Animal Physiology
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Module - 1
Lecture - 10

Welcome back to the lecture series in animal physiology in the NPTEL lectures so, we are through with 4 different topics. We started with introduction to physiology when we were talked about all the different systems, which get integrated to make dynamic system from there. We moved on to the first unit, which was membrane physiology we talked about the structure of the membrane. And the dynamics of the membrane and several other features from there we moved on to the heart the major pump of the body which distribute the blood all over the body.

And after that we talked about the cardiovascular network which regulates the supply of oxygen to all the different cells. And removing carbon dioxide and other toxic materials from there and in that context we talked about several situation. And what we have studied in membrane physiology and all these things, because the, for the fundamental basics of diffusion. And filtration absorption osmosis hydrostatic pressure and all those things so, now we will switch on to the fifth section of this course that is nervous system.

And will have 3 to 4 lectures in the section or may be 5 in case we kind of lack behind so, what we will be covering here. So, first thing what we are going to cover in the nervous system is the most fundamental unit. The smallest structure of the nervous system which the smallest cellular structure like may be right which is the neuron the different classifications of neuron different types of neurons. And the supporting cell which constitute the nervous system. And then we will be talking about the smallest functional unit of this which is in the form of electrical activity in the form of action potentials will talk about that action potentials. We will talk about the different chemical currencies, which helps in information transfer in the form of neurotransmitters. And then we will be talking about the different I should say different module or different circuits like convergent circuit divergent circuit or tap-tip circuits and all those things so, let us start with our section 5.

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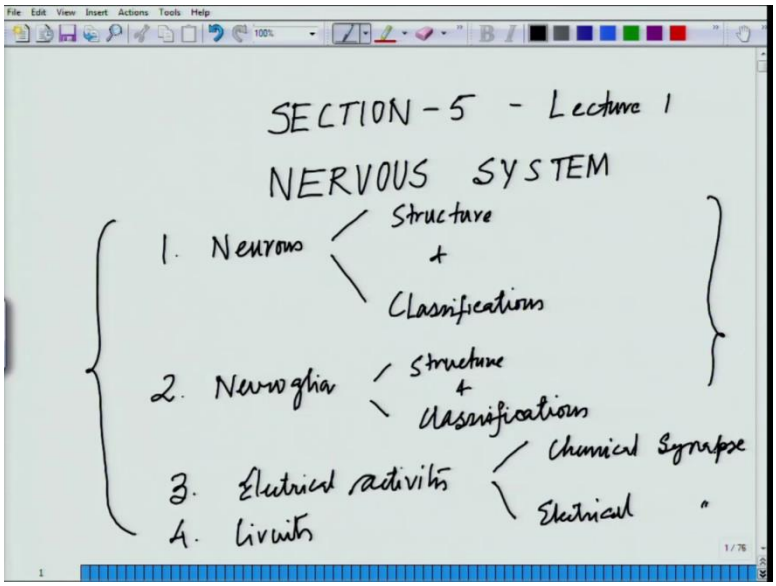

So, this is where we are now we are in section 5 which is the nervous system so, this is the first lecture of section 5 lecture 1 nervous system. So, in this class our major goal will be start off with a neurons that is what trying to tell you neurons. And the structure and classification of neuron and classification of neurons this is part 1. And part 2 will be will be talking about a supporting cells which are called neuroglia neuroglial cells and there structure and classification again same line structure. And classification classification and then on we will be talking about the electrical activities a very basic electrical activities will be dealing under that will be talking. The chemical synapse electrical synapse and of course, in the beginning we have to define. What is synapse of course, electrical synapse and we will talk about the different circuits. So, this will kind of give you an overall idea about how the nervous system functions at the cellular level.

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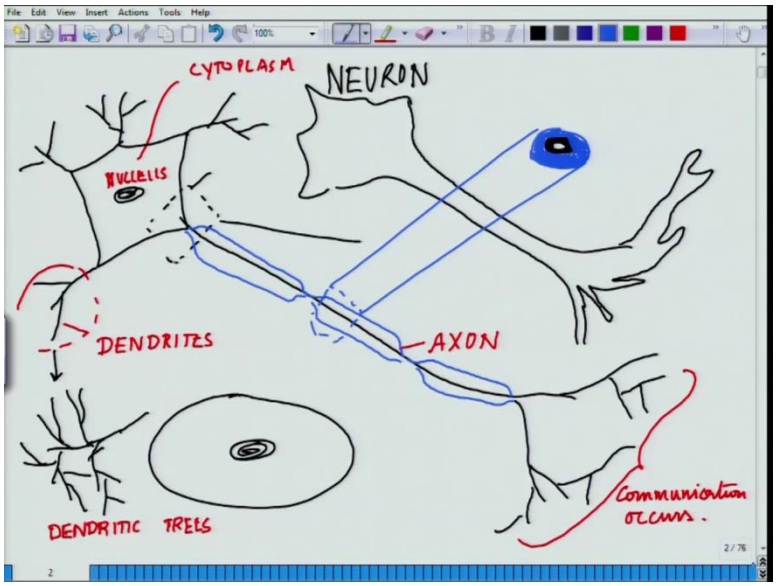

So from here let us move on to the neuron and the classifications of neuron at some point or other in your high school or somewhere you must have been exposed to the structure of the neuron. So, the basic structure of the neuron is something like this this is how the basic structure of a neuron looks like. And on these sides you see small processes and soon we will put all the nomenclatures of all these things. And if I have 2 kind of blow this up little bit it will look like this it is a kind of a tube which is moving down like this. It is a blowup, which it is a kind of three dimensional structure lot of averagization and everything. So, what are the nomenclature of this this is a very, very distinct polarized structure it is unlike whenever we draw a cell we draw something like this like this is the nucleus. And this is the cell body and everything. And this is the membrane, so in this situation it is a very, very polarized structure in the sense that one specific.

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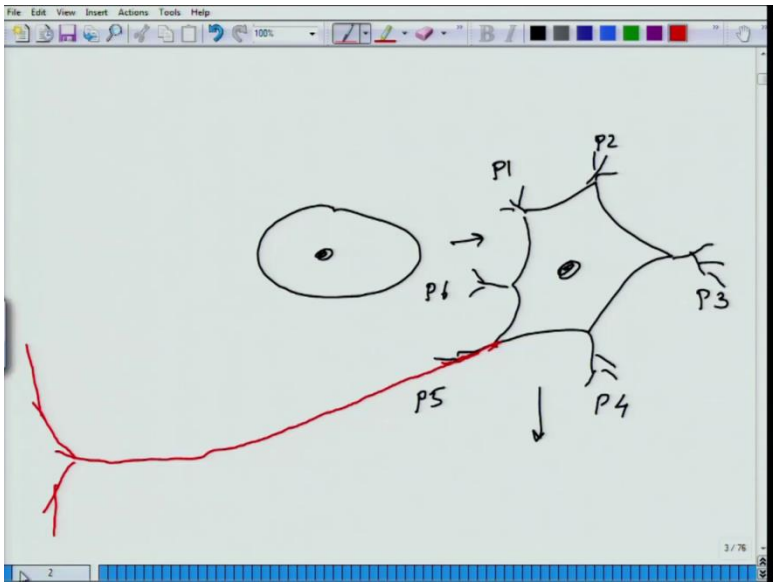

So, if you have to see how the neuron develops it develops like this so, initially it is a cell like this. And then it start protruding out sorry it put protrudes out in multiple directions and from those multiple directions the processes starts coming out as of. Now, this is very symmetrical there is no problem, but then a very interesting phenomena takes place. So, for example, this is process 1; this is process 2; this is process 3; this is process 4; this is process 5; this is process 6. So, then out of these processes P 1 to P 6 it could be any number it does not matter just for the simplicity sake I am just giving some number. There is 1 of the most fundamental mesmerizing thing happens out of these 6 1 decides to elongate. And what we see next is this say for example; in this case say for example, the 61 decide sorry 51 decides say for example.

So, then this process becomes like this. So, this is how it looks like so, now, the question arises what mix it decide that the fifth or the 60 or the first or the second or the third or the fourth will become a longer process. This is a fundamental problem of neurobiology and there are labs across the world who are trying to answer this question using several genetic tools several molecular tools several surface related surface chemistry tools. They are all trying to answer these things that how possibly 1 of the process is can become a longer process as compared to other processes which are smaller processes. So, here will not go in depth on that aspect of it, because that is not under the, purvey of this course what we will do we will give them the different names.

So, this longer process if I go back to my previous slide this longer process is called axon a x o n a longer 1 these smaller processes are called dendrites. And these dendrites form a huge mesh out here or network it is something like if you go in the microscopic details you will see it is almost like this. It is kind of a branches of the tree if I have to draw it so, this is called dendritic tree dendritic trees from you will see the word dendriomer dendriomers and all these things they all originate from there. So, here you have the nucleus here you have the cytoplasm with all the different cell organelles. And this is the zone where communication occurs and will come to that communication occurs. And this long processes what you see it has 2 possibilities either it will be covered with a specific kind of cell called which forms a insulated layer.

It is something like just imagine in your house you have these electrical connections these electrical connections. And the wirings the wires are covered inside a insulator inside plastic casing imagine exactly something like that. So, there is here is the wire this is the cross sectional view of the wire and on top of that you see a plastic casing like this if I had to give you. The cross sectional view of this it will look something like this so, this is your wire which is you axon here is the covering on all the side. So, this covering which is formed here is formed of there are some supporting cells in the nervous system which constitute. That well just since I am repeatedly using this word nervous system I will just take a slight 1 step backward before I kind of you know I think I made small error here.

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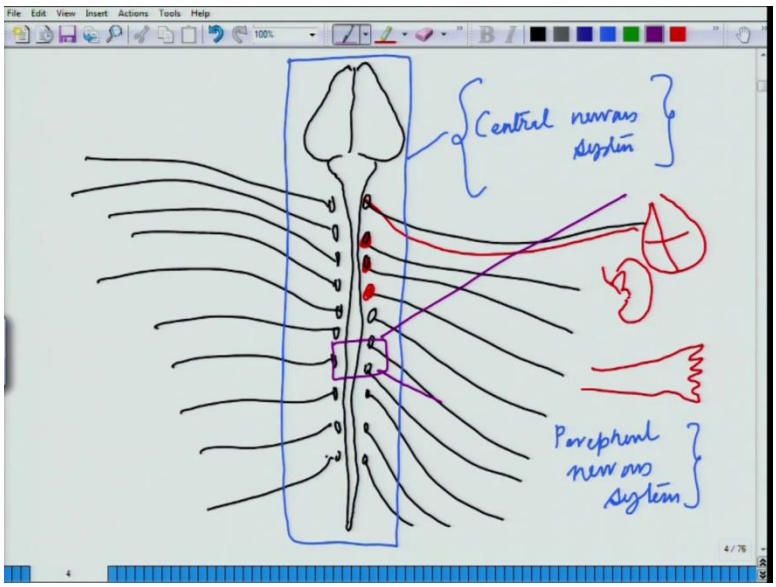

Introduce you in the first days if I have to draw the nervous system it will look like this and will come back its just I am taking a slight 1 step backward. So, from the top it is look like this, this is the brain and this is the spinal cord you see and these are within the spinal cord what you see is. So, these are the different branches of neurons which are different path ways of neurons which are coming out from it could it will it could reach your eyes ears heart legs hands. And everywhere something like this and there are several circuits which are involved in it. So, these are called ganglions there are aggregation of several neurons at this place and this whole complex structure is called a nervous system. It is the controlling unit, which helps us to receive information decipher information and take a decision accordingly how you are going to act.

It is almost the computer of our system which makes all kind of decision making and this part of the circuit which I am putting in blue. Now, the spinal cord and the brain is called central nervous system central nervous system. Whereas anything which is outside this. The nerves, which are taking care of your heart or something, which is taking care of your kidney or like you know so on. And so forth your hands and legs and everything all those neurons, which are caring information from outside this falls under peripheral nervous system. So, there is central nervous system and there is peripheral nervous system. And there are 2 path ways out along this spinal cord which I wish to highlight in the beginning which I missed up on. So, let me go to the next slide.

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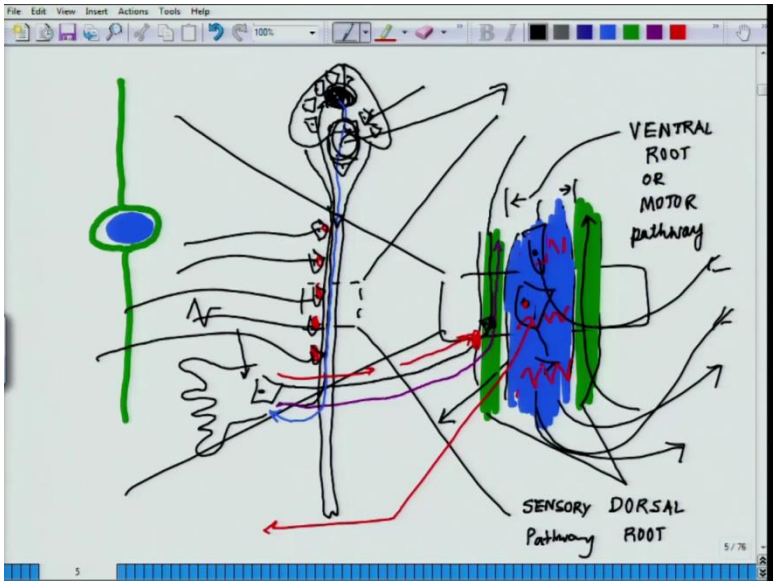

So, this is what I am going to highlight now so, if this is the brain and this is the brain stem and this is the spinal cord something like this. So, and now what I am trying to do is that I am magnifying this part of the spinal cord or any part of this spinal cord. There are 2 circuits which are functioning here which is something like this on the flanks you have something called dorsal cell root. And in the center let me put different colors that will make things easier for you people to understand. The one which I am shading with blue in the center something like this and I am shading the both the flanks with green.

So, this green over here what you see is called the dorsal root let me put the terms now, this one and this one is called the dorsal root. And the center 1 this part from here to here is called the ventral root so, what is dorsal root and what is ventral root next question? So, dorsal root is the one which say for example, I hit you hit somebody hits me like my hands. So, series of signal from here is traveling all the way along these the nerves which are present here likewise if they are travelling all the way to the spinal cord. And out there say for example, this is let me draw it is say for example, here is my hand.

So, there are some neurons sitting here so, these neurons get the signal that somebody has hit so, it generates an electrical signal that electrical signal is travelling all the way likewise. So, the direction of travel is like this is travelling at it enters the spinal cord through the ganglion you remember I was drawing all the ganglions out here. It enters that through the ganglions then it follows this track now, follow my follow the magenda color the signal it is moving like this and this track continues likewise along the side. So, this is where the information is being carried so, there are 2 options this neuron meets transfer the signal to another set of neuron. And this will take it to the brain and telling me that telling the brain that someone has hit you out here.

So, now, what the brain will do and so, this information goes all the way so, you have to follow this. So, say for example, if follow this signals so, this is going all the way to brain likewise in the brain what happens the brain decodes the signal. So, someone has hit you so, be be careful someone has hit you so, you have a pain out here. So, the brain decodes the signal at some point some of its locations and from the brain this signal is being send down by another with a different path way. This is this path way which tells me to remove my hand from the site where I am getting hit that path way which brings. The information back from brain likewise is called the ventral path way or it is also called the, or motor path way.

And the other one the one which carries the signal all the way up to the brain is called sensory path way as the name indicates. Because sensory path way and motor pathway as the name indicates sensory pathway sends the signal to the brain. And if I had to draw a cross section just imagine look at this if you see the, if you see the tip of the cross section. So, this tip is your ventral pathway which is bringing the information. And this periphery what you see is the dorsal pathway. So, you see this tip there is you could you could see that there is a bulge which is coming out from this pen. So, that is the dorsal pathway so, imagine if something like this if this is the dorsal pathway then this is the ventral pathway which is going in the center. That is how I drawn it so, if you have to see the cross section of the cross section of this whole thing will look like this cross section will be let me choose let me take a cross section be like this.

And what you will see is so, this is the cross sectional view so; these are the dorsal pathway which are going up. And this is the ventral pathway which is bringing the information back so, this part is ex extremely important that is why I actually just missed upon this. So, that is why I decided to come back to it and then I will go back to the neural neuron so, all the neurons where they are sitting exactly. So, all the neurons all the different neurons are at different place there are 1000s and 1000s of them all over the place. They are sitting along the spinal cord they are sitting in the ganglion likewise they are sitting all over the place. So, and these neurons have long long process which are there and what you see is the ventral pathway out here.

The one which is bringing the information this ventral pathway is also called the motor pathway. Because that is govern by the motor neurons the neurons which are present on this pathway are called the motor neurons which brings back signal to for us to add. So, just to give you practical understanding of this most of the time will see during car crash or accident or car injuries or you know any kind of this, spinal cord injuries a person become paralyzed. They are unable to move their hands or you know some part of the body or some side of the body basically. What happens in that situation is this, the neurons which are present on the ventral pathway they kind of damaged damage takes place here out here. And that is one of the challenging problem for in countries like Germany countries like u s where there is very high speed driving you know specially in the freeways in Germany or in the highways of united states.

The speed is fairly high 80 miles 100 miles 100 20 miles per hour so, this is the kind of speed with which the car moves. So, if there is a crush and if 1 survives most likely would the major impact which comes it comes on the spinal cord. And when it comes on the spinal cord what happens there are injuries which takes place along these. And whenever there is injury on the ventral pathway essentially; that means, the signal which is coming from the brain for the specific tissue. These kind of the connectivity kind of gets compromised so, the signals though the person can sense it. So, you pinch them or something they may be would sense it, but they may not be able to respond it. And very interesting later these motor neurons are the first 1 to form in while we are getting developed in our in mother spoon.

These are the first set of neurons which are formed they form very, very early and they are really susptible to these kind of injuries or damages. And there are few other diseases which motor neuron diseases like those of you know have heard about Stephen hawking one of the biggest scientist of our time he suffers from a disease called amyotrophic lateral sclerosis. That is a disease where most of the motor neuron which are you know present out here starts to die. So, that is why you see his in a kind of very specializes structure where all his eyebrows motor neuron which are controlling the eyebrows can move most of the other motor neurons are unable to act.

So, it is also called I just forgetting the name, but basically it is called an a ones and these ha lugerring diseases it is also called lugerring disease. So, there are whole series of diseases related to the nervous system and will come to that there are disease which you must have heard called ozymers which takes place in the brain. And specific area of the brain called hippocampus which is involved in memory acquisition. There are diseases like Parkinson disease where specific area of the brain which is regulating somewhere here, which is regulating in the movement they starts to die. So, we discussed all these things, but you have to keep in mind the basic over all structural architecture of the nervous system. Because that will be the key to understand how these disease actually affects us and mind it all these, disease eventually starts with a single neuron. So, now, coming back where I left you guys I told you that I just have to take detour before I come back to the neurons.

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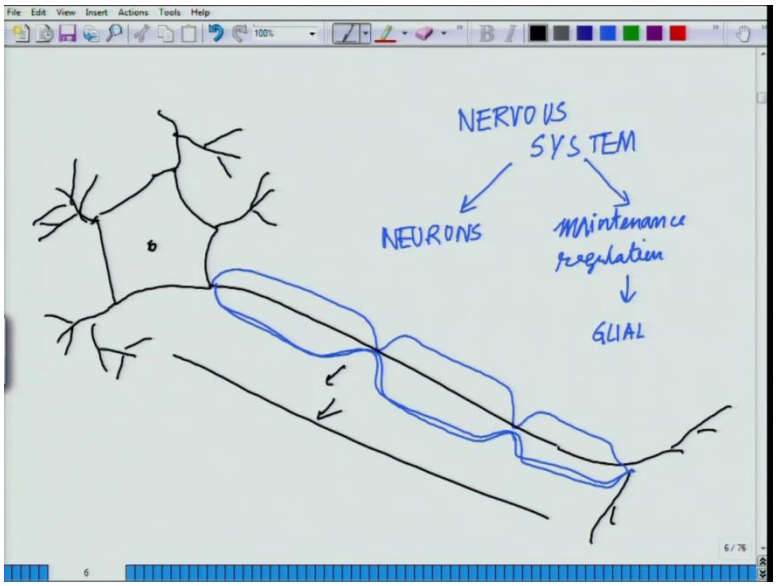

So, now I will come back to the neurons because now I am much more comfortable to talk about the neurons. Now, I showed you is a position where what are the different circuits so, coming back to the basic structure I have already drawn the basic structure of the neuron. So, it is highly polarized structure and we discussed that this polarity is so, really interesting and challenging problem in the field of nervous system likewise. So there are several variations to this structure well talking about the variation one of the variation is that they may have these kind of. And will come how these structures are formed while will be talking about the supporting cells of the nervous system one more thing which I just missed up on while talking about this nervous system not only consist of.

So, nervous system, consist of 2 different kind of cells broadly speaking the one different cell types of nervous system. The one which is involved in all kind of communication or similar transfer are called neurons which we are discussing. Now, the other one which is involved in the maintenance and a one of the major work is the maintenance. And regulation those are called glial cells they have a, they have enormous functions in the nervous system as more. And more research are being done in glial cells we realizing that they are exceptionally dynamic. And they play some very critical role in ensuring the signal transmission; transmission takes place properly.

And some people even believe that they have they are also some kind of signal generator which may have some role to play in some form of information transfer apart from it they help in ensuring. The homeostasis they have certain components which help in strengthening the immune system. And some of the diseases of these glial cells include multiple sclerosis m s which means the glial cells, starts dying. And the consequences very fatal will come to those different diseases and then apart from it. There are other glial disorders which, leads to some form of higher per excitability and all those things so, coming back. So, the nervous neuron could have these insulation 1 option or there may be non-insulated. There may not be any insulation there may be just you know just like this like it this one way 1 classification.

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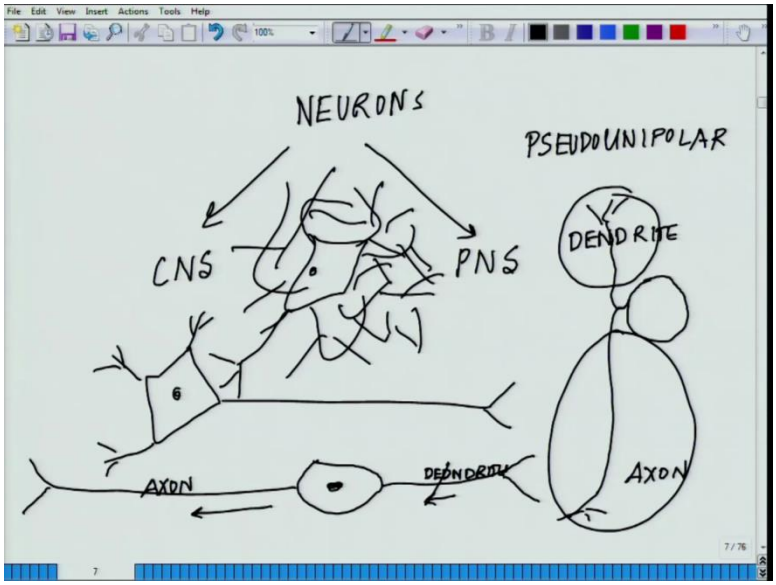

Neurons could be present in the c n s or in the P n s they could be c n s neuron and they could be a PNS neuron based on that their variations of size. And everything changes basic structure of neuron what I drew could have whole range of va variations one of the variation is something like this. The single it comes out like this which is called pseudo unipolar neuron there actually 2 processes one is a dendrite, the other one is an axon. So, the longer one is the axon the smaller one is the dendrite they could be bipolar, because this is called pseudo unipolar pseudo unipolar. They could be bipolar bipolar means here is a cell body and here you have 1 process on direction. The process another direction one is considered as dendrite the other one is considered as axon and its bipole instead of having multiple processes coming out.

And these different kind of neurons are located in different parts these is the dendrite one second dendrites. So, depending on the location they may have a very huge dendritic arbor almost like this you know some of the purkinji cell like that. The dendritic arbor is very huge as compared to so, they have a different role to play in the information storage and information gathering. So, this is the overall classification if I have to see a very kind of simple straight forward classification. And based on their structure and their functionality functionality depends on whether. They are acting in the peripheral neuron whether they are acting for a sensory function or for the motor function.

So, based on the functions we can classify the neurons as functional classification so, in the functional classification. We have 2 forms of classification they could be sensory they could be motor within the sensory. There could be various specialized 1s you know which are involved in the special senses something like the rods cones which are sensing light and colors they could be hear cells. They could be the cells all factory all factory neurons where is a motor neurons could be the one which is the higher motor neuron lower motor neuron and so on and so forth there are whole range of such classification.

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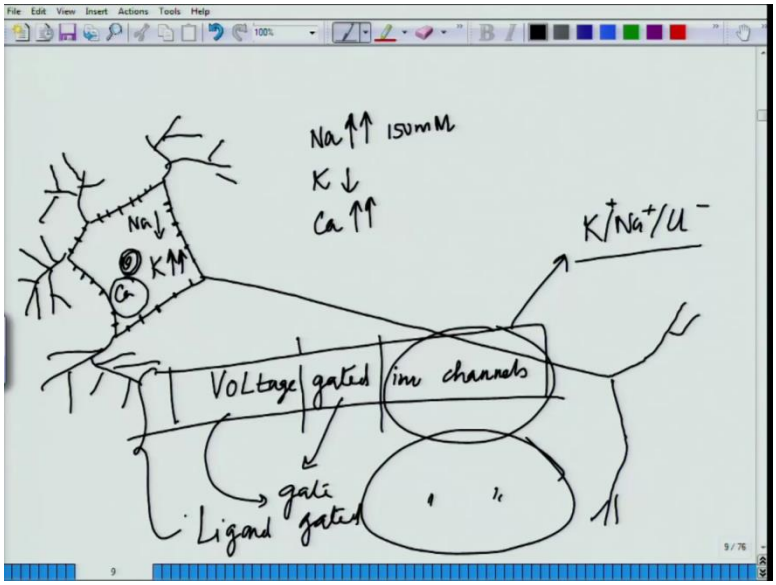

So, from here we will move on to the functional unit of a neuron what it exactly does so, this is the basic structure. So, if you remember in the membrane physiology class we talked about that these are called excitable cells. So, now, today we are going to highlight that part why these are called excitable cells.

So, these polarized structure just like any other cell has a very low sodium as compared to the sodium outside which is almost 100 50 unimolar. They have a, very high potassium. you could see potassium they have calcium slightly higher because here calcium is been stored inside the circoplasmic critical out. So, what happens with the cells they have a series of likewise what I am putting as dots. Now, they have series of something called voltage gated ion channels voltage gated ion channels what does that mean if you break. The word in a specific point voltage gated ion channels ion channels you know channels which promote the movement of ion like potassium sodium chloride likewise gated means.

There is a gate and voltage gated means it is the voltage which helps into open or close say in other word what we are talking about is that within the cell. There are whole bunch of ion channels whose opening and closing will depend on the voltage across the membrane. This is the very very core understanding of it and there may be other kind of channels which are called ligand gated ion channels. So, ligand gated ion channels are the once where a ligand or something binds to an ion channel and then they it opens. So, these 2 pieces of information is exceptionally important that how these, action potentially generated, because these are the key players in ensuring the generation of action potentials.

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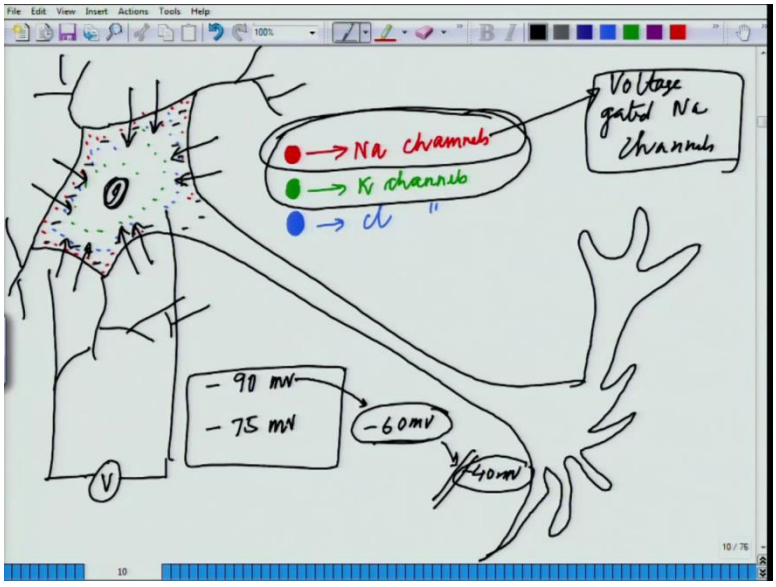

Now, coming back to the structure of the neuron and now we will try to understand how this structure is involved in so, this is the arborization. And this is where the dendritic trees are now so, let me represent these voltage gated ion channels like this. And will have different color codes for them so, likewise they are all over scattered all over. So, the red ones are I should have done it with lightly bigger marker red ones are red and the green ones. And the blue ones ok let me go back red ones are the sodium channels which are voltage gated. Then green ones are potassium channels and you have the blue ones, which may be chloride or you know calcium.

So, let us keep it chloride sorry do not mix it up chloride channels likewise may be there may be some other which are like calcium or something else. So, what at this point only we are dealing with these 2 so, if you put an electrode inside the cell. And another electrode outside the cell and try to measure the voltage across it giving point of time you will see a neuron stands at a membrane potential with respect to inside. The membrane potential is around approximately 90 milli volt or maybe you know minus 75 milli volt.

So, the inside the cell it is it is negative inside with respect to the outside fine now, in this situation what happens say for example; some way or other I could say for example I create a situation here look at this drawing. This drawing I create a situation that I change this voltage slightly towards positive say for example, I bring. It down to minus 60 milli volt or say minus 40 milli volt a very if I bring it down to minus 60 or minus 40 milli volt most likely at minus 40 milli volt what will happen is that. There are a series of ion channels which respond at minus 40 milli volt and those are these channels voltage gated sodium channel. And these sodium channels only opens to allow the sodium to enter from outside to inside is it making sense. So, the sodium can only enter like this inside the cell. So, some way or other membrane becomes minus 40 milli volt. So, what will happen if it is become minus 40 milli volt immediately there will be a huge amount of sodium which is going to change?

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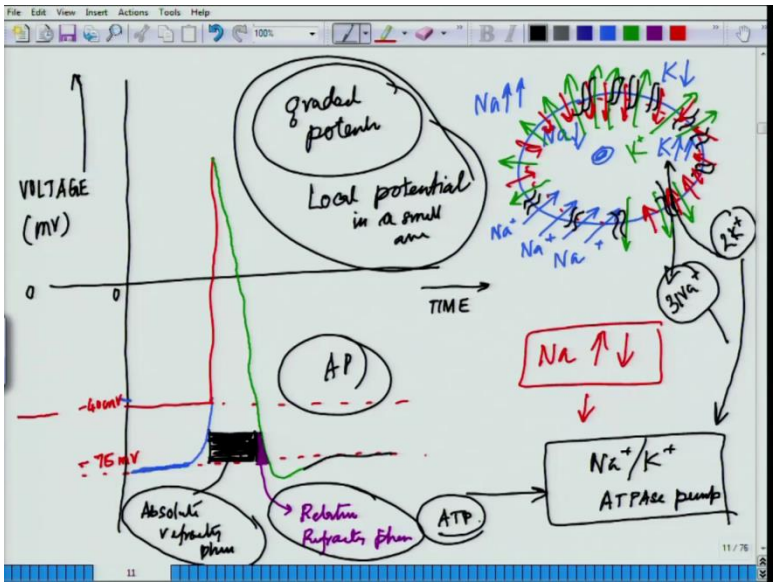

So, let us start to put them in terms of a graph that will much more easier for us to understand so, this is 0 milli volt this is sorry this is time. And this is voltage in milli volt this is 0 milli volt and we have miming time and this is where the cell is sitting which is say minus 75 milli volt this is where the membrane. So, cell is sitting as minus 75 milli volt now somewhere other you give some stimulus let us go back to the previous diagram. So, I told you there is one way is that you change the voltage by manually you change. The voltage across it or you create a situation something some kind of signal comes here somewhere or other. And what it will happen in is that one such signal comes and it binds to the surface some kind of a signal may be a photon.

It could be something these opens up some of the pores, which allows sodium to say say for example, let us this is the cell out here. And which has low sodium and high potassium outside very high potassium potassium is low. And potassium is very high here so, if sodium is starts gushing in likewise the sodium is getting in stage 1. So, what will happen is that a membrane will shift to something like minus 40 milli volt. The shift will be like this membrane potential changes to minus 40. But, it reaches minus 40. There is something called all or none phenomena takes place what it does is that the sodium channels which are open. So, if I represent it in the sodium channel by red that promotes all other sodium channels to open so, much. So, it is kind of you know fibers 6 of them bring it to minus 40 and then in unicell of opening.

It is all of a sudden it looks like as if the membrane became kind of collapsed membrane failed to really handle the sodium. So, all the sodium gets into the cell sodium entering is taking place so, what you see is that you see a sharp rise from here on like this it over shoots this 0 and if it over shoots this 0. So, this is the rate limiting zone it has reach to around minus 40 and if you recollect while I was talking about the pacemaker cells in the cardiac I was telling. The always continuously remain at minus 40 from minus 40 they keep on shoot shooting an action potential. They could shoot an action potential begin at minus 40 because that is the zone where the sodium channels open faster though they do not need a fast activity sodium channels, because this is what is happening is that.

There are the sodium channels, which are very, very fast activity these are called fast activity sodium channels they open very fast. And closes very fast this goes up when it starts going up, so these sodium channels open open also very fast and closes also very fast it is a very, very fast kinetics. The next step from here is once they reach a certain voltage all, this stop to open now then the next thing happens once. The membrane potential become positive then that potential promotes a series of another set of channels to open which opens which allows certain specific ions to move from inside. The cell to outside the cell, that is like this the one which I am drawing in green now, these are potassium ones the potassium gushes out of the cell. So, once the potassium start going out of the cell so, the membrane starts to come back to its original situation like this.

Because you are trying to balance now, but this is a stage when the cell is reaching sodium and cell is lacking in potassium. So, there has to be a way by which you can regain the balance and then comes the third key player here. The pumps come into play sodium potassium ATP A'se pump and we have talked about these pumps in our membrane physiology section. They throw away 3 sodium ions from inside the cell and they takes in 2 potassium inside the cell. And these are called sodium potassium ATP A'se pump, because inside the cell you need ATP in order for these pumps to add which, brings. The cell back to its normal membrane potential which is minus 75 or minus 90 depending on the cell type and here let me highlight. This is the zone when pretty much, no sodium channel can really open this is called absolute refractory phase. The sodium channels are completely in activated and they cannot open and then I will just shade a, this is the zone where sodium channels are activated, but they are not open. So, this is the

phase of relative refractory phase and this is called absolute refractory phase relatively refractory phase.

And absolutely refractory phase so, this is how the most simple currency of electrical activity is being transmitted by the neurons. There are many other things which are which I am going to come before moving on you will come across another terminology call graded potential. And what is graded potential graded potential are local potentials at they they are very local always remember this. These are very, very local potential, which functions in a very small area local potential in a small area whereas, action potentials spread once it starts. It is spreads all the way through it is all or none so, in order for the action potential to become all or none you have to cover. That barrier of from say minus 75 milli volt to come to minus 40 milli volt or you know minus 35 milli volt this is the zone where all the sodium or the voltage gated sodium channels gets activated.

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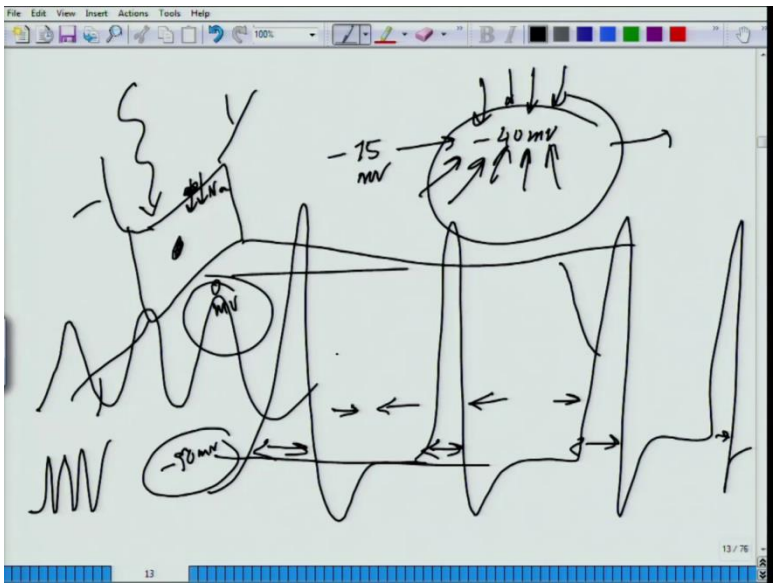

So, this is very important for you people to understand that whenever, stimulus comes something like this; this is a neuron a stimulus which comes it opens up. The voltage gated sodium channels initial 1 or few of them they bind say for example, something comes. And bind they allow some of the sodium to get in this is not sufficient unless from minus 75 you could reach to minus 40. But if reaches minus 40 you cannot stop this process then this will almost ensure something like enzymatic thing or. There will be lot

more sodium voltage gated sodium channels in unison will get activated once they get activated. And it over shoots all the way and then comes back, because of the potassium currents so, this is the over shoot what you see here if this is 0 milli volt.

So, this is very, very interesting; this is very, very important for you people to understand that this is how a cell. So, you could have a, patterns you could have another 1 next coming and then likewise you know likewise this will continue. And there may be you know this may change the length may change the shape may differ. There are whole bunch of things, which could happen, because the threshold voltage remains the same once the threshold is there. So, these are the different kind of signals could be this smooth it could be more compress likewise. There are whole series of signals, which could be generated in that whole process.

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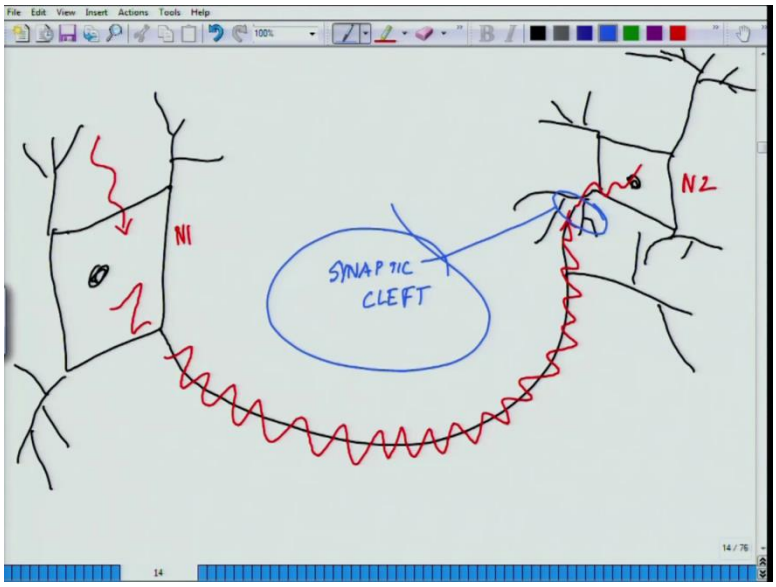

Then what is happening so, along this neuron the signal is moving so, this signal has to be transmitted to the next neuron. And how that takes place that is what we are going to discuss now and then neuromuscular junction or in the neuron to neuron junction. So, if for example, this is the second neuron and these are the dendritic arbors so, here is the signal which is coming. And that leads to a generation of action potential this action potential travels all the way along. This longer process likewise it is travelling. Now, this signal has to be transmitted to the next neuron if this one is neuron 1; this one is neuron 2 how it does so, how it transmit the signal from here to here. So, this particular gap is

called a synaptic cleft will come in depth into the, this and will talk about all the dimensions and everything of the synaptic cleft, but before I moved into the synaptic cleft and all other things.

I will just summarize what I have finished now, so we talked about the neuron structures and classifications. We have not dealt with glial part we will be dealing with that we have talked about the basic architecture out here. And the cross section and then we talked about how the polarity things matters and then we talked about the basic structure of the nervous system. And then we talked about the different structures of the neurons and the, their functional classification. And the voltage gated ion channels and how it helps in generation of action potentials so, we will close in here in this class. And the next class will start with the synaptic cleft and the classification of glial and all other details.

Thank you.