Transport Phenomena in Biological Systems
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Lecture - 60
Action Potential and Axial Current

Welcome back, we are looking at mass flux or movement of ions when there is a simultaneous concentration gradient and electrical potential gradient. You have already seen the significance of the situation. And now we are going to look at the basis for the working of our senses, and the basis happens to be something called action potential and something called axial current is what you are going to see. And as you will see, the action potential arises because of the movement of ions across a neural membrane.

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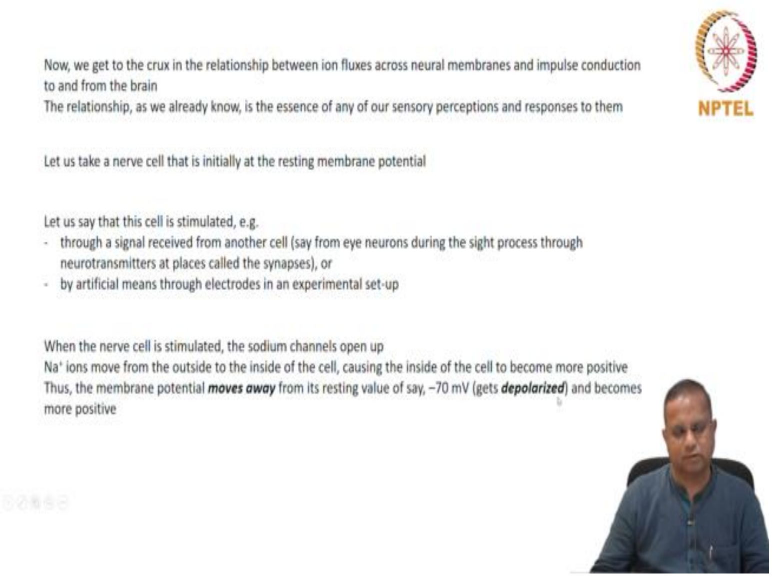

We are getting to the crux in the relationship between ion fluxes across neural membrane and impulse conduction to and from the brain. I hope you saw the video that was the link to which was given in one of the previous videos. The relationship as we already know is the essence of any of our sensory perceptions and our responses to them. Let us take a nerve cell that is initially at the resting membrane potential.

That is for our understanding, let us say that we are taking a nerve cell and let us assume that it is at resting membrane potential when we start our analysis, when we start a thought. Now, let us say, a time t = 0. This cell is stimulated by an image maybe by something pricking maybe by a nice smell by a nice taste, and so on. Let us say that the cell is stimulated through a signal received from another cell, say from eye neurons and so on so forth through neurotransmitters at places called synapses and so on.

You know some of this, so, I am not going to get into the details of where the current comes from? Where the impulse comes from? Or it could be by artificial means, through electrodes in an experimental setup, so the stimulation could either be natural, that is the situation that we are considering here, or it could be induced, in an experiment by electrical by electrodes. In either case when the nerve cell is stimulated, the sodium ion channels open up when it opens up the sodium concentration outside is usually higher than the sodium concentration inside.

Therefore, the sodium ions move from the outside of the cell causing the inside of the cell to become more positive because the sodium ions outside is moving inside more number of positive charges are coming in and therefore the inside of the cell becomes more positive. Therefore, the membrane potential moves away. Remember the membrane potential is intracellular minus extracellular potentials.

So the membrane potential moves away because it is becoming more positive from its resting value of let us say -70 millivolts. And this is called depolarization of the membrane potential the membrane potential is moving away from its resting value is becoming more positive and therefore it is getting depolarized, membrane potential moving away is depolarization and in this case because more positive ions are coming in more positive sodium ions are coming in it is becoming more positive, it is moving away from its resting value of -70 and it is getting depolarized.

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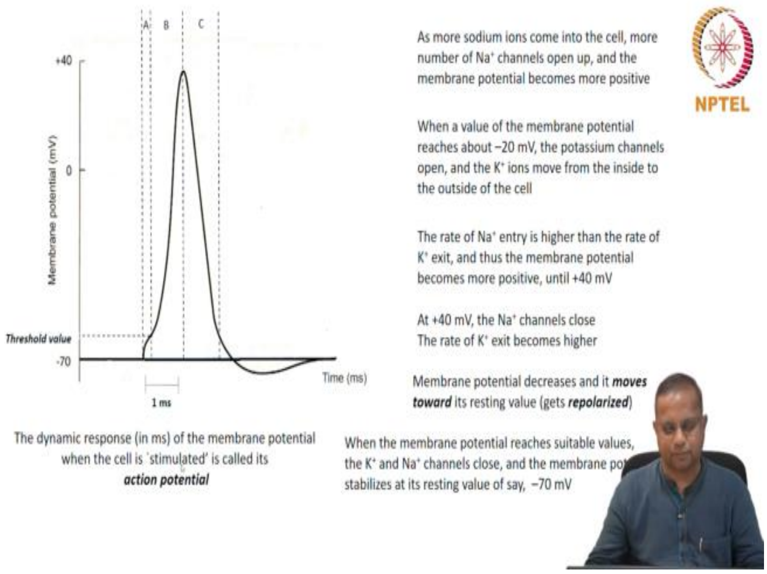

So, this is typically what happens you have the time value here axis here in milliseconds, this is approximately a millisecond. And this is the membrane potential in millivolts. We are at -70 here, 0 is here and 40 is here. So, here we are initially at -70 there is a stimulation and the sodium ion start coming into the cell. Thereby the membrane potential of this cell starts moving away from -70 and it is getting depolarized the membrane is getting depolarized.

As more sodium ions come into the cell, more number of sodium channels open up and the membrane potential becomes more positive. So it starts flooding in, when the value of the membrane potential reaches about -20 volts, this is somewhere here. So here we will come to this in little while, here when it reaches about -20 volts which is somewhere here.

The potassium channels open up and the potassium ions move from the inside to the outside of the cell, why the potassium concentration inside is typically higher than the concentration outside? And therefore the potassium ions move through their ion channels from the inside to the outside. So the movement is in the reverse direction potassium is also positively charged the movement is in the opposite direction.

The rate of sodium entry is higher than the rate of potassium exit when this happens and thus the membrane potential continues to become more positive, till it reaches about +40 millivolts all the way from -70 millivolts, at +40 millivolts the sodium ion channels close and the rate of potassium exit become higher, when the sodium channels close the potassium channels are still open and potassium still starts going out.

And the rate of sodium potassium exit becomes higher also and therefore, the membrane potential starts decreasing again and it moves towards its resting value or it is getting repolarized. If it moves away from its resting value it is called depolarization. If it moves towards its resting value, it is called repolarization, when the membrane potential reaches suitable values, the sodium and potassium.

Potassium and sodium channels close and the membrane potential stabilizes at its resting value of -70 millivolts after an undershoot, and so on, so forth. So this is typically what happens when sodium and potassium start moving inside out of the in and out of the cell. And the movement is initiated by the impulse that is received by the cell the sodium movement is initiated, which is followed by the potassium movement, when the cell gets stimulated.

The stimulation could either be natural or could be induced by an electrode. The dynamic response typically in milliseconds about 3 or 4 milliseconds, if you know 1, 2, 3 pretty much about 4 milliseconds or 3 milliseconds for till here of the membrane potential, when the cell is stimulated, is called the action potential. So this change in membrane potential like this, when the cell is stimulated is called the action potential. So the action potential is going to occur at 1 point on the membrane surface sorry on the cell surface and the membrane of the cell.

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Some more details, I still have not told you about threshold value. The speed of sodium ion channel opening is faster than the speed of potassium ion channel opening by the very nature of the ion channels and the cap on the ion channels 1 channel has cap on both sides. There are

2 caps 1 cap versus 1 cap and so on so forth. I am not going to get into the details of those you can go and read about them.

Some details at least the sodium channel has 2 gates, one on the extracellular side and the other on the intracellular side. The outside gate opens when the depolarization begins, but the inside gate is open at the resting potential and starts closing slowly with increase in depolarization at about 40 millivolts the inside gate of the sodium ion sodium channel closes completely 40 millivolts is the top the highest value at about 40 millivolts the inside gate of the sodium channel closes completely.

The sodium channel closes at 40 millivolts due to the closure of its inside gate. But the potassium channel has only 1 outside gate it does not have an inside gate on the extracellular side, and that opens up and the strength of the stimulus is important. This is what I meant the threshold the strength of the stimulus is important, if it is not high enough to cause the movement of the membrane potential beyond a critical value of -55 millivolts.

Then no action potential ensues, what I mean is if the strength of the signal is not high enough to cause the membrane potential to move beyond a -55 millivolts then there is no membrane potential at all it just this one just, then there is no action potential at all this dynamics does not arise. So, the strength of the signal has to be such that it moves the membrane potential beyond -55.

If that happens, the action potential will automatically happen. So, let me repeat if the stimulus is not strong enough or high enough to cause the movement of the membrane potential beyond a critical value of let us say -55 millivolts then no action potential ensues and beyond the magnitude of the stimulus or beyond this magnitude of the stimulus, any value however high within of course, some broad limits causes the same magnitude of the action potential.

Thus, the action potential is an all or none phenomenon only if it cross -55 is there going to be an action potential? If it does not cross -55 millivolts, there is going to be no action potential. So, this is the action potential which happens at a point on the cell membrane, because of the movement of because of the dynamics of the movement of the sodium and potassium ions.

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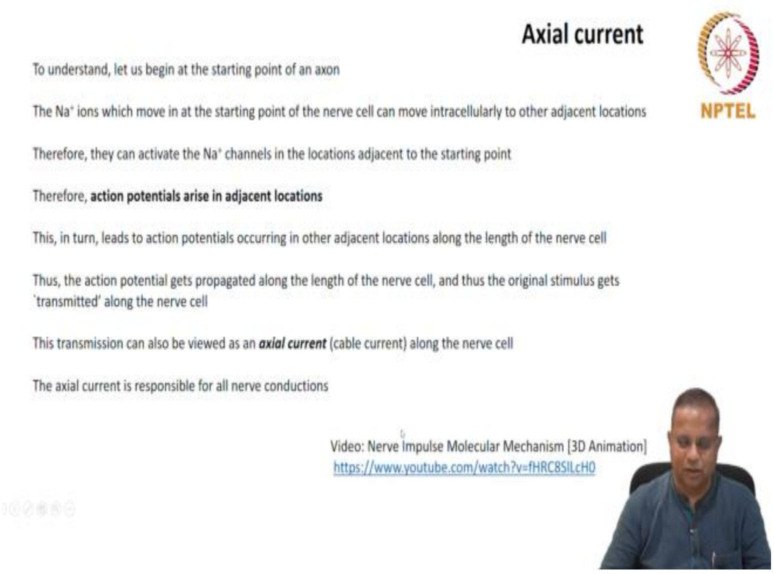

Now, what is axial current? To understand this, let us begin at the starting point of the axon, the sodium ions, which move in at the starting point of the nerve cell, can move intracellularly inside the cell to other adjacent locations, we are starting here therefore, we can consider the movement in this direction. So, the sodium ions which move in at the starting point of the nerve cell can move intracellularly to other adjacent locations in this cell.

Therefore, they can activate the sodium channels in the locations in adjacent to the starting point, so this is the starting point sodium channels come in now it can diffuse inside the cell when it diffuses inside the cell, it can start up another action potential just next to the initial action potential. Therefore, action potentials arise in adjacent location. This in turn leads to action potentials, occurring in other adjacent locations along the length of the nerve cell.

So, sodium comes in diffuses, sodium comes in potassium goes out and so on so forth action potential, then at the same time sodium is diffusing, then that is good enough to cause an action potential at a location just next to the original action potential. The because of the second action potential, there is still more sodium inside that is going to diffuse further, that is going to pass a third action potential this next to the second potential.

So, you are going to go through a series of action potentials along the length of this axon or the nerve cell. Thus, the action potential gets propagated along the length of the nerve cell, and thus the original stimulus gets transmitted across the nerve cell. That is typically what happens there is a series of action potential because of that, the stimulus is getting transferred across the nerve cell.

And this transmission can also be viewed as some axial current, a current in the axis direction axis of the neuron direction axon direction. So, the transmission can also be viewed as an axial current, this is also called the cable current across the nerve cell. So, the axial current is responsible for all nerve conductions either from the sensory organs to the brain or from the brain to the other parts of the body maybe muscles and so on so forth.

All those are possible only because of the series of action potentials which can be viewed as an axial current and all this happens in less than in the order of milliseconds or less so, that is amazing. Please see this video nerve impulse molecular mechanism 3D animation this is the link to it. Please look at this video this will explain this in a video form which would be, which would make things easier to internalize to understand and so on, and so forth.

(Video Starts: 15:12)

How does the pain you experience when you burn your hand? Result so quickly in an action by your muscles. Many animals respond to environmental stimuli using specialized cells called neurons. A stimulus is detected by sensory receptors, and the body responds through motor effectors. These cells working together allow you to respond very quickly to threats. When you touch something hot heat receptors have a sensory neuron.

Detect the stimuli and send the information of heat to an inter neuron in your central nervous system from there, a motor neuron sends a response from your central nervous system to the skeletal muscles in your arm, causing them to contract and pull your hand away. The fundamental process of neural transmission that underlies this action occurs in all neurons of the body.

Neurons transmit this information through changes in the electrical potential of the membrane by the movement of ions across the membrane. An electrochemical gradient governs the movement of these ions, resulting in an electrical impulse, the resting membrane potential in a neuron, when the cell is not firing an impulse is established by the unequal distribution of sodium ions outside of the cell and potassium ions inside the cell, making the outside of the cell more positively charged compared to the inside.

The electrochemical gradient is established and maintained by an enzyme called sodium potassium ATPase. When a neuron is stimulated, sodium ion channels open and sodium ions flow into the cell. This leads to a change in the electrical potential across the membrane called depolarization. The depolarizing electrical potential travels down the dendrites and over the cell body.

Multiple electrical potentials will combine at the axon hillock in a process called summation. If the depolarization is large enough an action potential is triggered action potentials are all or none electrical impulses that maintain their amplitude and strength down the length of the axon. The action potential travels down the axon when the depolarization of an area of membrane causes adjacent voltage gated sodium ion channels to open.

The influx of sodium ions results in membrane depolarization along the membrane. After a short delay potassium ion channels open and potassium ions flow out repolarizing the membrane for the neuron to fire again, the resting membrane potential needs to be reestablished sodium potassium ATPase is used to move sodium and potassium ions against their concentration gradients reestablishing the resting membrane potential.

As the action potential moves down the axon, ions are diffusing only a short distance, allowing the signal to move quickly. At the axon terminal, the electrical impulse passes to another cell at a cellular connection called a synapse. The space between the presynaptic neuron and a postsynaptic cell is called the synaptic cleft. The presynaptic neuron contains signal molecules called neurotransmitters that are packaged inside vesicles.

When an action potential reaches the end of a neuron neurotransmitters are released by exocytosis from the neuron into the synaptic cleft neurotransmitters bind to the adjacent cell at receptor sites attached to ion channels. The channels open, allowing the movement of ions into or out of the effector cell, which alters its membrane potential, thereby transmitting the signal from the neuron to the effector cell. Because nerve impulses move very rapidly down the axon of a neuron, and move from cell to cell across synapses, and you react quickly to a stimulus, like burning your finger.

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I think that is what I have for this class. Let us stop the class here we looked at action potential at a point and a series of action potentials along the length of the axon leading to an axial current cable current that is responsible for the conduction of impulses from the sense organs to the brain or from the conduction of the instructions from the brain to the other parts of the body. See you in the next class, bye.