Nanobiophotonics: Touching Our Daily Life
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Lecture No. 43
The Nervous System

Hello, and welcome. We are going to continue our discussion on Optogenetic Technology. But today, I decided that let us actually go out of our comfort zone from the areas of mathematics or engineering and go deep into biology. Electrical or electronics engineer do not switch off now. What I want to say is that neuro-photonics or optogenetics is the cutting edge or is the state-of-the-art work that is being done these days on bio-photonics, nano-bio-photonics where light is being made to interact with the nervous system or brain. But we have to understand the brain first, right.

Neurobiology or neuroscience is booming and we need to understand what exactly is that that we want to interact light with, right. Since neuro-photonics or optogenetics deal mostly with the nervous system, with the brain, with the nerve tissues, with the neural circuitry, let us try to understand how the brain works at a very rudimentary way, right. Today, I am going to discuss the brain completely from a biology point of view. But since my training is in electronics engineering, I will try to explain brain from a circuital point of view, from an engineering point of view.

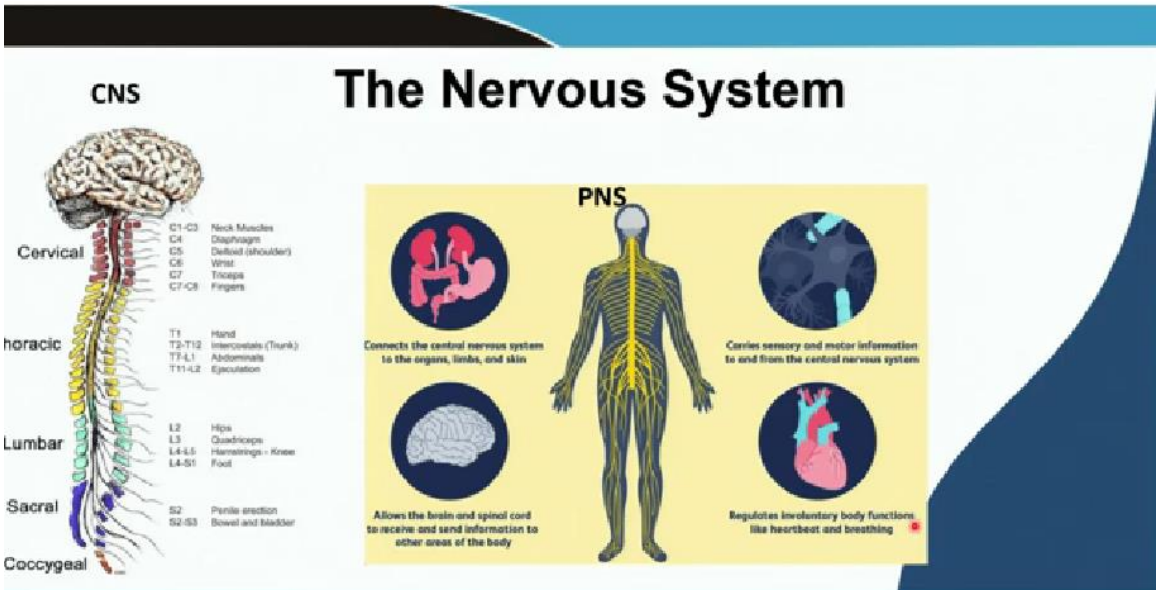
Be absolutely aware that as I said in my previous lecture, the human brain is the most complex and the complicated matter that we have ever encountered and under no circumstances I could describe brain in 30 minutes or even a 60 minutes lecture, right. Neurosurgery, neurology, neuroscience are fields in which people do, people spend their entire life on. So, couple of things that I want to mention beforehand, I am not a neuroscientist, I am simply an engineer trying to work through. These lectures, lecture number 43 and lecture number 44 is going to push you out of your comfort zone. It has pushed me out of my comfort zone.

But if you are persisting and you will find that this is very very rewarding, you will be able to know how fascinating our brain or our nervous system actually is, right. At the same time, it may so happen since I have not been dealing with nervous system or neuroscience for a long long period, it may so happen that one or two errors may slip in when I am giving a spontaneous lecture. So, no matter what I ask you to verify whatever present in this slide, I have tried to make them error free to the best of my capacity. But again, since this is not my specialty, I am not a biologist, one or two errors may sneak in. Because of my training in electronics engineering, if I see a circuit, it is immediately to me

because of my training to figure out whether it is wrong, right or wrong.

However, in this case, since I lack the required experience, what might be very obvious to somebody might not be obvious to me. So please, please verify whatever I am saying. Nonetheless, I think that most of the information that I will be providing you should suffice enough for you to understand brain from a simple and rudimentary point of view. So that you understand what exactly the light is exciting, which part of light is actually exciting which part of the brain. For the medical students, please, please write in your comments where I have gone wrong or what part of the nervous system I should have emphasized more and which are the areas where I have erred.

Anyway, let us start the nervous system. This is going to be a bumpy ride. So, get plenty of coffee or tea, any stimulant that you use as long as they are legal and let us go through the process. Let us try to understand the nervous system. So, the nervous system is as I said basically divided into two parts, the central nervous system and the peripheral nervous system.



The central nervous system contains the obvious the brain along with it there is this spinal cord, these are the combination of nerve tissue and both the brain and the spinal cord is covered is protected using a skeletal pack. Your brain is covered in this cranium in the skull and there is this spinal cord, the cerebrospinal cord these days they are calling it, but this skeletal feature they are present that protects the spinal cord from direct external injury. Your skull cranium and then you have your spinal cord, the skeletal part of the spinal cord that is covering that is acting as an armor that is protecting it against external injury or it acts as some sort of a scaffold, it provides the necessary mechanical stress. So, your brain and spinal cord contains the central nervous system which is covered, encapsulated, protected scaffold by skeletons, by bones. The peripheral nervous system

is those areas, those parts which are outside the central nervous system and which do not get any protection or any mechanical support.

The peripheral nervous system are the other nervous systems such as the nerve cells that are connected all over our body, skins, organs like heart, eyes, sensory parts, it connects the central nervous system, the peripheral nervous system connects the central nervous system with other organs. It allows the brain and spinal cord to receive and send information to the other areas of the body. So, if this is the CPU, central processing unit of a computer, so these can be considered as all the areas that is connected with the central processing unit, the mouse, the keyboard, the display system, other parts. The peripheral nervous system carries sensory and motor information to and from the central nervous system and it also regulates involuntary body functions like heartbeat and breathing. Meaning the nervous system is entirety all over our body.

We divide it into two parts, the central and the peripheral. The central is our brain and spinal cord. The peripheral is where nerves have extended from brain and spinal cord to all over other parts of our body like skin, like eye, like ear, the sensory information, all of those things are connected with nerve. All of these nerves, nerve tissues, nerve cells are connected and they carry information from the sensory organs, from eye, ear, skin, etcetera, heart, etcetera to the central nervous system. Central nervous system processes that and central nervous system also sends information through this circuital connection, through these nervous connections to our skin, our bodies, eyes, ears, etcetera.

We will be dealing more on the circuital aspect of nervous system in the next class. But today I am going to describe mostly what comprises the CNS, the central nervous system. Now understand a human body, a human being roughly, very roughly consists of about 20,000 genes, 20,000 genes and their expressions and their protein expressions produces the human body. Of these 20,000 genes, 6,000 genes, roughly 6,000, these are rough estimate 20,000, obviously it is not going to be 20,000, nothing will be in that round number, but roughly 20,000 genes, of that 20,000, 6,000 genes are specifically for the nervous system. Certain genes, you know genes, short codes of DNA that produces, that has the capacity to produce proteins, 6,000 of these 20,000 genes are specific to the nervous system only.

6,000 genes, another 6,000 genes are specific for other parts of the body. So, 12,000, 6 plus 6, 6,000 is only for the nervous system, 6,000 is for the non-nervous system of the body and the 8,000 remaining is common between nervous system and rest of the body. So, 8,000, 20,000 genes, 8,000 is common all over the body, 6,000 specifics to nervous system, 6,000 specifics to non-nervous system. CNS and PNS are both nervous system, central nervous system, peripheral nervous system. If one gene, if just one gene is turned

off or is not working properly or recessive, it can cause severe amount of problem in the entire nervous system.

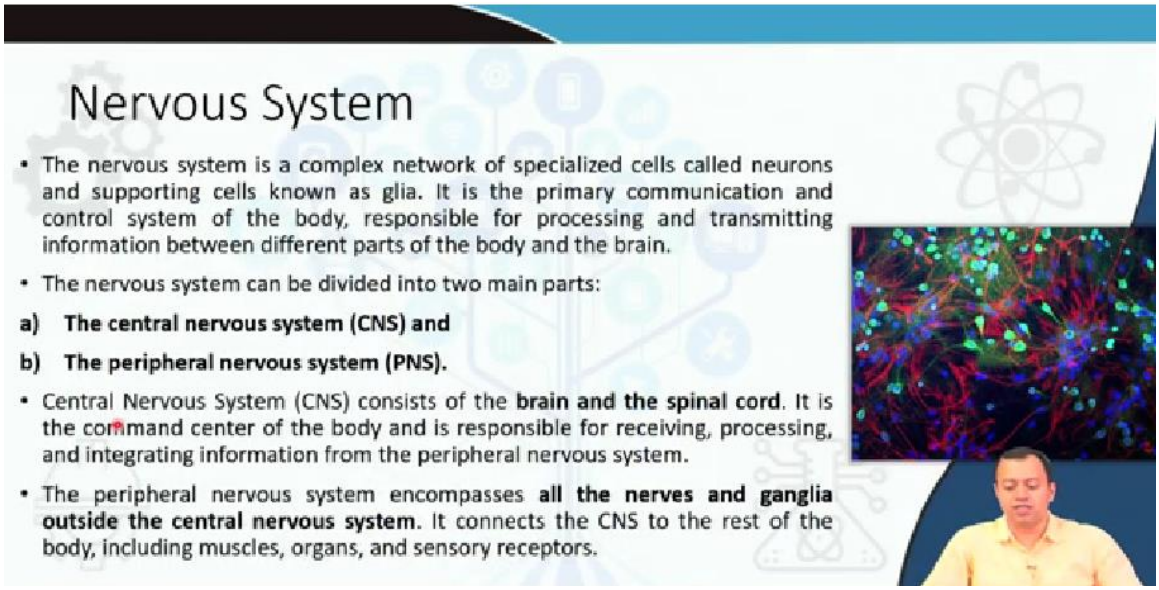
Of that 6,000 genes that is unique, even some of the common genes of the 8,000, if one gene has some sort of a problem, it is not turned on or it is mutated or any other case, it causes severe severe problem in the overall nervous system. Huge amount of problem starting from epilepsy to the probably you have seen with the Zika virus, the brain of babies coming out, the skull of the babies coming out, becoming short and deformed, malformed, the brain does not develop properly. All of those are because of one particular gene of that total 20,000 of that specific 6,000 is not working properly. So, we have to take it obviously quite seriously. Above all, your sense of self, you know cognition, the Latin term cognition means knowing, your sense of self is this.

You are basically this part, rest, your skin, your eyes, your ears, your memories, etcetera, all are byproducts, all are axioms, all are byproduct of this. This is what your being, what your self is and ironically you are trying to understand this today. If you want more detail on the skeletal part, I can recommend certain books to you, but what I found I did not know, so I found it nice. See the spinal cord is protected by this tethered or by this broken chain of skeletons and this part which is near your waist, which is near at the back of your waist is called the lumbar thing. And probably you have heard, I have recently heard, hence I am more interested, there is thing called lumbar or some slip disk which causes huge amount of problem when you sit.

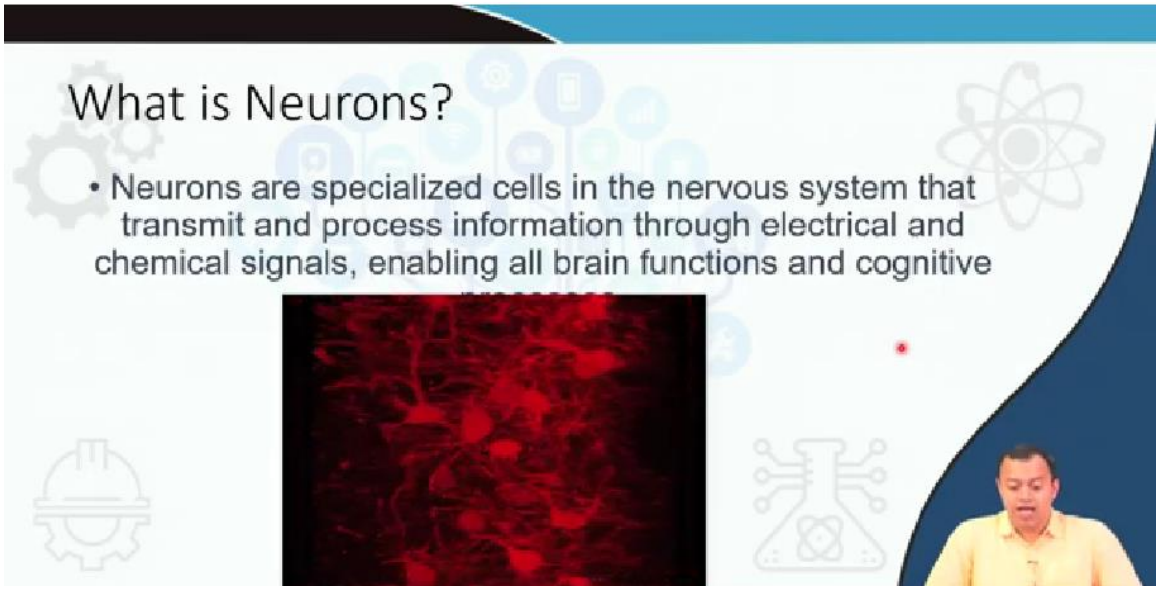
One of my colleagues is having huge amount of problem while he is sitting and supposedly there is a slip disk. So, something has happened between this L4 and L5 where the bone is actually deformed or it has broken or some sort of a problem has happened which is directly touching the nerve cells and causing huge amount of pain. It is supposed to protect it, the two, two, two, two this skeletal fragments in between which the nerve should be there, but one has gone up or one has gone down and they are now pinching the nerve resulting in huge amount of back pain, waist pain and the person has difficulty. Now, he has to do exercise, physiological exercise, yoga etcetera, so that the deformed skeletal part of those disks becomes straight again. Anyways, so let us go into the nervous system.

So the nervous system is a complex network of specialized cells called neurons and supporting cells called glia. Nervous system is basically made up of neurons and glia and it is primarily communicating the, it is the primary communication and control system of the body responsible for processing and transmitting information between different parts. So, as I said it consists of CNS and PNS. CNS consists of brain and spinal cord and peripheral nervous system comprises of all other nerves and ganglia. Ganglia are

specialized neuron cells present in PNS, peripheral nervous system.

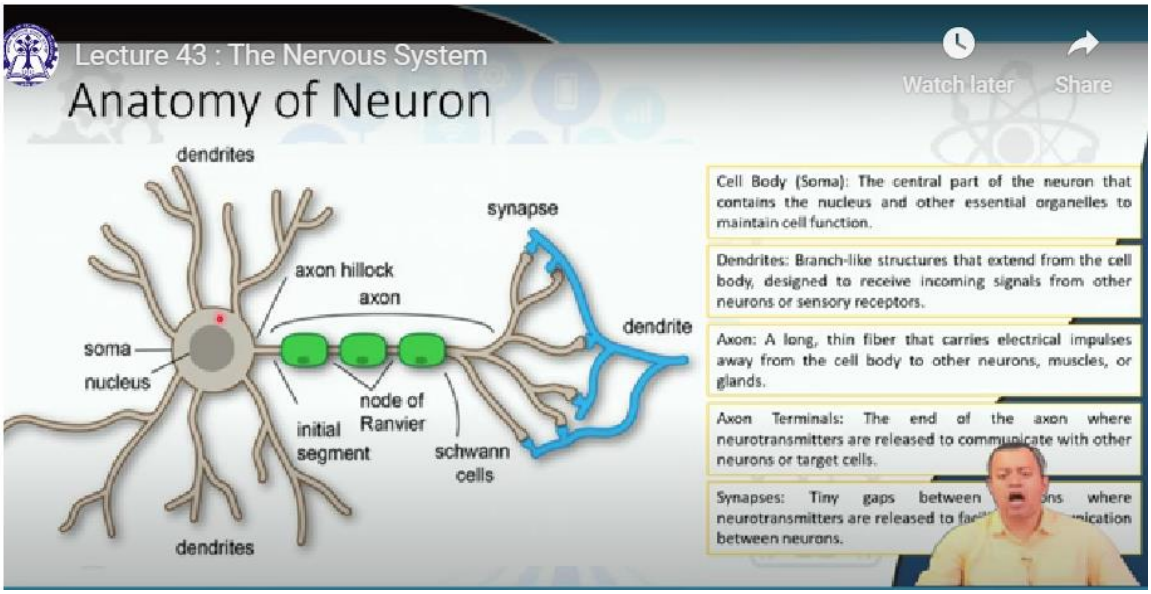


The special nerve cells present inside CNS are neurons. Neurons are also present in PNS, but PNS peripheral nervous system has some kind of a special neural cells that are not present in, usually not present in central nervous system brain and spinal cord and that is called ganglia. We also have something called glia which we will be discussing in just a second. So, this beautiful picture is that of the neurons. So, what exactly is neuron? This is fascinating you have to understand this.



Neurons are the hereditary, so not hereditary that is gene. Neurons are these unit cells of the nervous system. So nervous system, specifically central nervous system can be broken down into its cellular part and that cell is neurons. Neurons are specialized nerve cells which specializes it, nerve cells and neurons. Neurons are nerve cells that specializes in sending electrical signals long distance.

Neurons are specialized nerve cells or neurons are nerve cells I keep on using the term specialized before. Neurons are nerve cells that specializes it, specializes in sending electrochemical or electrical signals at a long distance. Cells in the nervous system that transmit and processes information through electrical and chemical signals enabling all brain functions and cognitive functions. This is the neurons, the nerve cells and it has a fascinating, fascinating structure. Most neurons, almost all neurons are characterized by a long, long, long, long branch usually called axons and some dendritic, some branch like structures connected with it called dendrites.



So if it is a cell there is a long, long tail kind of thing, long, long, long, long, long tail that calls axons that carries information from the nerve cell to a targeted area and this neuron also contains branches, also contains antennas connected with it which are comparatively short few microns and they are there like branched out. They are like this extreme branched out that are called dendrites and that are mostly there to receive the information. Nerve cell send information, transmits and receives receiver. The transmission is usually through a long tail, a long, long, long, long, long chain of this cells and tissues and sorry not tissues, a long chain of this itself is a cell, this itself is a cell. So, these are not cells, this entire thing is cell.

See this is what happens when you are not specialized in a particular topic. So, the entire thing is the neuron which is a nerve cell. It contains a filament or a tail, the cell contains a long, long tail with that tail the axon it transmits. It transmits electrical signals, but it also needs to receive signals.

It also needs to receive signal. The receiver is the dendrite part. This axon, this long tail can be few meters long. It has been found some meter long in some long mammals like whales and elephants. In human being, few microns or few millimeters long these axons

are also detected. Whereas the dendrites are much, much smaller, very close to the surface of the neuron and they are branched.

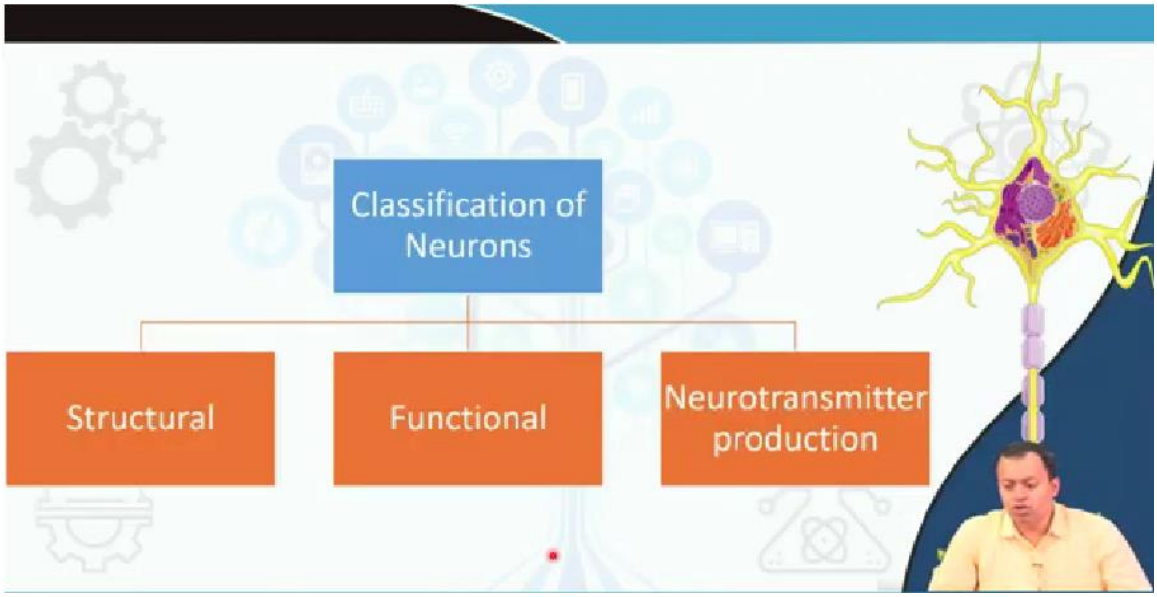
Just like you have one single long tail of axon, neurons on the other hand have large number of branches. These branches are there to collect the information. Now be absolutely aware that there are always exceptions to this rule. There are always exceptions to this rule, but this is a typical example. This is a general typical example axon sense information, dendrites receive information usually.

Neurons usually contains axons and dendrites usually. There are exceptions, but for those of you who are into electronics engineering or physics background who are looking it from the first point and who are already thinking this is too much biology, do not stress on the exception part for the time being. Once you have sufficient knowledge, then go into exceptions and then figure out that the opposite could also be true whatever is told us is completely wrong there are exceptions, but again those are exceptions. For the time being if I start giving you exceptions or different type of neurons and what are the problems, you understand neuron first, understand what is a typical neuron first. So, the cell body this is where the nucleus is the central part of the neuron that contains the nucleus and other essential organ to organelles to maintain function.

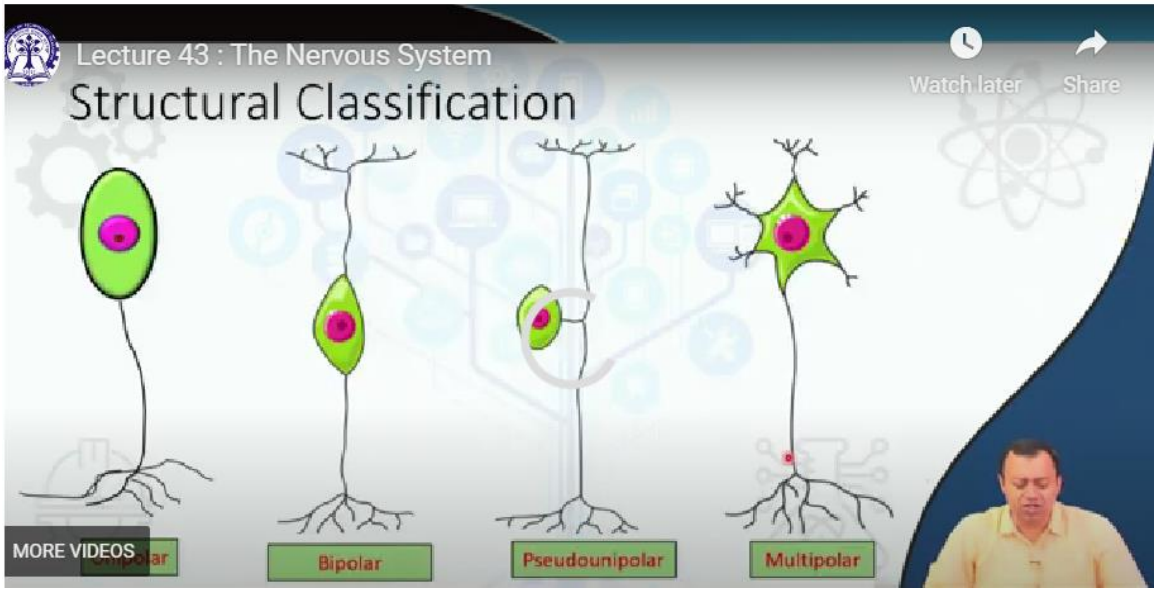
Dendrites are branch like structure that extend from the cell body designed to receive incoming signals. Axon is a long thin fiber that carries electrical impulses, fiber is the term I use tail, fiber is a better term away from the cell body to other neurons muscles or glands. Axon terminals the end of the axons where neurotransmitter I will be discussing neurotransmitter and synapses. So, the axons are this fibers or tails since I have used the term tail contains electrical impulses to say other neuron connecting them with the dendrites of another neuron or directly to muscles or some other part. They do not directly physically connect with the dendrites; the transmitter and the receiver do not physically connect.

There is a small gap between transmitter and receiver between axon and dendrite between axon and muscle there exist a small small small gap. This gap is called the synaptic cleft and this information passage electrical impulse passed between the axon and the dendrite between the transmitter and receiver through this intercellular space they are not physically connected through this small gap through this synaptic cleft is through specialized molecules. The specialized molecules are called neurotransmitters. There is a small gap these gaps contain large number of vesicles they discrete molecules transmitter molecules attaches themselves to the receptor of the receiver part of the dendrite and thereby information is passed through. There is no physical connection there is a small gap between two wires between transmitter and reflector.

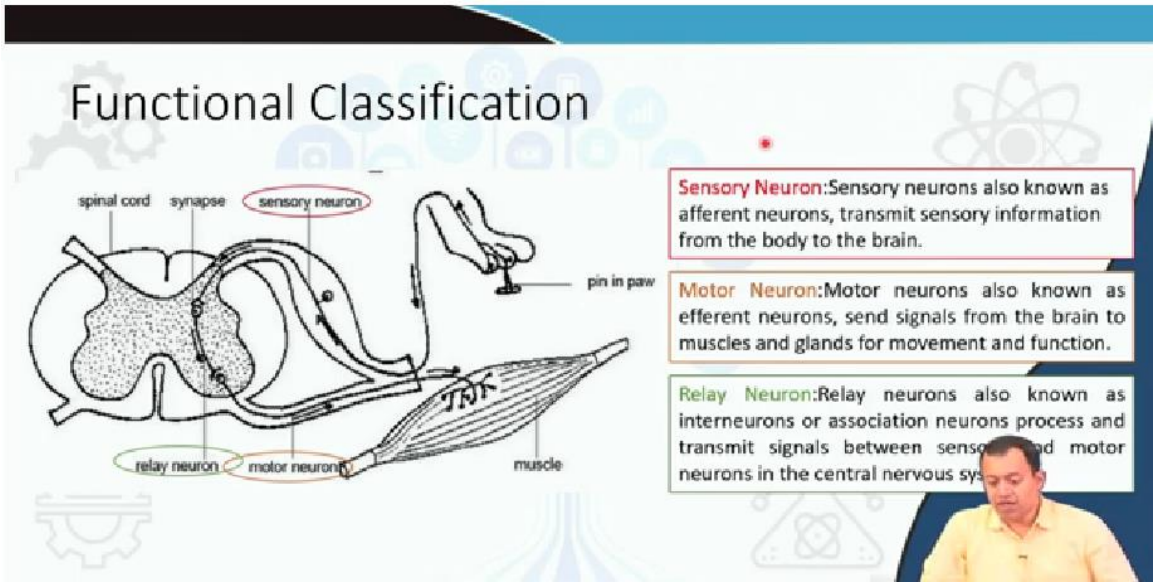
Any gap between neurons where neurotransmitter is released to facilitate communication between neurons. Axons are not physically connecting themselves with dendrites or with other neurons there is a small gap.



So, neurons by this time you would have understood this is the axons and this is the dendrites and this is the cell nucleus there are large number of mitochondria especially near the synaptic cleft etc. So, neurons could be classified into structural functional and neurotransmitter production. So, the structurally neurons could be classified into unipolar, bipolar, pseudo unipolar and multipolar.



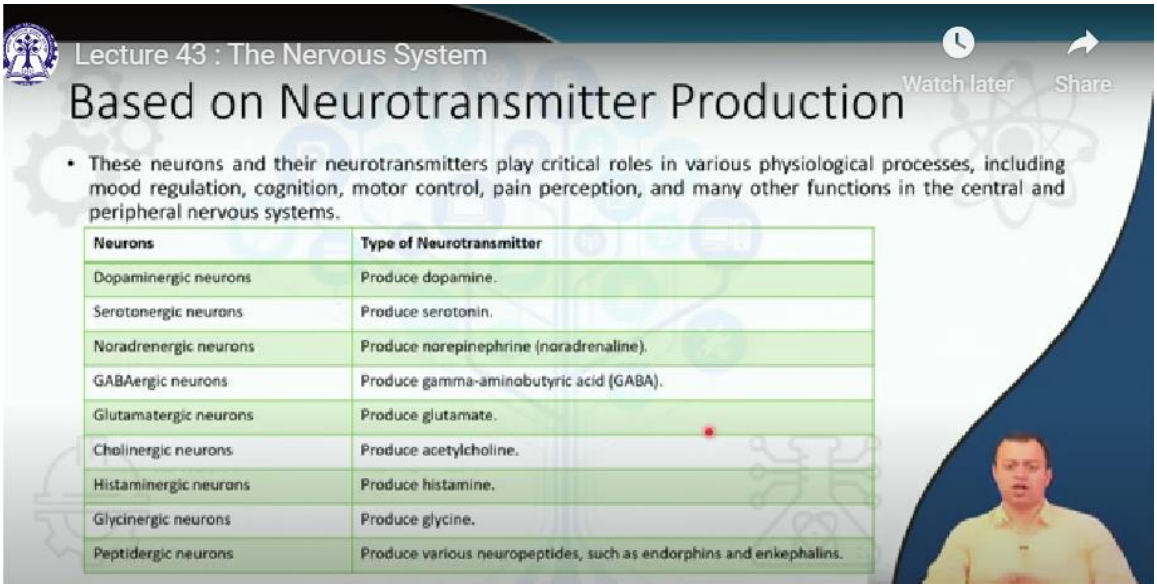
Unipolar has very less number of dendrites one axons going through bipolar has you know two axons and then there are some branching pseudo unipolar, but most of the neurons are like this multipolar. These are dendrites very close to the neural cell very close to the periphery very close to the body and a long chain that has then branched out this is axon these are dendrites you will be able to distinguish it in no time even electrical engineers like me can do it and look into it the branch the short branch are dendrites the long long tail terminating somewhere or branching out this long tail is axon. This is transmitter it is transmitting long distances and this is receiver this is receiving information from somewhere else maybe this is sending information and there is a gap existing between this with respect to this they are not physically touching there exists a gap between them.



So, neurons can be classified into three sensory neuron motor neuron and relay neuron motor I think the term itself suggests movement you know electrical engineers' mechanicals have been using motor and engines etc. Motor simply means movement motor neurons are efferent neurons and signals from the branch to muscles and glands for movement and functions sensory neurons are afferent neurons I will be telling you this is a fantastic topic coming up transmit sensory information from the body to the brain this is sense this is sensing your eyes your ears touch etc.

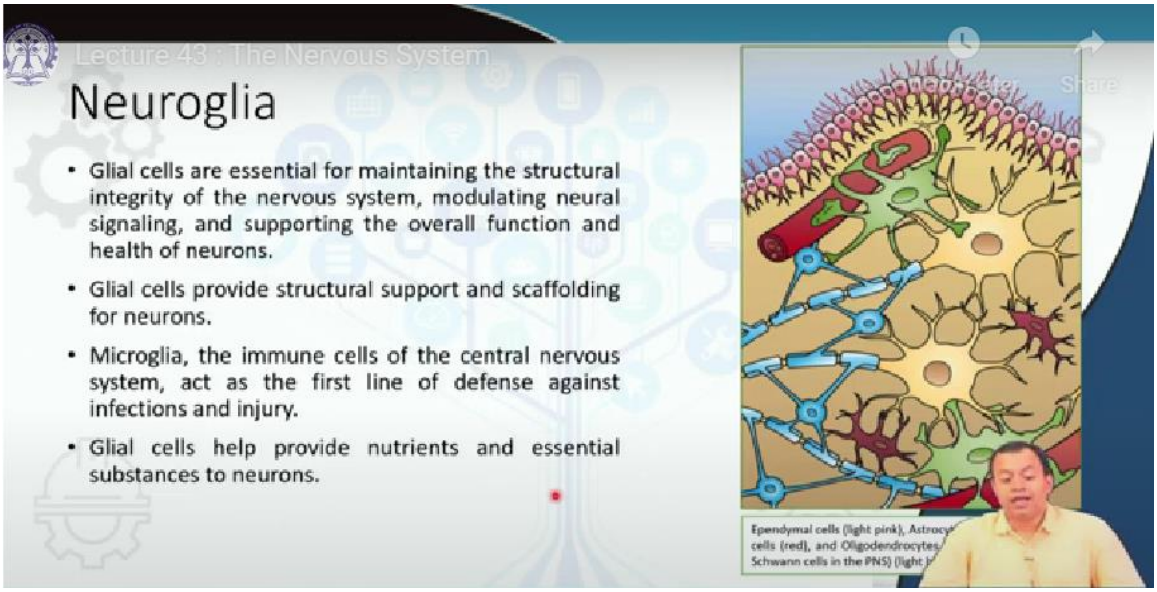
Motor neuron is movement and relay neurons relay neuron also known as interneurons these are the interconnection these are the interconnection between afferent and efferent afferent is where the brain is sending information if efferent neurons are where the brain is receiving information and the relay neurons are interneurons are the interconnect between afferent and efferent between receiver and the transmitter. And yeah those are

the functional classifications of neurons based on neurotransmitter these specialized molecules that are transmitted that are secreted by this synaptic cleft between transmitter



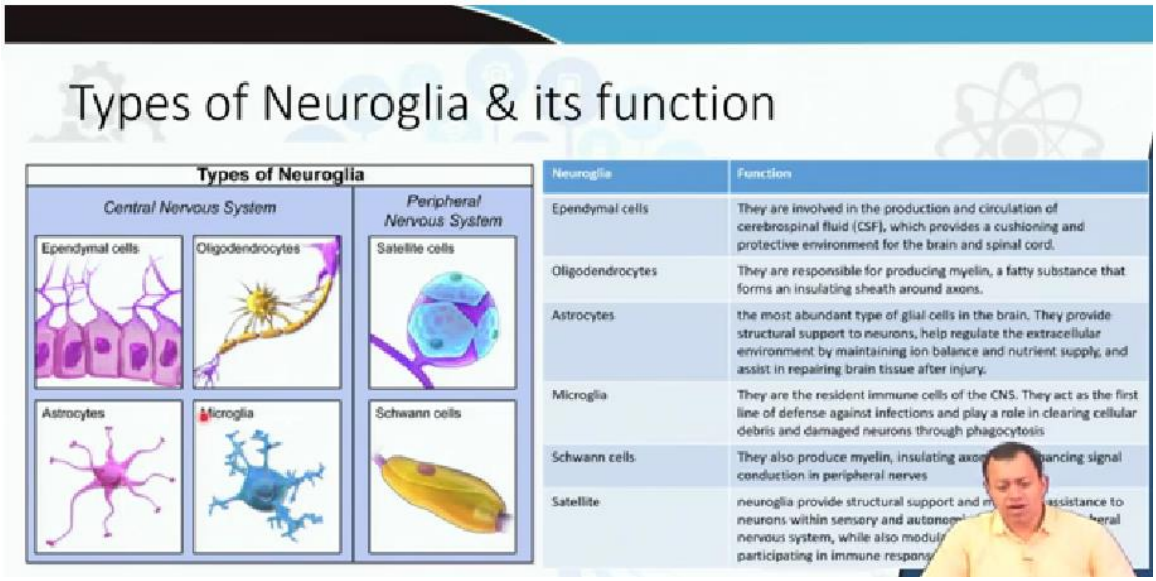
and receiver synaptic cleft between transmitter and receiver that allows information electrical signal to pass through one part another resulting in everybody function like movement of the hand or my eyes blinking or knee jerk movement whenever you know with a small hammer probably you have seen doctors trying to do it hit at the at your knee your knees like that they hit it with a hammer and your it jerks off all these things uses this neurotransmitters. So of the several neurotransmitters dopamine and serotonin are the one that probably you have heard of these are the special molecules that carries information between the transmission and the receiver signal these are very very special molecules the neurons and their neurotransmitter plays critical role in various physical processes including mood regulation cognition motor control pain perception and many other function in the central and peripheral nervous system dopamine serotonin also your brain secretes these neurotransmitters they can come to the blood stream and they can either elevate your mood they can make you depressed they can make you happy it is said that when you eat lots of chocolates or fall in love your body contains huge amount of your blood contains huge amount of dopamine and serotonin that has been secreted by the by the brain. So the neurons also produce these kinds of neurotransmitter these kinds of molecules which has several different functions several of them we still do not understand the exact function and how they are being regulated dopamine and serotonin are the one which are most common and which has been most studied but still we are lacking the to know what are the exact function of these molecules secreted by the neurons but several of these the total information on this are still missing. So there is another type of specialized cell called glia or neuro glia that comes with neurons that are present plenty in the nervous system and they are not involved in sending any electrical signal or they are

not there to transmit message from one part to another part.

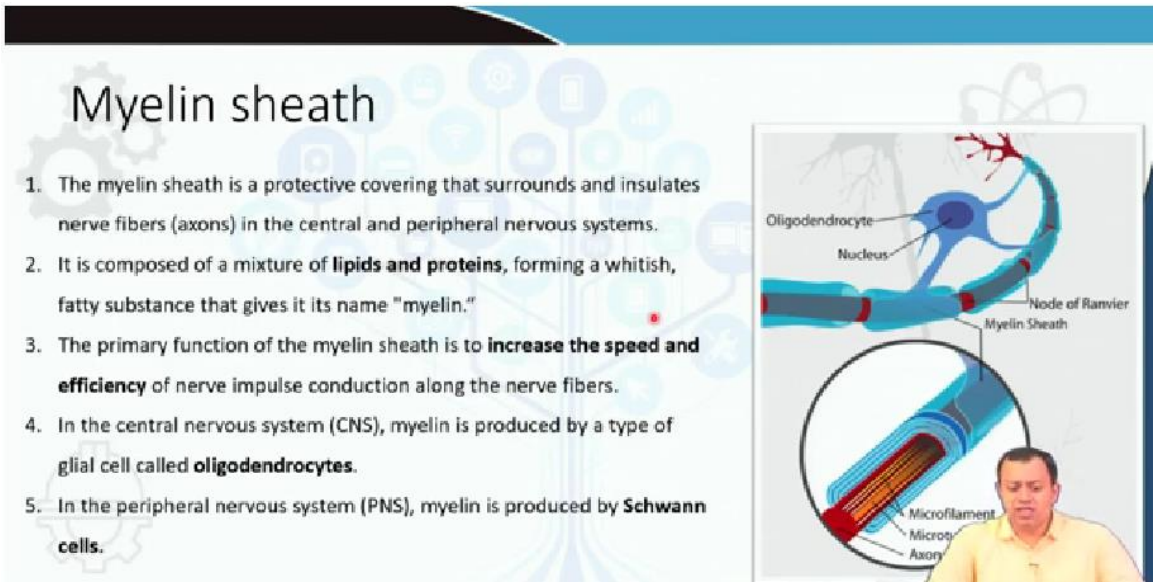


So, what are glia for well two things mostly glia are mostly there to give scaffolding to give support to the neural cells to the neurons to the axons they are the scaffold and they are also there to repair any damage that has been caused into the neural circuitry if part of the neural cell is damaged the glia contains enough stem cells enough stem cells that get converted into either parts or completely into neurons that can help repair the damage glial cells are essential for maintaining the structural integrity of the nervous system they modulate the neural signaling and support the overall function and health of neurons glial cells provide structural support and scaffolding microglia the immune cells of certain central nervous system act as the first line of defense against infection and injury and glial cells help provide nutrients and essential sustenance to neurons substances sustenance to the neurons. So, the glial cell are I mean I found it fascinating see electrical engineers or electronics engineer you have wires like copper wires that connects two part of the circuit and then this copper wire is covered in some kind of a insulating sheet the cover of the rubber sheet of the copper wire or aluminum wire we used to peel it off with our teeth and connecting our bread board this is incredibly similar to that there are myelin cells this lipid rich insulating mediums etcetera that is simply encapsulating the neurons and the axons you will see. I mean this is fascinating whoever come came up with this idea I mean are we some sort of a complicated circuit somebody decided that instead of using semiconductors and copper wires let us use organic material and create a circuit organic material can also transmit electrical connection and made this particular circuit. So, glia is basically that the copper wire the equivalent of copper wire is your neurons that is sending electrical connections electrical signals and the copper wire is covered by some sort of an insulating which also provides structural information which also helps it to repair if there is some broken part. So, that it does not get broken it does not get attacked short circuit does not happen you cover it with some kind of a polymer or rubber sheath right any wire that comes in through any copper wire that comes through it is not openly exposed it is

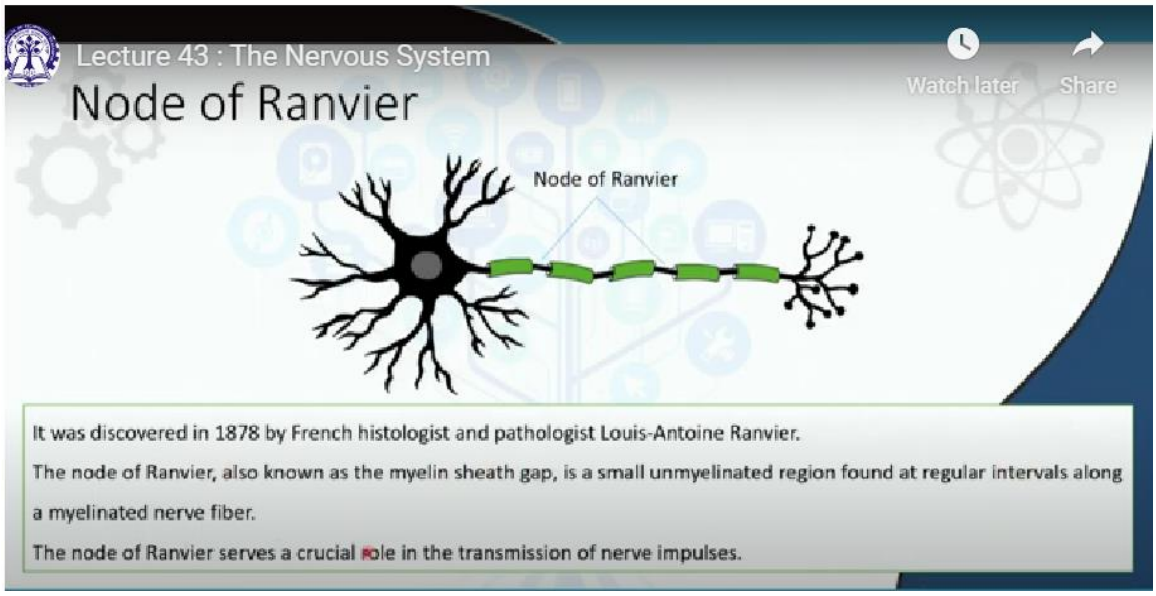
covered the glia is exactly that I mean fascinating somebody created a giant complicated circuit and that is us right.



So, there are several types of neuro glia I ask you to read it at your own leisure there are astrocytes which basically means star cells they provide structural support for the neurons help regulate the extracellular environment micro glia are the immune cells swan cells are the myelin sheet that they are the lipid rich sheet, but swan cells are mostly in the peripheral nervous system and so on and so forth. I have mostly found astrocytes micro glia and swan cells to be the most important one. These are also there you should read about it and there are other functions, but overall understand this electrical transmission or electrical signal is passed by nerve cells these are neurons and these nerve cells are protected by another types of cells which do not transmit any electrical simulation or electrical signals it is simply there to protect the connection protect the neurons and those are glial cells.

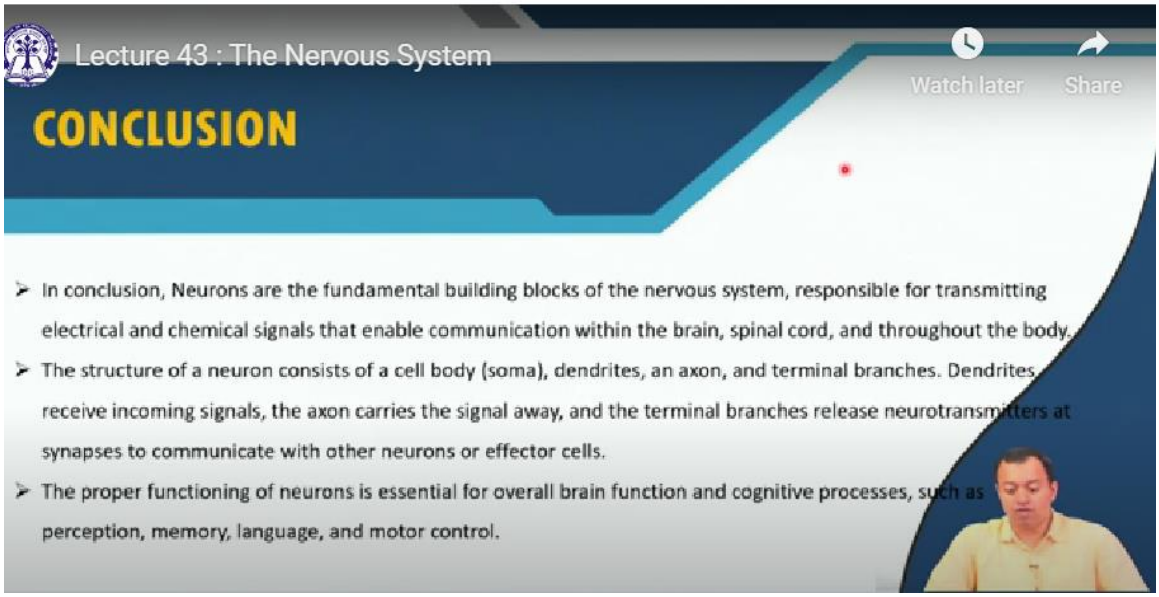


There is this myelin sheet which is a lipid rich sheet this is myelin sheets and they are you know is a protective covering that surrounds and insulates the nerve fibers in the central and peripheral nervous system it is composed mixture of lipids and proteins forming a whitish fatty substance that gives the name myelin the primary function of myelin sheet is to increase the speed and efficiency and in PNS it is produced by swan cells oligodendrocytes is the one that produces CNS this is fascinating. It is not fully covered the myelin sheet or the glia this is not fully covering the axon there are some

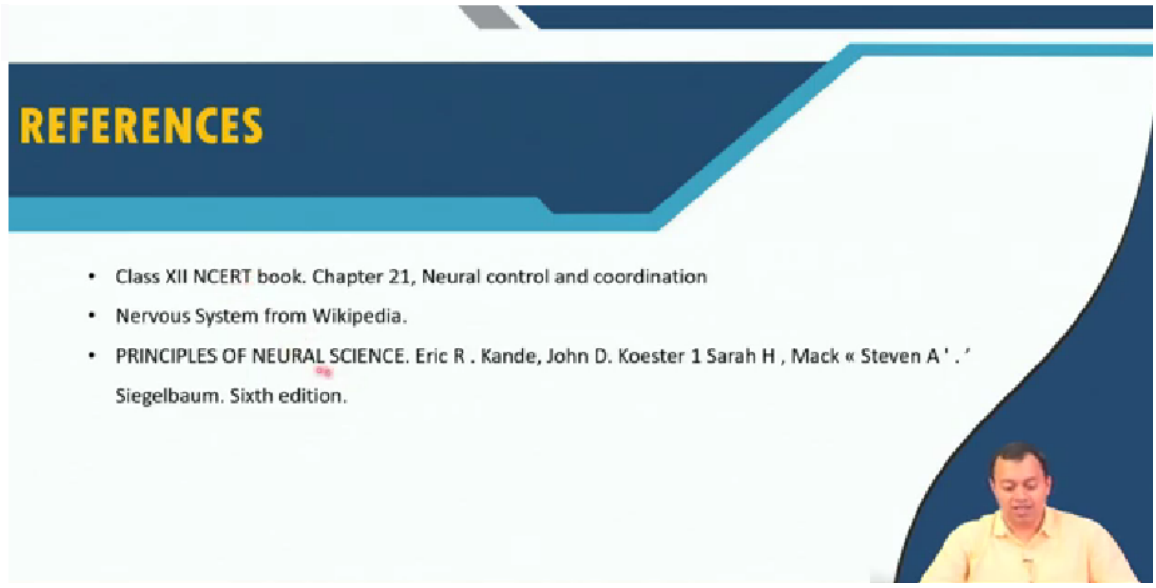


exposed areas in between they are called nodes of Ranvier and they are their gaps in the myelin sheet and they helps in modulating the electrical signal that needs to be transmitted from this neuron through this dendrite and these are the synaptic claps these are the areas from which it is connected with other neurons.
So, that is basically it I hope this is not too difficult for electrical or electronics engineers I understand that this is not something that you read on a daily basis but we need to go through we need to have certain some amount of understanding of the brain. I promise there is only one chapter left one lecture left on this topic and we will directly return back to something that is more familiar to us.

So, these are the concepts that I covered and these are the conclusions fundamental building block of our nervous system is neurons the proper functioning of neuron is



essential for overall brain function and the structure of neuron consists of dendrites and axons along with the body. So, these are my references believe it or not this is perhaps



the best book to start with class 12 high school biology, but then the more you go deeper these are the topics that you should read. Thank you very much.