Lecture 12 - The Nervous System: Neurons

Nervous and Endocrine systems

The nervous and endocrine systems work together to coordinate the actions of all other systems of the body to produce behavior and maintain homeostasis.

The ***endocrine system*** produces chemical messengers that are transported through the circulatory system. It requires seconds, minutes or hours.

The ***nervous system*** is more rapid, requiring only thousandths of a second.

Embryonic development

The nervous system originates from ectodermal tissue during embryonic development.

Neurons

Neurons are cells that transfer stimuli to other cells.

Structure of Neurons

Cell Body- contains nucleus and organelles

Dendrites- receive input

Axon -conducts impulses away from the cell body

Axon Terminals - ***Neurotransmitters*** are manufactured in the cell body but released from axon terminals. The neurotransmitters stimulate other neurons.

Nerves and Ganglia

Axons and dendrites are bundled with axons or dendrites from other neurons to form ***nerves*.** Clusters of neuron cell bodies are called ***ganglia*.**

Central and Peripheral Nervous Systems

The nervous system can be divided into the ***central nervous system*** (CNS) which includes the brain and spinal cord and the ***peripheral nervous system*** (PNS) which includes everything else.

Classes of Neurons

Sensory neurons (afferent neurons) conduct sensory information toward the CNS. Sensory neurons have a long dendrite and a short axon.

The brain and spinal cord contain ***interneurons***. These receive information and if they are sufficiently stimulated, they stimulate other neurons.

Motor neurons (efferent neurons) send information from interneurons to muscle or gland cells (effectors).

Neuroglia

Neuroglia (also called glia) are cells within the nervous system that are not neurons.

There are different kinds of neuroglia, and they provide neurons with insulation, physical support, metabolic assistance, and protection.

Myelination

Neuroglia that insulate neurons do so by wrapping around the long fibers (either axons or dendrites).

The insulation properties come from ***myelin*** contained within the cells.

The layer of insulation is referred to as a ***myelin sheath***.

If these insulating cells are located in the peripheral nervous system, they are called ***Schwann cell***s.

Terms that are used to describe structures found in both the CNS and PNS

You will be responsible for learning the terms listed under PNS in the table below. Be aware that these structures have a different name if they are located within the CNS.

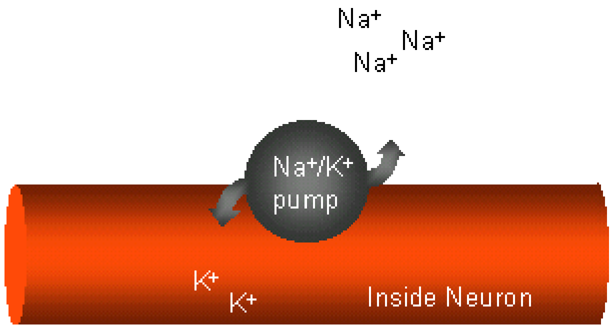
Peripheral Nervous System (PNS)	**Central Nervous System (CNS)**
nerves	tracts
ganglia	nuclei
Schwann cells	oligodendrocytes

Membrane Potentials

Membrane potentials were first demonstrated using the giant axons of a squid (1mm dia). An oscilloscope measured the electrical difference by placing one electrode outside the neuron and the other inside the neuron.

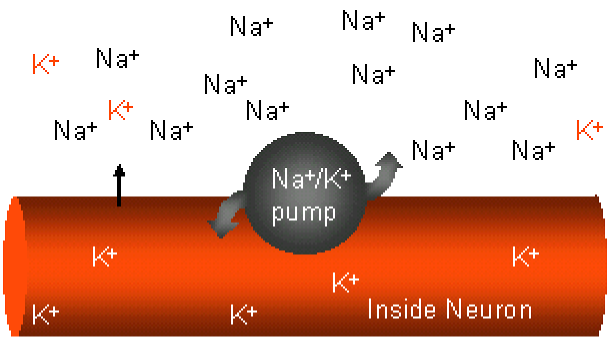
Resting potential

The sodium-potassium pump pumps out 3 sodium ions (Na^+) for each 2 potassium ions (K^+) pumped into the neuron. This results in more potassium ions inside and more sodium ions on the outside.

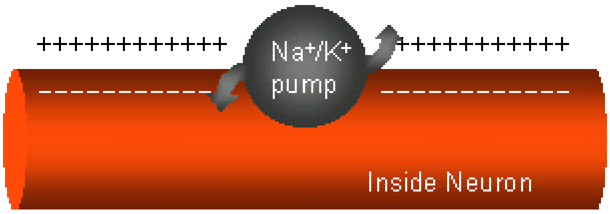


Unequal pumping (3 Na^+ out to 2K^+ in) results in more positive charge on the outside compared to the inside. The membrane is ***polarized***.

Some K^+ channels are open so K^+ tends to leak out. This adds to negative charge inside. The charge difference prevents further leakage.



The charge difference is measured in millivolts.



Gated Channels

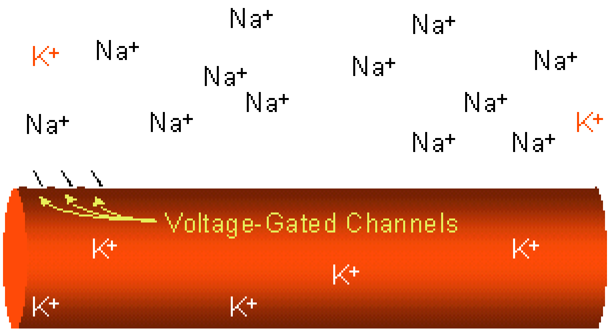
The membrane contains channels that open or close depending on the electrical state of the membrane.

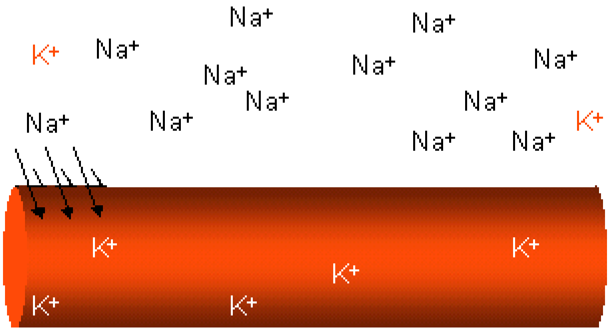
For example, sodium gates open and then close slowly when the membrane is depolarized but remain closed when it is polarized. When the sodium channel is open, sodium can pass through.

In a resting (polarized) neuron, sodium gates are closed. A slight depolarization will not cause the gates to open but if the depolarization is greater than a ***threshold*** value, the gates will open.

Propagation of an *Action Potential*

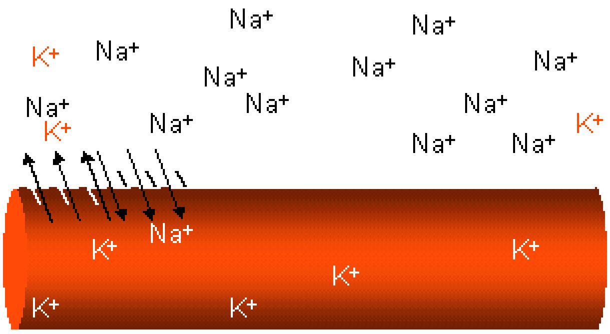
Stimulation of the neuron causes Na^+ gates open allowing Na^+ to rush in. This results in depolarization of the membrane in the area where the stimulation occurred. Depolarization of an area of membrane stimulates more Na^+ gates in adjacent areas to open, thus spreading the depolarization.





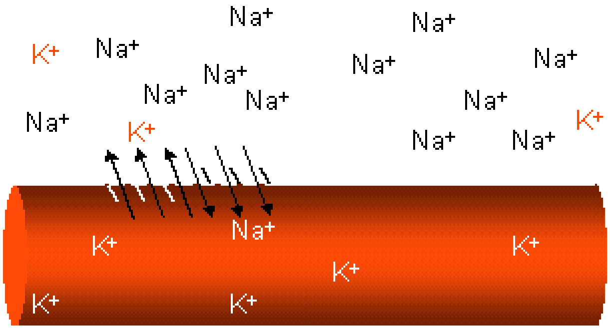
Immediately after depolarization, Na^+ channels close and K^+ channels open causing K^+ to flow out. This process returns positive charge to the area just outside the membrane, thus restoring the resting polarity.

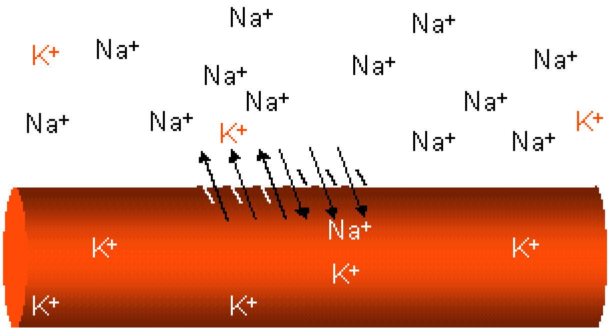
The depolarization and repolarization events described above are called an ***action potential***. During an action potential, the depolarization spreads all the way to the action terminal where the axon joins another cell. The action potential is "***all or nothing***." The intensity of an action potential ***does not diminish*** as it spreads along an axon.



The sodium-potassium pump operates continuously to restore the ionic gradient.

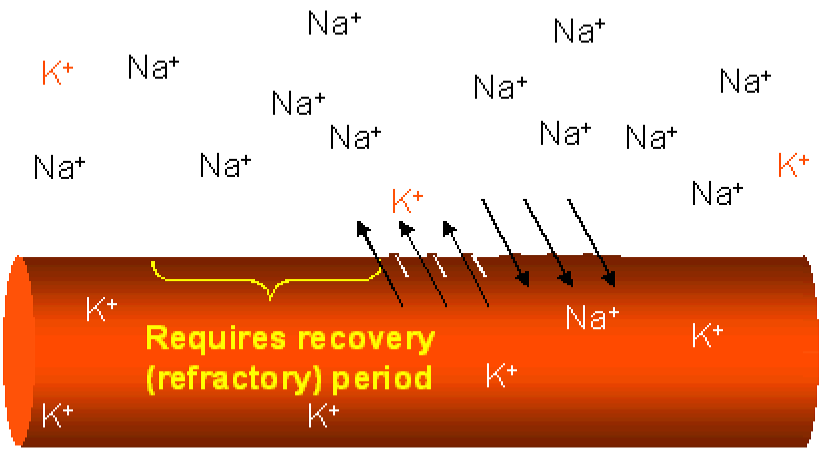
In the diagram below, depolarization caused by the influx of sodium can be seen spreading to the right.



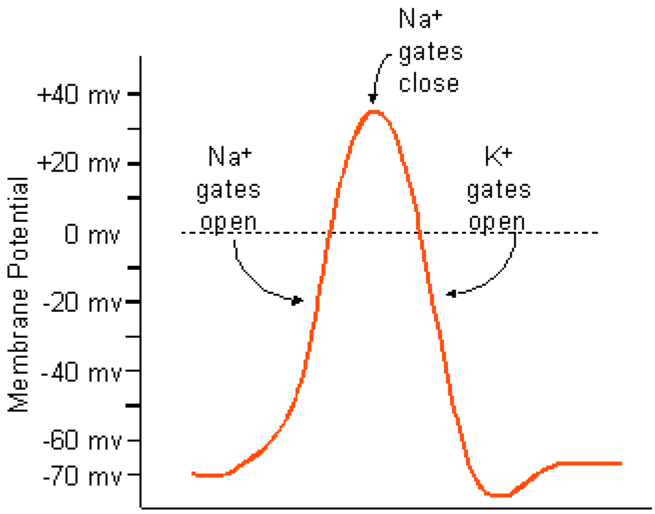


Refractory Period

The action potential cannot reverse its direction because membrane that has just been depolarized cannot be depolarized again until after a brief recovery (called refractory) period. During this period, the membrane is insensitive to stimulation.



The diagram below shows the voltage difference across the membrane as an action potential proceeds. Initially, the inside of the membrane is approximately -65 or -70 millivolts compared to the outside. When sodium gates open and sodium ions rush in, the inside temporarily becomes positively charged. Potassium gates then open and potassium ions rush out, restoring the negative charge.



Most action potentials last a few milliseconds and there may be as many as several hundred action potentials per second.

Saltatory Conduction

The gap between the Schwann cells in the myelin sheath is called a ***node of Ranvier***. Gated channels in are concentrated in this area and not in the area under the myelin sheath.

The action potentials jump from node to node (saltatory conduction). This increases the speed at which a neuron can conduct a signal.

Sodium-potassium pumps require a substantial amount of energy to pump the ions, so the presence of insulation reduces the amount of membrane that requires active sodium-potassium pumps, thus saving energy.

The **diameter of the neuron** also is related to the speed of conduction. Larger diameter axons conduct faster. Example: squid axons are 500 microns dia.

Synaptic Potentials

Synapses

A ***synapse*** is a junction between two neurons. It is separated by a ***synaptic cleft***.

The axon terminal of the ***presynaptic cell*** contains numerous vesicles with ***neurotransmitter*** stored within them.

The action potential causes calcium channels to open in the plasma membrane of the presynaptic cell. The calcium ions (Ca^{++}) diffuse into the neuron and activate enzymes, which in turn, promote fusion of the neurotransmitter vesicles with the plasma membrane. This process releases neurotransmitter into the synaptic cleft.

Neurotransmitter molecules diffuse across the cleft and stimulate the ***postsynaptic cell***, causing Na^{+} channels to open. Depolarization of the postsynaptic cell results.

The depolarization of the postsynaptic cell is referred to as a ***synaptic potential***.

The magnitude of a synaptic potential depends on:

the amount of neurotransmitter

the electrical state of the postsynaptic cell. If it is already partially depolarized, an action potential can be produced with less stimulation by neurotransmitters. If it is hyperpolarized, it will require more stimulation than normal to produce an action potential.

After the neurotransmitter is released into the synaptic cleft, it must be quickly removed or inactivated to prevent the postsynaptic cell from being continuously stimulated and to allow another synaptic potential.

In some cases there may be enzymes present in the synaptic cleft that break down the neurotransmitter immediately. For example, acetylcholinesterase breaks down the neurotransmitter acetylcholine.

In other cases, the axon terminal may reabsorb neurotransmitter and repackage it into vesicles for reuse.

Excitatory and inhibitory postsynaptic potentials

A synaptic potential can be ***excitatory*** (they depolarize) or ***inhibitory*** (they polarize). Some neurotransmitters depolarize and others polarize.

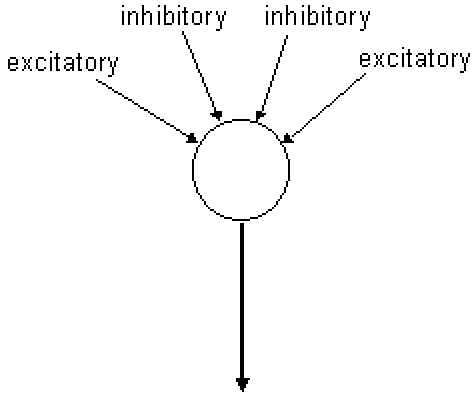
There are more than 50 different neurotransmitters.

In the brain and spinal cord, hundreds of excitatory potentials may be needed before a postsynaptic cell responds with an action potential.

Synaptic integration

Synaptic integration is the combining of excitatory and inhibitory signals acting on adjacent membrane regions of a neuron.

In order for an action potential to occur, the sum of excitatory and inhibitory postsynaptic potentials must be greater than a threshold value.



Synapses closest to the trigger zone will have the greatest influence.

Temporal and Spatial Summation

The effect of more than one synaptic potential arriving at a neuron is additive if the time span between the stimuli is short. This is called ***temporal summation***. The summation effect is greatest when the time interval between stimuli is very short.

The effect of more than one synaptic potential arriving at a given region of a neuron can also be additive. This is called ***spatial summation***. The summing effect is greater if multiple stimuli all arrive at nearby areas of a membrane. The effect is less if they stimulate separate, distant areas.