium and this is slightly larger amount of the channel opens for a longer duration of time.

So, the potassium basically adds in a lot of positive charge and that reduces the, that increases the positivity inside basically reducing the negativity outside, so this is local. So, both of these are local phenomena and what actually happens with that is something which we need to consider. So, in both of these scenarios I think we should see how the voltage graphs goes by.

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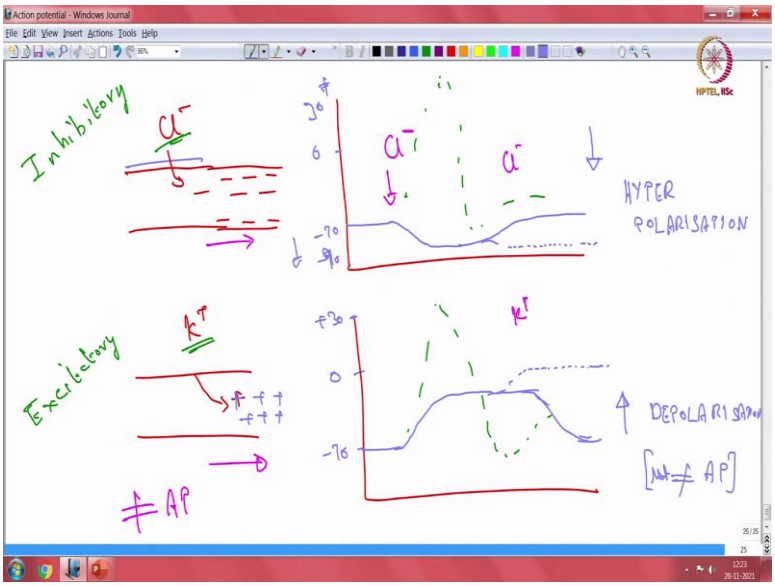

So, in the first case we have stated how much was that -70, 0 and 30 +30 -70, 0 and +30 ok. So, this is not an action potential. So, the first thing is this is not an action potential because this is not happening within that part of the membrane. So, membranes can have different kinds of properties and we have already discussed as to the membrane property that is generated is basically a function of the membrane.

So, when you change the membrane itself, a membrane or the cylinder itself, then the property of the potential itself changes and this is important for this reason. So, when we put in the first case, first case is this one we have put in chloride negative. So, we will start with analyzing what happens.

So, when we put in chloride. So, resting membrane is at 70 and then the chloride actually changes it to -90 and then that is continued for some time and then it gradually changes back to normal. So what happens is something called hyper polarization; hyper polarization is because the membrane potential goes down further from -70 to -90, this is with stimulus of which causes a chloride channel to open.

So, second scenario is again resting membrane, it's like this the potassium channel opens up and the potassium channel is basically positive. So, you have an influx of potassium channels and then it goes on like that and it continues for some time before coming back to normal.

So, what happens here is it does not reach the action potential threshold, incidentally I have not spoke about yet. Threshold is something which we discussed in the axon. So, this is again the current is like this; this is depolarization still, but not sufficient enough for an action potential.

So, these are local changes which are happening. So, there is a small membrane, and you have the changes happening within this small membrane. So, here what is happening is the ions which are accumulating. So, if we are putting in chloride and if we are putting in potassium, this causes current ionic current which is propagated through the inside of the cell.

So, this is changing, but it is not as much as an action potential, but there is a current which is getting propagated along the inside of the membrane and that is called as an inhibitory potential.

So, we will come to the postsynaptic later on. Here what is happening is this is actually causing positive ionic current. So, the positive ionic current is getting transmitted along the membrane, it also getting transmitted along the membrane, but there is no action potential and so that is the difference.

So, that is the significance of the story. So, what is happening is there are currents which are generated which are lesser than that of the action potential which I have shown earlier, so there is no action potential. So, that firing which is not happening here and there is no action potential which is not happening here.

So, without action potentials being generated there is information which is being generated because of a gate which is the sodium channel and the potassium channel and this gets transmitted as an ionic current through the membrane. This is not getting transmitted on the outer boarder of the membrane, it is getting transmitted through the substance of the tunnel.

And so, when it is negative, we call it as inhibitory and this we call it as excitatory. So, why inhibitory and why excitatory is the question. So, what is happening is when there is hyper polarization and then there is depolarization. So, these are two things which we need to explain. So, we come to what is different from an action potential, why this is

very different from an action potential, the channels which are very different, membrane properties are very different.

So, those are fundamental differences as opposed to the action potential where when you reach something called as a threshold and action potential is generated irrespective of the extent of stimulus and the action potential continues or reaches its destination you know it goes through the various parts of the action, various parts of the voltage curve irrespective of all other stuff.

Here it is not like that, here of course one thing which I have not even spoke about is it can be actually graded. So, say so for example, you have another stimulus over here. So, this actually can take you know more hyper polarization and if it is in the case of potassium here this can further subtly change.

So, you can have small change in the membrane potential. So, these are summating. So, the concentrations of each of these things are summating. Again, you should remember that there are very natural doubts which come into your head about why does this not happen on that side of the membrane and why there is so much of discrepancy between the discussions so far.

The first part of the discussion was very straight forward, here we are looking at very concentration gradients, we are looking at current gradients and things like that which did not seem to figure out in the first part.

So, I reiterate that the action potential is the currency of the nervous system, which is what the transactions which happen through that, but the computational part of the nervous system is actually these things. So, IPSP's and EPSP's where gradients are generated. Now, what is so great about gradients versus action potential? Action potentials are limited because you have constant amplitude whereas, this IPSP's and EPSP's have freedom in the amplitude. So, we look at how this would change in very interesting fashions over here.

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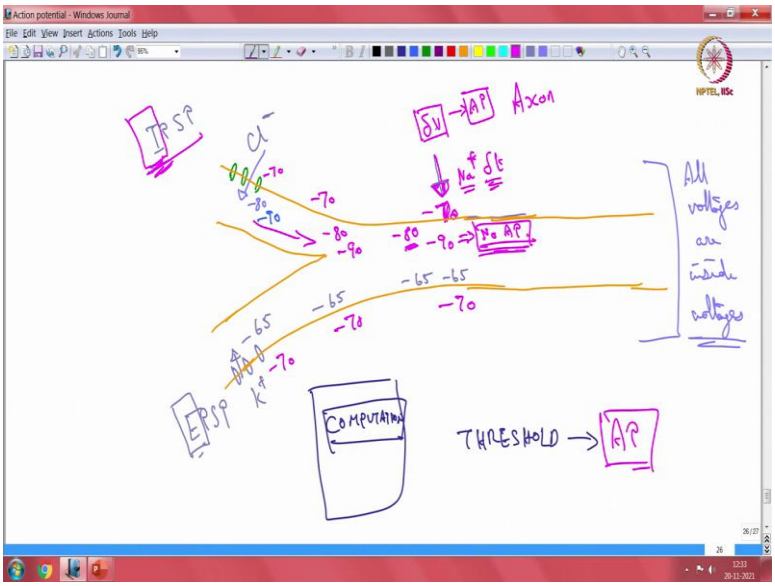

So, far we have been discussing one single cylindrical membrane suppose we have something which is branching ok. So, we have branches, and we make it more interesting that we have a chloride channel which is over here, chloride channels across here and we have potassium channels across here.

Now, we did connect the chloride channels to IPSP's and potassium channels through EPSP's so excitatory inhibitory. So, I did not explain why it is excitatory and inhibitory. So, we need to go back to the membrane and what happens to the membrane when there is a bifurcation when then these gradients are being generated.

So, we start with chloride, and we need to plot the membrane potentials and difference. So, here we start with -70 and there is -70 and -70 over here. So, here also it is -70 -70 -70 milli volts which I have described earlier.

So, when there is an injection of chloride the -70 becomes -80 so as to say. So, then this is only inside ok. So, all of this what I am writing as - is on the inside, all voltages are inside voltages, this is important because there is a shift in this one, but for the purpose of understanding I have no other way, I am not using two voltages because it would be extremely confusing.

So, we are just using the minus which is incidentally the convention of describing membrane potential. So, when we describe -70 it is always understood to be the inside of

the membrane and that is the membrane potential which comes into discussion for cross biological experiments and data ok.

So, we have put in a stimulus over here and that stimulus is generating a -80 because there is a chloride channel which is open now that current gradually moves along this one and that produces a -80 and that produces a -80.

Now, assume that this is the axon which we will discuss subsequently and then we have given the action potential stimulus as before. So, action potential stimulus we have given this one which goes through the potassium.

So, the potassium opens for a finite amount of time dt through which the action potential should have been generated, but now what happens is what was -70 is now -80 and the action potential takes a longer time to get generated because the potential is -80.

Now, say for example, this is the standard stimulus, the voltage which is given as standard in the sense that this particular change in voltage is sufficient to generate an action potential otherwise. So, you have a voltage which otherwise would have generated an action potential, but because there is a chloride current which has come downstream from an upstream source you have -80 and so there is a prolongation, there is an increased time which is taken for the action potential.

But suppose that you have the chloride current for a longer duration of time and that in turn is causing -90 at source and that -90 gets propagated along downstream we are looking at -90 and then there is -90 which implies no action potential.

So, this EPSP's IPSP's, so what an IPSP does is that it prevents an action potential from happening. So, that is the importance of why the I part of the IPSP is there. So, an IPSP basically reduces the chance of an action potential happening somewhere downstream and we make it more interesting.

So, we on the opposite side. So, you already have a minus potassium which is gone into the system and you have raised it to -60 ok. So, -60 is actually the threshold. So, we will not lose -60, we will use it as -65.

So, -65 and then this change is getting propagated as -65 -65 -65. So, the amount of sodium which has to enter for the standard voltage change the action potential is

generated slightly earlier. So, it facilitates an action potential generation. So, that is the excitatory part. So, I think it has become cluttered, I will discuss this in greater detail in the next one.

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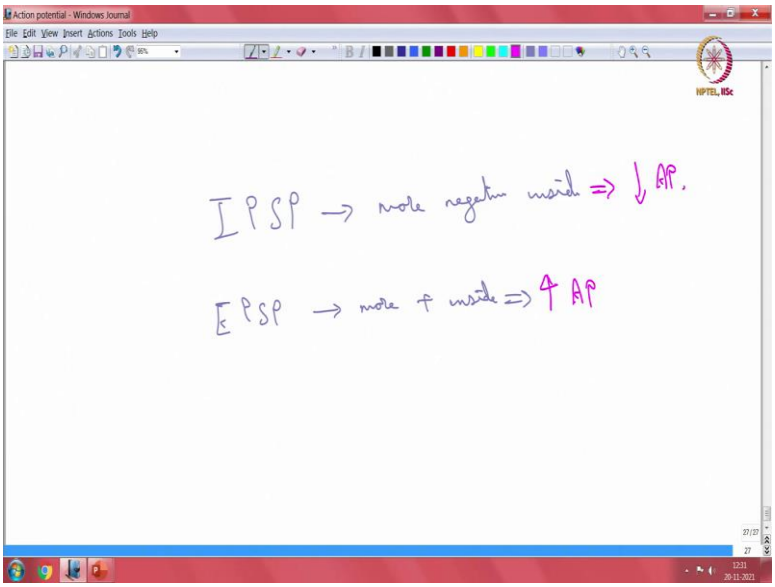

So, IPSP causes more negative inside, EPSP more positive inside, implies increased chances of an action potential, implies decreased chances of an action potential.

So, we are now stepping from mundane communication from one part of the neuron or something to computation. So, we started with a gate, a very dumb gate so as to say where you know it is just on or off and then it helps you generate something, here we are actually looking at thresholding.

So, we are saying that there is computation happening across this junction over here. So, this across this junction green, green, green, green, green, green, green yeah.

So, there is computation happening over here because it changes the threshold for generating reaction potential. So, that is a very important step. So, we started with messages, now we are sitting at computation and this is very powerful computation we are looking at very very analog computation.

So, you have gradients of current generated from channel opening these gradients would determine whether thresholds for action potentials are reached or not. So, that is a very

important step I think it would become clear subsequently when I discuss the parts of a neuron, the functions of a neuron and how computation happens is much later.

So, next is parts of a neuron. So, there we discussed so far three separate entities we have discussed an action potential, we discussed postsynaptic potentials that is inhibitory postsynaptic potentials and excitatory postsynaptic potentials. Action potential is basically something called as an all or none phenomenon, basically that you know once triggered it goes through the entire sequence of events. IPSP's and EPSP's are basically gradients of currents ionic currents, and they modulate the generation of the action potential downstream.

So, these are from different kinds of stimulus. So, it can be a positive which is facilitatory, which is the excitatory postsynaptic potential on the contrary it can also be inhibitory, that is it prevents an action potential, which is basically an inhibitory postsynaptic potential.

So, IPSP's, EPSP's and action potentials form the language of computation of the nervous system and how this computation is executed. One part I have actually shown you or two parts where the action potential is uniformly sent across from one side to another side of the nervous system. EPSP's and IPSP's help in computation.

So, you are looking at gradients of current which are used across junctions in the pathway and these junctions form sort of nodes where summation happens between ionic currents of different gradients.

So, you have gradient, you have a charge for the current and this sum it to ensure that downstream something happens for the action potential generation. So, a little more detailed discussion we will have and then we will continue subsequently in the next class.

Thank you.