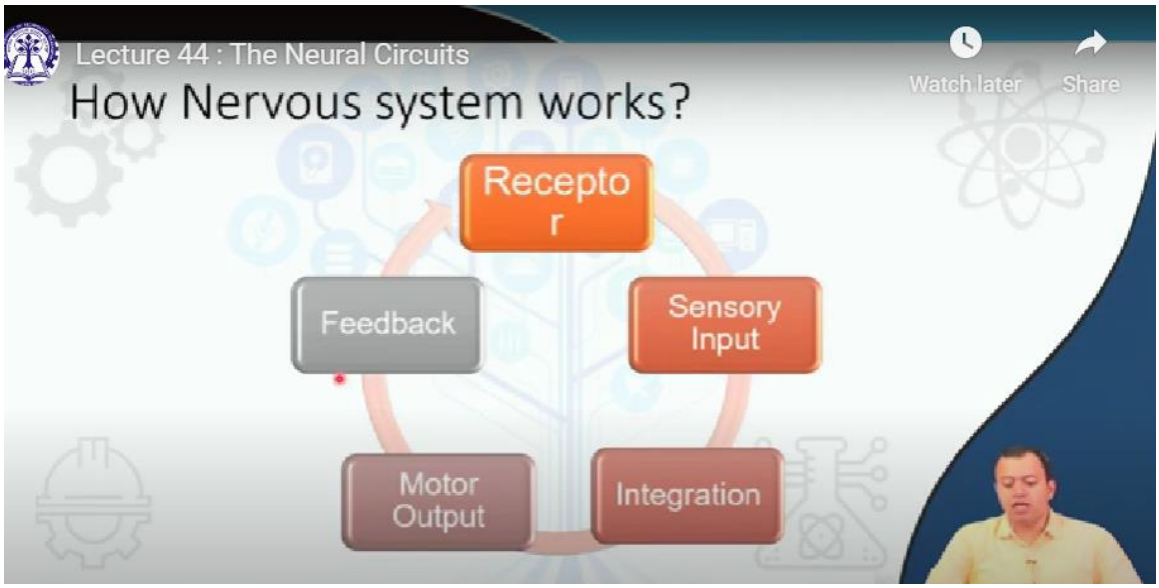
Nanobiophotonics: Touching Our Daily Life
Professor. Basudev Lahiri
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur
Lecture No. 44
The Neural Circuits

Welcome back. We are trying to understand the brain. In the previous lecture, we have discussed about the nerve cell, neurons along with the glia, neuroglia and in today's lecture, we are going to discuss about the neural circuit. These are the two topics that is purely from a biological standpoint. So, I ask you to power through because I think you will understand or you will try to get something very interesting here in these two topics even though if you are not from a biology background. So how does the nervous system work? It is basically a loop.



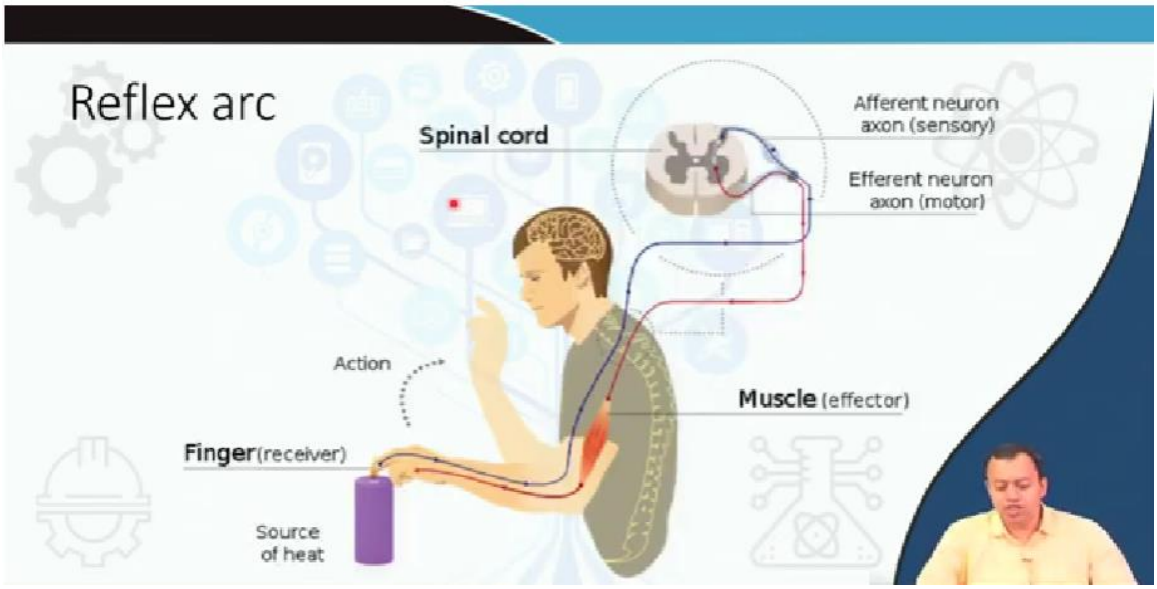
There is a receptor that contains information from various inputs, sensory input, motor input, etc. They integrate, there is a feedback system and based on that some sort of a motorized or movement happens. Understand this. You remember the knee jerk movement when a piece of when a small tongue or small hammer is made to touch your or hit the base of the knee, your leg automatically goes up or even a better one, light a candle on the candle flame, try to touch it with your finger.

Immediately your finger or your hand will be jerked back. That happens. This stimulus response, suppose you are careless and you have touched a hot surface. You have touched a hot surface, a hot cup of coffee for example. Unknowingly you have touched it.

Your hand involuntarily will simply be jerked back. So that is all of that information.

Think about how fast your brain processes this information from the skin, the nerves that are present in the skin takes this information back to the sense organ that is the skin. The nerves take this information back to your head, back to your brain including your spinal cord where the processions take place that this could be dangerous for the body. It immediately brings back another set of information into the muscle of your hand resulting the hand to contract or jerk back.

So sensory input and the motor output they are integrated, this processes feedback and it returns back to the overall central processing unit. So, this is something that I wanted to discuss about is the place where your finger is touching the flame, the source of your heat. So, there are two types of neurons. One is the afferent neuron, the blue one that brings the signal from the sensory organ, the receiver, the skin into your brain or the spinal cord. This actually the motor and sensory functions mostly take place in the upper portion of the spinal cord.



Not all information happens just here. There is certain cortex, it connects it to sensory cortex and it connects it to motor cortex but see the afferent neurons, afferent, afferent means the neuron that is bringing information to the brain. Efferent is the neuron that is transmitting information from the brain to the sensory organ. Afferent A input, efferent output. So just by your finger you have touched the flame, the sensory organ, your skin has passed the heat information.

This information in the form of electrical impulse is carried through the afferent neuron into the spinal cord section. The spinal cord then processes it and passes it into the efferent neuron via local neuron, interneuron. These are the local neuron. Certain number of neurotransmitters are passed through specialized molecules that is passed through from afferent neuron to interneuron. Neuron then passes another type of neurotransmitter specialized molecule to efferent neuron; the red color and it returns back and attacks the

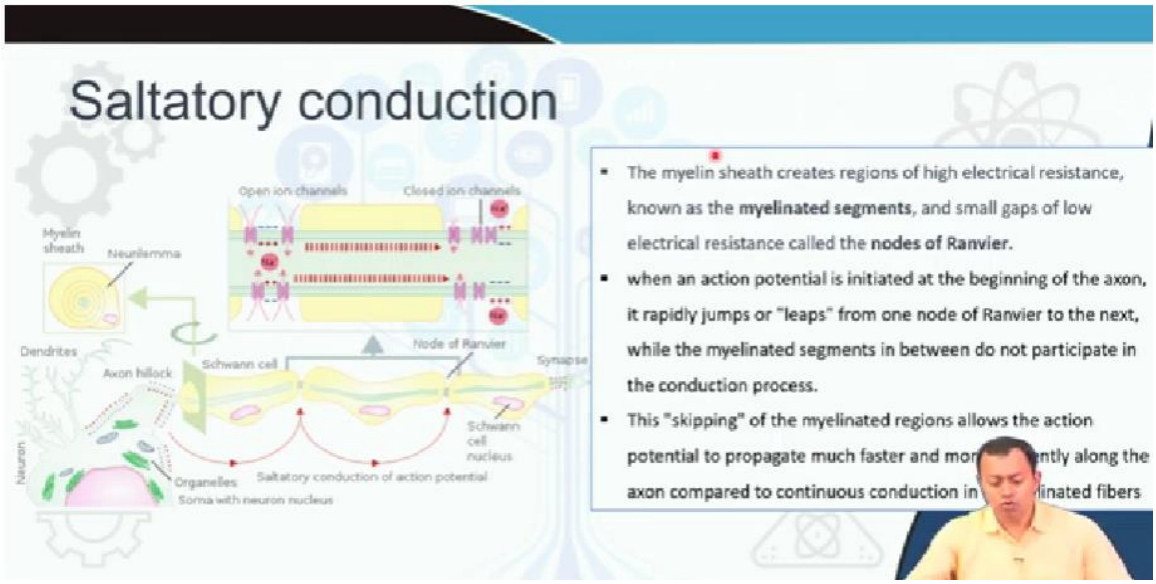
muscle in your hand that results in the jerking movement.

The exact same thing happens when your base of the knee is hit by a hammer. A piece of afferent neurons takes the information through your knee into the spinal cord, the motor cortex and from there the information is exchanged from afferent neuron it goes to interneuron, from interneuron it goes to efferent neuron. The efferent neurons then return back to the muscle, two muscles, the top muscle and the bottom muscle. The top bottom muscle is contract upper muscle is contracted, bottom muscle is relaxed resulting in your knee simply going up, simply getting jerked. The same thing with your finger.

This is an incredible process of electrical signaling. People who are interested in DSP, Digital Signal Processing, I strongly suggest you work in this particular area of neuroscience where these molecular signals, where these electrical impulses send by different molecules, different ions results in different movements of the body. You must have seen there are several patients whose motor neurons are not properly working, who has problem in movement. Either their head keeps on shaking, you have seen old people whose hands are completely trembling, there is a tremor or people who have paralyzed a portion of their body is no longer able to move. If we could understand what neuron produces what particular electrical signal which results in what specific movement and if there is some kind of a neural damage in the spinal cord or somewhere else, can artificially these neurons be stimulated with some external force like you have pacemaker present in the heart for people whose hearts are weak that pacemaker produces the pace of the heart so that it keeps on beating.

Can we have some kind of a biomedical bioelectronic chip or machine implanted into the brain of those people who have suffered from paralysis or who are suffering from this tremor to regulate or stimulate the particular neurons produce this particular loop between afferent, efferent and the in between interneurons so that the movement can be regulated, the movement could be so called normalized. Think about it. This is purely electrical signals. Those of you who are making drones or who are making robots, you know small robots or this robot dog that move etc. It is the exact same information that you are feeding.

It is exactly the same information you are feeding when you are working on a drone or a mechanical robot or a mechatronics-based robot dog that moves around. If that can happen at a crude scale, can we not miniaturized it and put it into human beings who are suffering from this type of problem. Anyways, so let us go into the nitty-gritty of it. These are the Schwann cells, the myelin cells, the lipid rich areas that protect the neurons. They are also gapping which cause the nodes of Ranvier.



The myelin sheath creates region of high electrical resistance known as the myelinated segment. It is lipid and the small gaps of low electrical resistance called nodes of Ranvier. So, you basically are modulating the resistance. Modulation of resistance, semiconductor people. Modulation of resistance is exactly what we do.

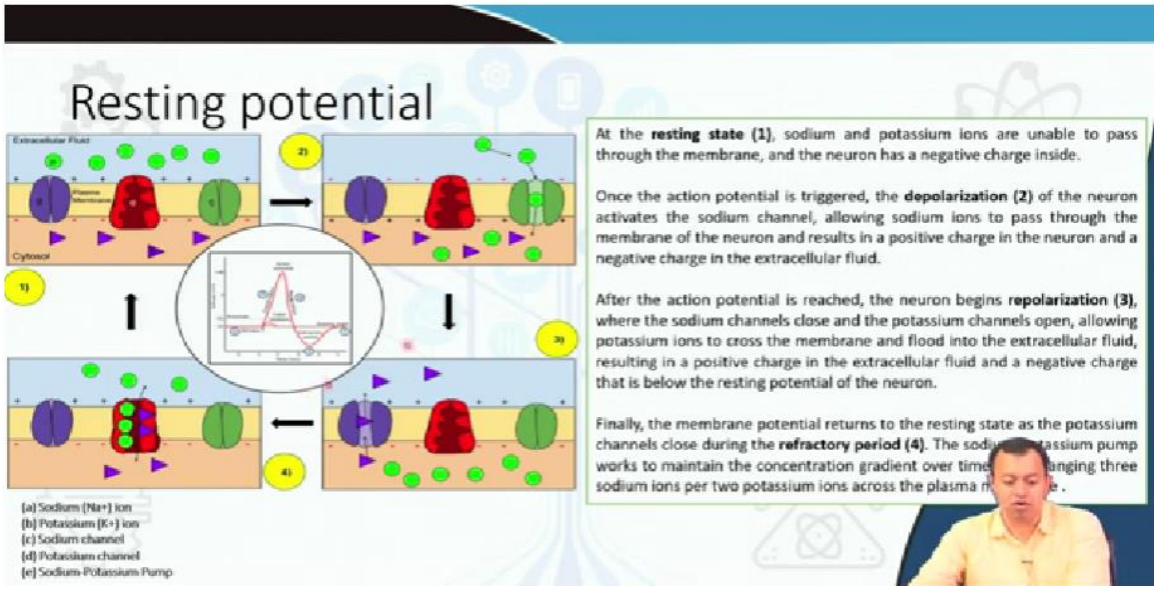
You dope in semiconductors. Here sees how brain have figured it out, myelinated segments and small gap of low electrical resistance, nodes of Ranvier. When an action potential, it is the spike. It is basically the synaptic spike that happens. The stimulant, the electrical signal, so this information that has gone and this processed, this is an electrical spike.

The term is action potential. The action potential is initiated at the beginning of the axon. It is repeatedly jumping or leaps from one node of Ranvier to the next. Current flows the least resistance path. You have the least resistance versus high resistance where will the current go while the myelinated segment in between does not participate in the conduction process.

The skipping of the myelinated regions allows the action potential to propagate much faster and more efficiently along the axons compared to continuous conduction in unmyelinated fibers. So, it skips information, skips. There are several ions, ion channels. You will see potassium and sodium. They simply skip, jump from one area to another area.

It becomes very, very fast. These are high resistance areas. These are low resistance area completely covered by intracellular fluids, cerebrospinal fluids, etc., etc. So, it allows the skipping of this electrical potential from low resistance to low resistance areas thereby

passing the information in a very, very strong manner.



So resting potential is where there is very little amount of electrical spike. The electrical spike is not there. At resting state, the sodium and potassium ions are basically the ubiquitous currency by which the electrical signals are passed from neurons to neurons. The nervous system, there are other molecules as well. But sodium and potassium ions are the one that carries the electrical potential and that modulates the electrical spike that passes through the body.

At the resting state, sodium and potassium ions are unable to pass through the membrane and the neuron has a negative charge inside. Once the action potential is triggered, the depolarization of the neuron activates the sodium channel. This blue one is the sodium channel. I am color blind. Green one is the sodium channel.

Allowing sodium ions to pass through the membranes of neurons and result in positive charge in the neuron and a negative charge in the extracellular fluid. Previously it was opposite. Previously the neuron was negative. The extracellular fluid was either neutral or slightly positive. But now positive has gone inside the sodium channel.

The sodium ions have gone inside and it has depolarized. The neuron is now depolarized. Initially the neuron was negatively charged. Now there are amount of positive charge in the neurons and a negative charge in the extracellular fluid. When you have negative charge and positive charge opposite, you understand there is a potential flow of electrons after and flow of electrons is electrical current.

After the action potential is reached, the neuron begins repolarization where the sodium channel closes and the potassium channel opens allowing potassium ions to cross the membrane and flood into the extracellular fluid resulting in positive charge again back into

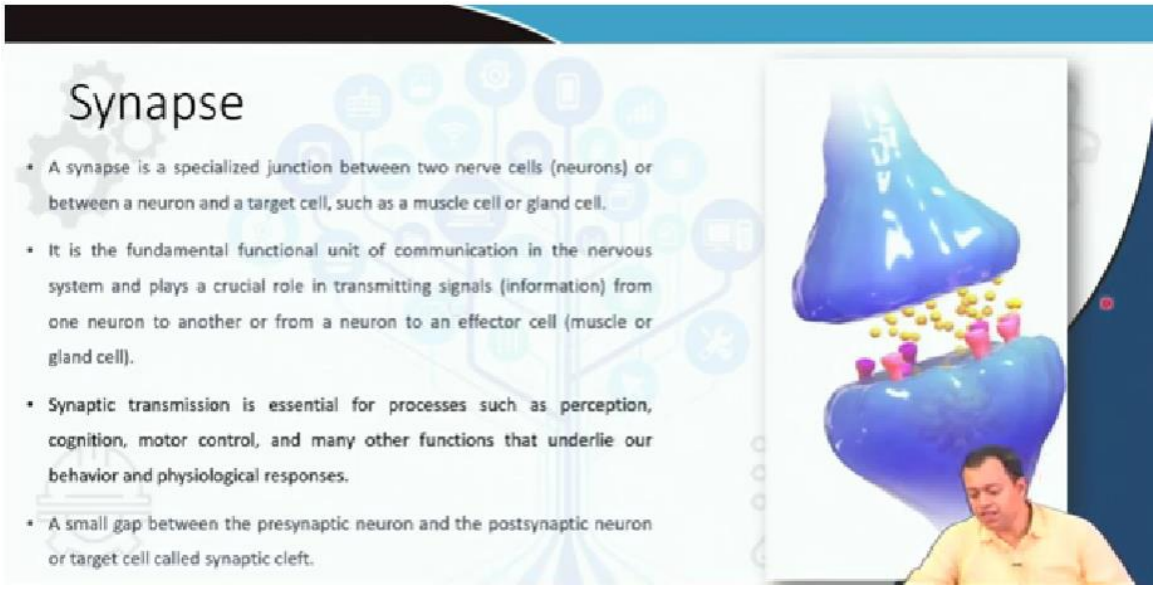
the extracellular fluid and negative charge into the neuron. Finally, the membrane potential results to the resting state as potential channel closes and the sodium potassium pump works to maintain the concentration gradient. People who are suffering from dementia having problems, you know, remembering name of people, name of recent events, you probably have seen in this old people who keep on forgetting their houses etc. This sodium potassium pump that allows for the proper electrical channel, electrical spike to go through that is damaged. As a result, the memory or all other parts they are unable to access.

A particular spike has to go through, a particular electrical spike has to go through where the memory will be, we still do not know fully, the memory will be accessed and based on that memory you will take a particular action like from this particular road go left or go right, left is my house, right is not my house that memory that connection is not being made. How is this connection made? Previously neuron is negatively charged, outside is positively charged, you have a trigger that allows neuron to open potassium sorry sodium ions goes inside making the neuron more positive, the outside is negative now. So, the electric current flows through slowly potassium starts coming in, sodium is flushed out, these things repeat and what was neuron was initially negative then become positive, then it again became negative and the resting potential, the rest state is achieved. How fast this happens and in how many places this happens? How many neurons are completely firing at a time in your body as you perform some sort of a task? Human body overall have around 86 billion neurons, human body has around 86 billion neurons, a substantial amount of them are present in the central nervous system but peripheral nervous system also has. They are mostly there to send electrical signals through sodium and potassium ions, their polarization is modulated, the modulation of polarization allows a particular electrical spike through go through and these spikes thousands and millions of spikes per second allow you to perform all the functions of your body including breathing, including heart beat, including all other bodily functions, motor functions, sensory functions, memory, learning all of that.

So the more and more a particular task is being done your brain will get exhausted think about it when you are studying something for 1 hour, 2 hour, 3 hour you are being asked to go for a walk or exercise or entertain yourself why? Then the other part of your neurons are active, the other neurons previous neurons were involved in a particular task and it is happening over and over and over you are getting mental fatigue because the finite amount of potassium and sodium are saturating previously what was the potential reached is no longer present, your neurotransmitters are exhausted, your sodium potassium pump is exhausted it is no longer possible so the neurons are no longer firing you are unable to understand the lesson anymore. At that time people are asking you to go for an exercise, go for a walk, refresh yourself so that other part of your neuron, other part of the brains is firing this part is allowed to come back to a resting potential, to come back to a resting

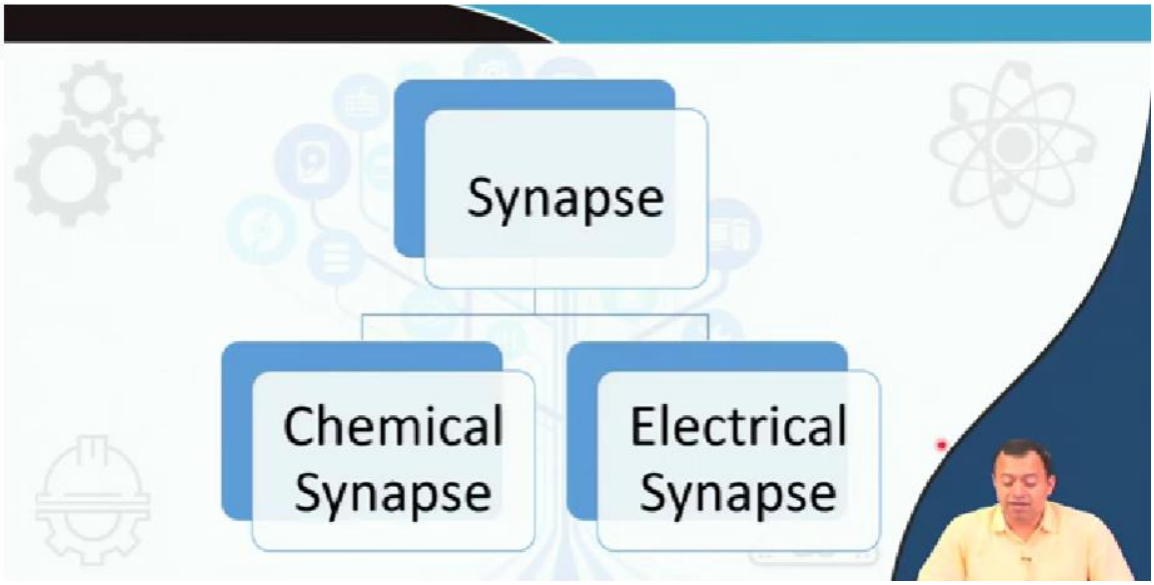
potential so that the sodium and potassium can regroup, can come back to the original positions. If it remains at a depolarized state after certain time the electrical spike will saturate, it will no longer pass through because it is in a constant depolarized formation the electrical spikes are saturated it is constantly going. Look what I am telling you is from a very analogy or very simplistic form of view obviously, neuroscientist will give you far better explanation, but understand this at the end of the day the best way you can rest is to sleep, what happens when you sleep your neurotransmitter those vesicles that sense this dopamine and serotonin all those specialized molecules they replenish. At the same time whenever there is huge amount of circuitry neural circuits have enacted upon among each other there is some sort of debris, some sort of materials that are no longer needed they need to be flushed out or they need to be excreted during sleep what we have figured out your brain performs that maintenance and cleaning when nobody that has in the house they clean it.

So when you are sleeping when all other functions mostly your sensory function mostly your motor functions all have ceased to exist your brain is flushing away all those additional byproducts of the chemical reaction that has taken place because of this sodium and potassium channel going through the reaction the chemical reaction that have taken place the byproduct that has formed needs to be flushed out. So they ask you to sleep mostly if you are trying to learn something specific these days they are saying that study and after that go to sleep so that debris additional material goes out and the information gets embedded in your head as memory, but anyway these are deep neuroscience things I am not a specialist you need to learn it if you are interested from someone who is far better than me.

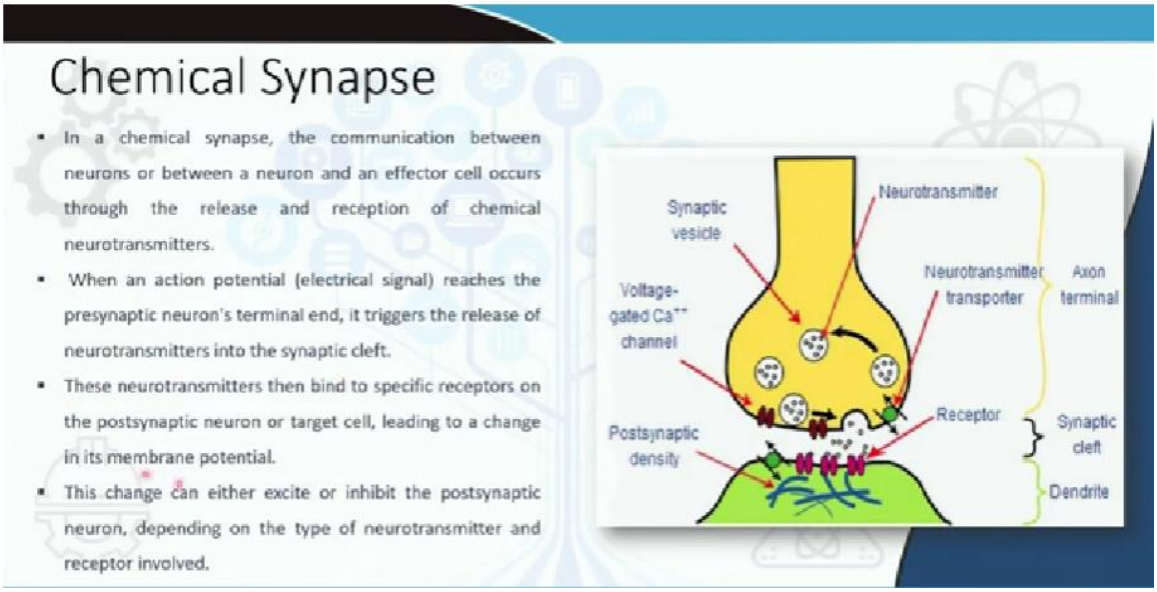


So, this is the synapse and this is the synaptic cleft these are the specialized molecules neurotransmitters they are sent by the axons and these are the receptors that are the part of the dendrite that are attaching and this gap this physical gap that exist where the connection happens. A synapse is a specialized junction between two nerve cells or between a neuron and a target cell such as muscle cell or gland cells it is a fundamental function unit of communication in the nervous system and plays a crucial role in transmitting signal. Synaptic transmission is essential for process such as perception, cognition a small gap between the presynaptic neuron and the post synaptic neuron is the synaptic cleft.

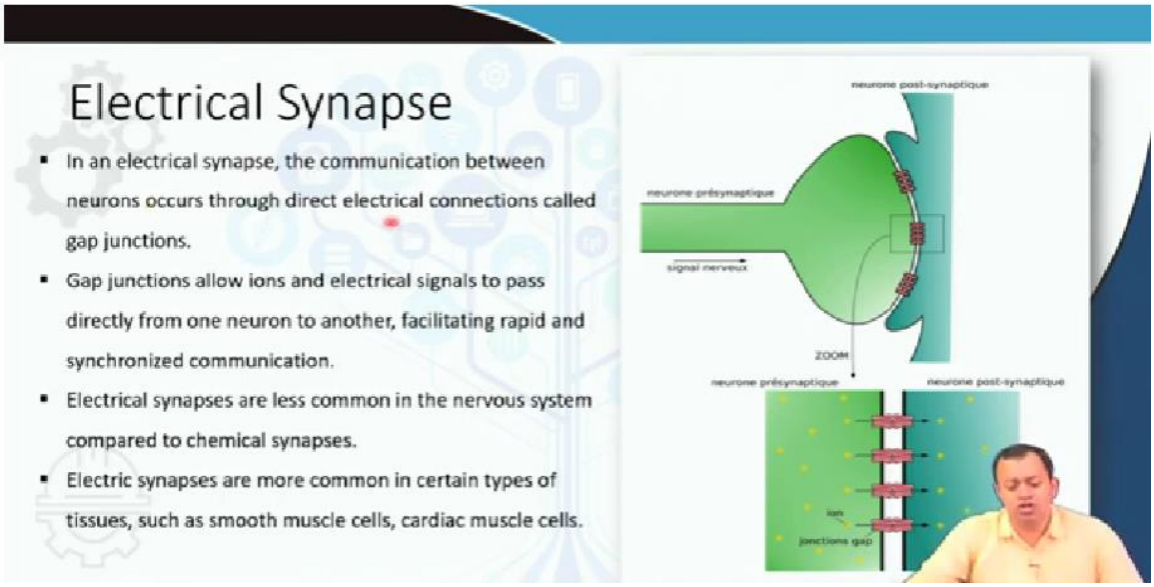
This gap is the cleft where the hand holding where the exchange of data these are the neurotransmitters dopamine serotonin and these are the specific receptors attaches to specific neurotransmitters. This brings in information this receives the information this can be a particular another neuron or this could be part of your muscle or gland allowing you to do this movement. Think how fascinating these are how many billions and millions of neural circuits are firing every second as you live and breathe. As you are watching this video how many of your neural circuits do you think it is firing you are able to see you are able to hear your brain is processing my information how much number of neurons are constantly firing sending these sorts of information electrical impulses sodium and potassium pump is working and perhaps a bit of my lecture is also being understood and converted into memory.



Synapses are divided into chemical synapse and electrical synapse.

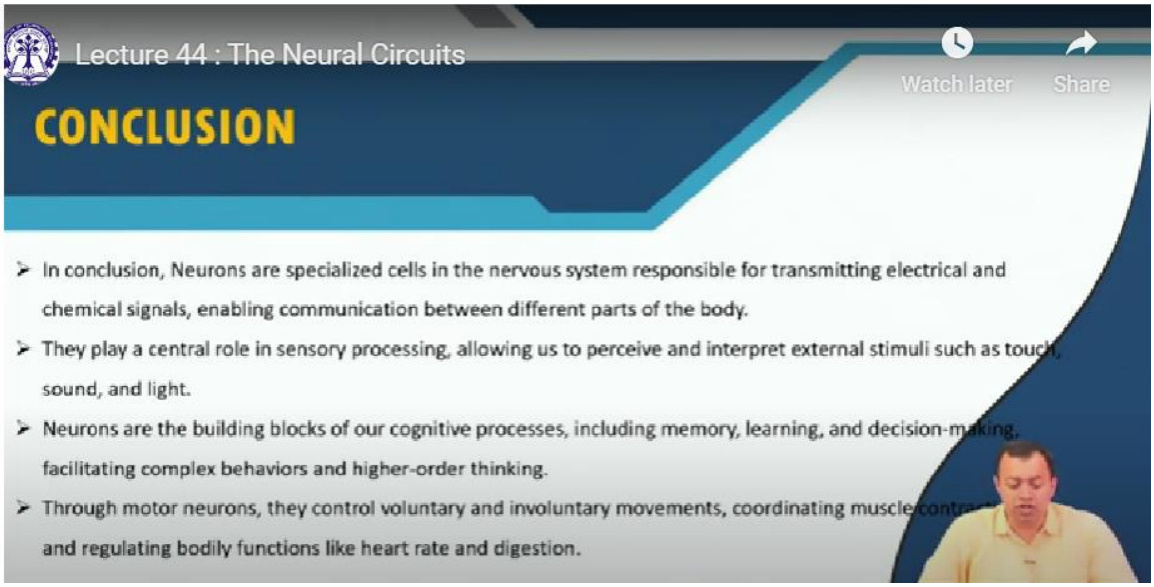


Chemical synapse is the communication between neurons or between neurons through the release of chemical neurotransmitter when the action potential the electrical signal reaches the presynaptic neuron transmission it triggers the release of neurotransmitter as I said the postsynaptic neuron or target cells bind to specific receptors the neurotransmitter bind them and this change can either excite or inhibit the postsynaptic neurons they can either excite these neurons or you can stop it depending on the type of neurotransmission receiver that has been involved I understand this is going complicated, but I will finish it soon.

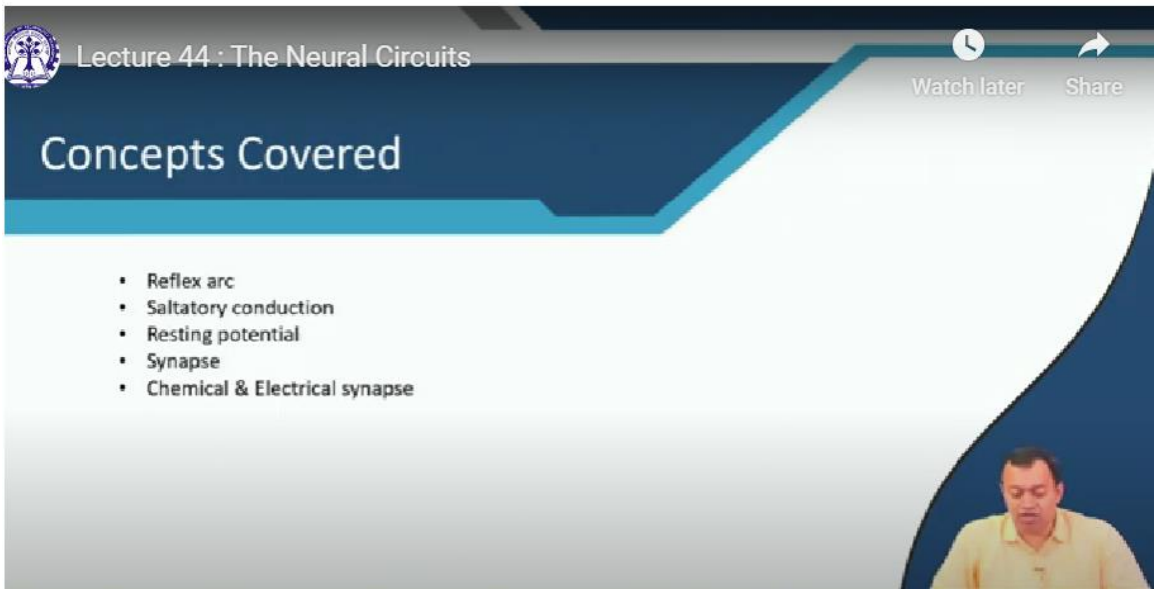


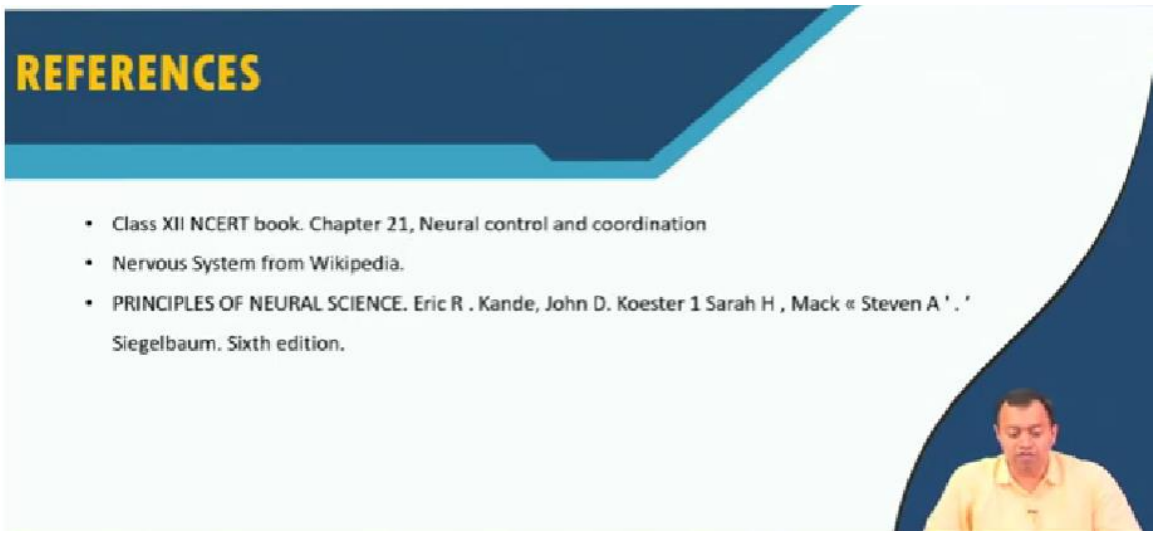
Electrical synapse the communication between neurons occurs through direct electrical connections called gap junction. Gap junction allows ions and electrical signal to pass directly from one neuron to another facilitating rapid and synchronized communication

electrical synapses are less common in nervous system compared to chemical synapses electrical synapses are more common in certain types of tissue such as muscle cells cardiac muscle cells etcetera.



So, these are my conclusions through motor neurons they control the voluntary and involuntary movements neurons are specialized cells etcetera etcetera and these are the overall concepts that I tried to cover and these are my references.





I promise no more biology I will go into the next lecture to something that is somewhat common to what we have discussed before, but please repeat what I just gave you in lecture number I think 43 and 44 because it will help you understand which part of the neuron we will target with light and thereby can we trigger some kind of optoelectric or photochemical reactions into the neurons resulting in some sort of some sort of extra movement some sort of reaction into the body. Thank you very much.