52: THE ACTION POTENTIAL and THE SYNAPSE

Neurons are the focal point of both the PNS and the CNS since they are the ones that carry the electrical impulses that go back and forth between the brain and the body. There are several basic mechanisms in the neuron's axon that work together to accomplish the task of transmitting an impulse: the sodium-potassium pump, ion channels, and neurotransmitters in the synapse.

All along the axon's plasma membrane there are many sodium-potassium pumps. These pumps use one ATP every time they pump. One complete pumping action pumps 3 Na$^+$ ions outside the membrane and brings 2 K$^+$ ions inside. The net result is one more positive ion outside than inside. This means that eventually there will be more positive charges outside than inside. Another way of looking at it is that the inside is now more negative than the outside. Therefore, you often see the inside of the axon labeled with a negative sign and the outside with a positive. This is confusing to students when they see that both ions being pumped having positive charges. The negative charge on the inside is in comparison to the outside, which has even more positive ions. What the ion pumps have done is set up a gradient. Remember, atoms want to be equally distributed everywhere. Now that we have most (but probably not all) the Na$^+$ ions on one side and the K$^+$ ions on the other, what will happen if we open ion channels that will let them travel across the membrane? Yes, the Na$^+$ ions will rush in through ***sodium gates***, and the K$^+$ ions will rush out via ***potassium gates***. This rushing in and out is called the ***action potential***. This active rushing of ions IS the electrical signal we keep talking about neurons carrying.

After the Na$^+$ ions have all rushed across the membrane, we now have the reverse situation—we have the inside of the axon being positive and the outside being negative. Once the K$^+$ gates open and the K$^+$ ions rush across, we no longer have a positive inside, but we are not quite back to where we started. To be able to do another action potential, the axon must restore the original amount of negativity inside. So the sodium-potassium pumps go to work and start pumping Na$^{+\,i}$ ions out and K$^+$ ions in. Once everything is back to where we started, this is called the ***resting potential***. The resting potential is when the axon is all set and ready to go for another action potential. The word "potential" is appropriate here because in this state, the axon has the potential to carry a signal, but has not done so yet. (For those of you who like details, in this resting state, a very precise voltmeter will register the inside of the axon at about -70 millivolts, mV. After the action potential has fired, the outside will then register at about +40 mV.)

The axon we are showing here doesn't have any Schwann cells around it. Something very interesting happens under the Schwann cells. The action potential can kind of "jump" through the insulated Schwann areas, without having to do all the rushing in and out of ions. The rushing of ions occurs only at the nodes of Ranvier, where there are gaps between the Schwann cells. Since it seems that the action potential can "jump" from node to node, the Latin word for jumping, "saltare," was used to form a word for this neuron action: ***saltatory***. Since we also use the word "conduct" for electricity, the complete term for this jumping of the action potential from node to node is ***saltatory conduction***. (For a visual demonstration of this, see the video listed on the lesson page.)

When the action potential has gone all the way down the axon it ends in the terminal knobs. This electrical impulse, the action potential, cannot jump the gap that exists between the terminal knobs and the dendrites of the next neuron. (This area where knobs meet the next neuron is called the ***synapse***. The actual empty space between is called the ***synaptic cleft***.) Instead, the action potential causes calcium ions to rush into the knobs and thereby causing the waiting vesicles to fuse with the membrane and spill their contents into the gap. We saw this use of calcium in module 1 when we studied fertilization of the ovum. Calcium ions cause vesicles to do exocytosis. The neurotransmitter chemicals in the vesicles can be of various types. (For more information on neurotransmitters, see the additional info on the lesson page.) Each transmitter will have a matching receptor on the sides of an ion channel embedded in that dendritic plasma membrane. (NOTE: Sometimes axon terminals touch the soma, too, not just dendrites.)

Some neurotransmitters fit into receptors on Na$^+$ channels. Others stick to receptors on K$^+$ receptors. If two neurotransmitter molecules stick to a Na$^+$ channel it will open to allow an influx of Na$^+$ ions. Since this is what happens in an action potential, the result will be that this next neuron will be encouraged to start a new action potential. (Mulitple Na$^+$ gates have to open to have a new action potential start. One is probably not enough.) If neurotransmitters stick to a K$^+$ channel, then K$^+$ ions will flow in and... nothing will happen because having a lot of K+ on the inside is part of the resting potential, not the action potential. This action of K$^+$ ions is called an ***inhibitory*** response because it discourages, or inhibits, the next neuron from beginning a signal. The action of the Na$^+$ ions is called an ***excitatory*** response because it encourages, or excites, the next neuron into action. If enough Na$^+$ ions flow into this next neuron, an action potential will begin in the hillock and move down into the axon. One role of the soma is to collect all the various inputs coming from all these ion channels and sort of "sum them up" and then generate—or not generate—a new signal.

This process is, of course, more complicated than described here. For exaxmple, there are a number of neurotransmitter chemicals that have different actions in the synapses. Also, there are ***enzymes*** waiting in and around the synapses that capture and either destroy or recycle the neurotransmitters. The neurotransmitters have to be disposed of immediately so they don't keep acting after the signal is finished. They, also, need to be reset every time. And all of this (everything on this page) happens in a fraction of a second!

NOTE: You will need to use the cut-off strip at the bottom of the info page for lesson 11.