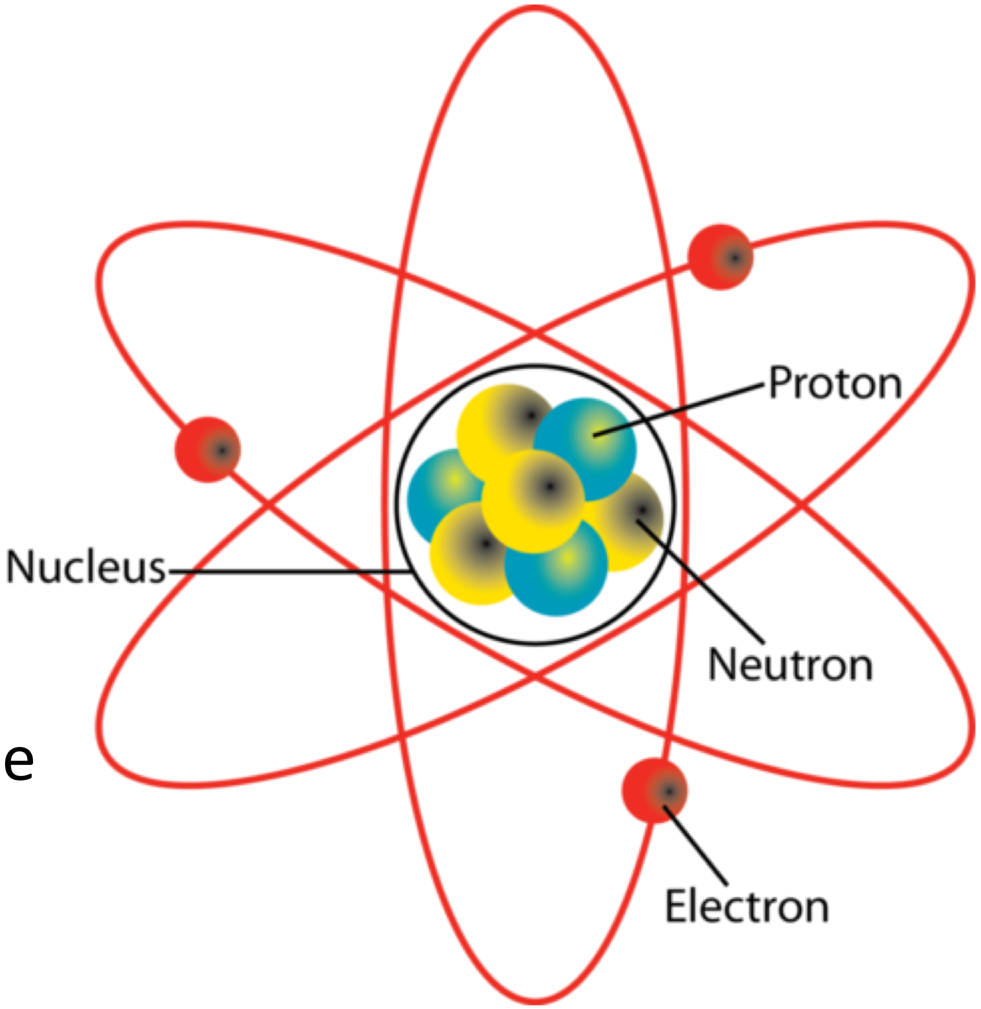
Action potential

Additional Materials to Lecture 2

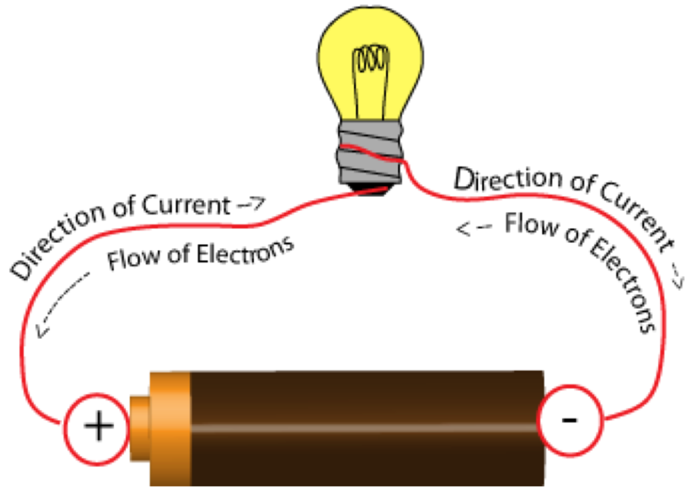
Reminder: electricity

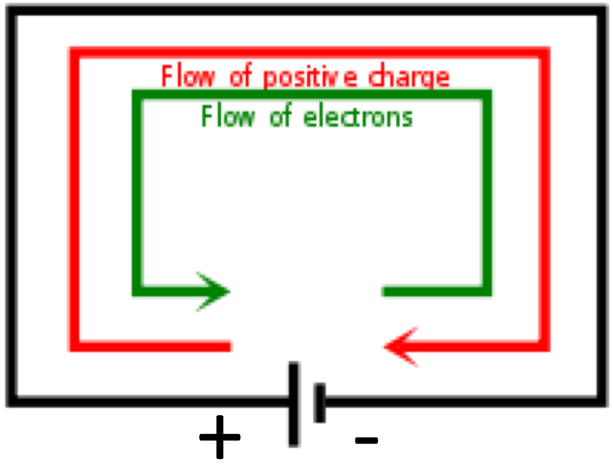
- **The electron**
- The basic concept of electricity is a sub-atomic particle called an electron.
- The electron is negatively charged, and orbits the nucleus of the atom at about the speed of light. It is held in place by the electro-weak force, which is in turn caused by charge attraction between the light electron and the heavier protons that with neutrons make up the nucleus of the atom.
- It is thought that electricity happens when electrons break free of the atom.



Reminder: electricity

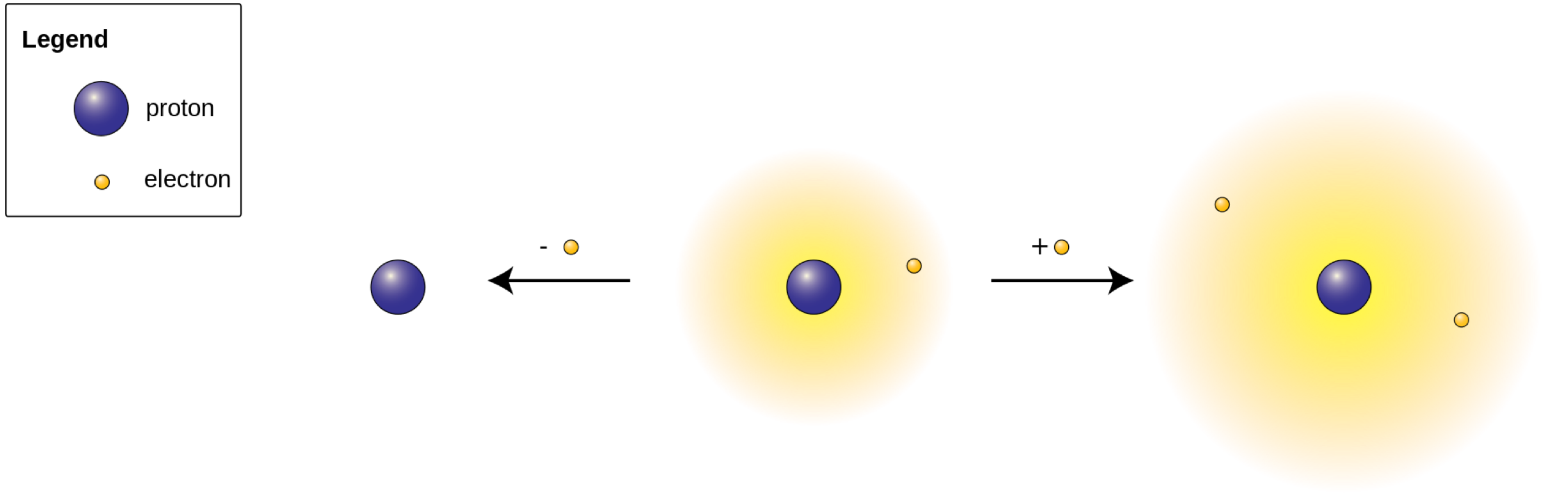
- **Atomic Charge and Electricity Flow**
- Electricity flows in the direction of lowest potential, in other words, we can say that the electrons flow from the negative charge to the positive charge
- Since electrons can wander away from their original atoms, and get picked up by other atoms, the atoms that have more electrons than normal are considered to be negatively charged, and the atoms that have fewer electrons than normal are considered to be positively charged.





Reminder: electricity

- **Ions:** We call an atom that is carrying a charge, whether it is negative or positive an ion.



Hydrogen atom (center) contains a single proton and a single electron.

Removal of the electron gives a cation (left), whereas addition of an electron gives an anion (right).

The hydrogen anion, with its loosely held two-electron cloud, has a larger radius than the neutral atom, which in turn is much larger than the bare proton of the cation.

No. of protons	1	1	1
No. of electrons	0	1	2
Charge	+1	0	-1
Notation	H^+	H	H^-
Classification	cation	neutral (not an ion)	anion

Reminder: electricity

- **Ions**
- In chemical systems based on water, many ions are created by the nature of water which levers apart many common chemicals into their component ions.
- If the external shell of the atom, called the valence shell, has an odd number of electrons, the ion usually has a negative charge, and if it has an even number of electrons the ion usually has a positive charge.
- It is possible in some cases to strip off two valence electrons, in which case you end up with a double positively charged ion.

potassium ions (K+)
chloride ions (Cl-)
sodium ions (Na+)

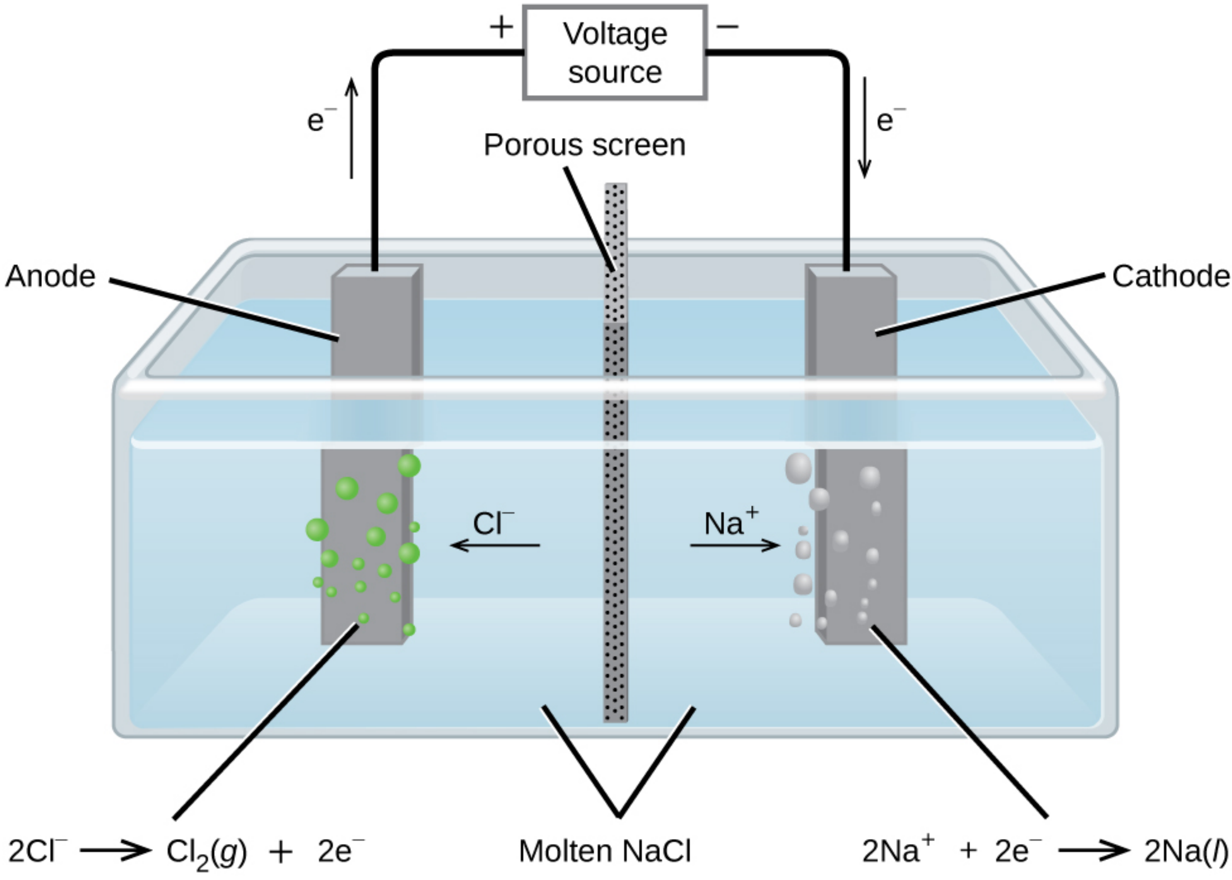
Reminder: electricity

Electric Charge

- Electrical Charge is measured in Coulombs:
- 1 Coulomb = 6.25×10^{18} electrons.
- The charge of a single electron is $1.6 * 10^{-19}$ Coulombs.

Electric Current

- 1 A is the amount of current flowing when 1 Coulomb passes a particular point in one second.
- In fluids, both the positive and negative ions as well as electrons move as current



Reminder: electricity

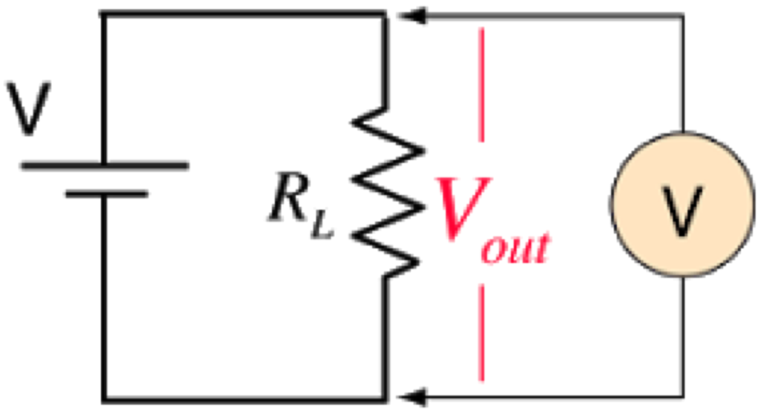
Voltage, is the difference in electric potential between two points.

The difference in electric potential between two points (voltage) in a static electric field is defined as the work needed per unit of charge to move a test charge between the two points.

In SI units, work per unit charge is expressed as joules per coulomb, where 1 volt = 1 joule (of work) per 1 coulomb (of charge).

Voltage or electric potential difference is denoted symbolically by ΔV, but more often simply as V.

A voltmeter can be used to measure the voltage (or potential difference) between two points in a system; often a common reference potential such as the ground of the system is used as one of the points.

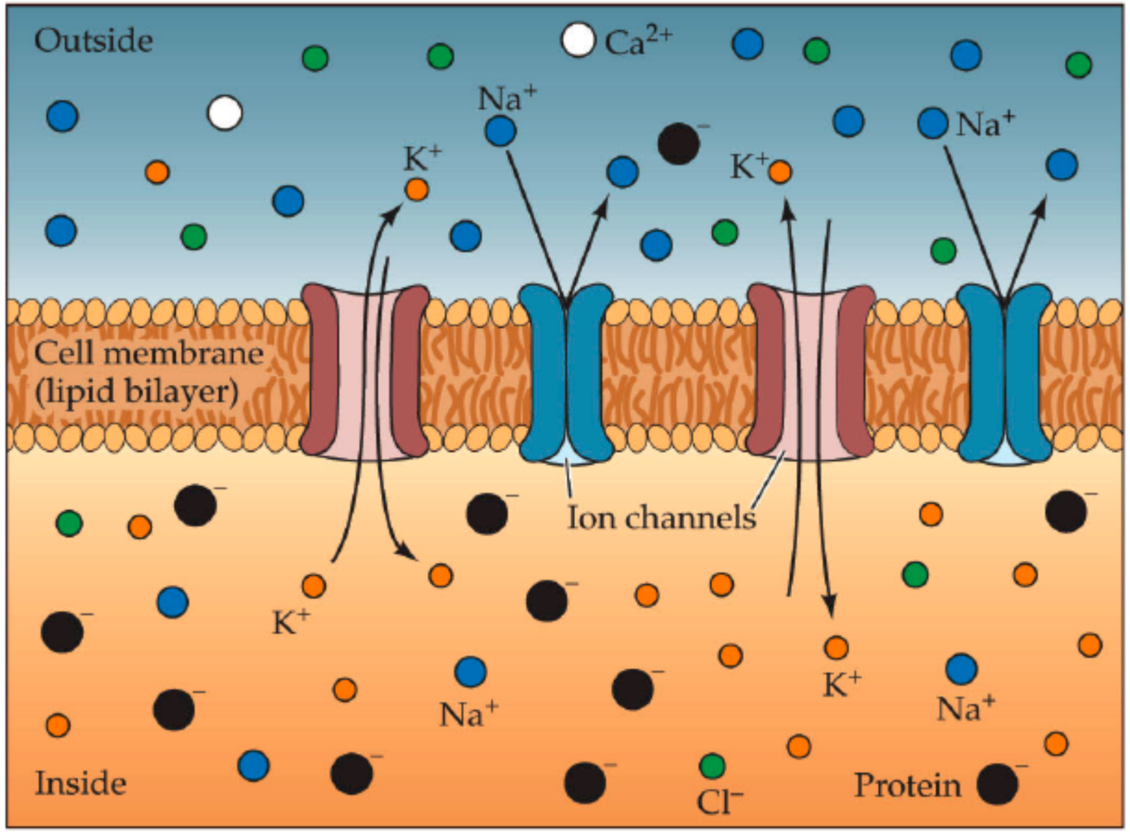


A voltmeter is connected in parallel to measure the voltage change across a circuit element.

Resting membrane potential of neuron

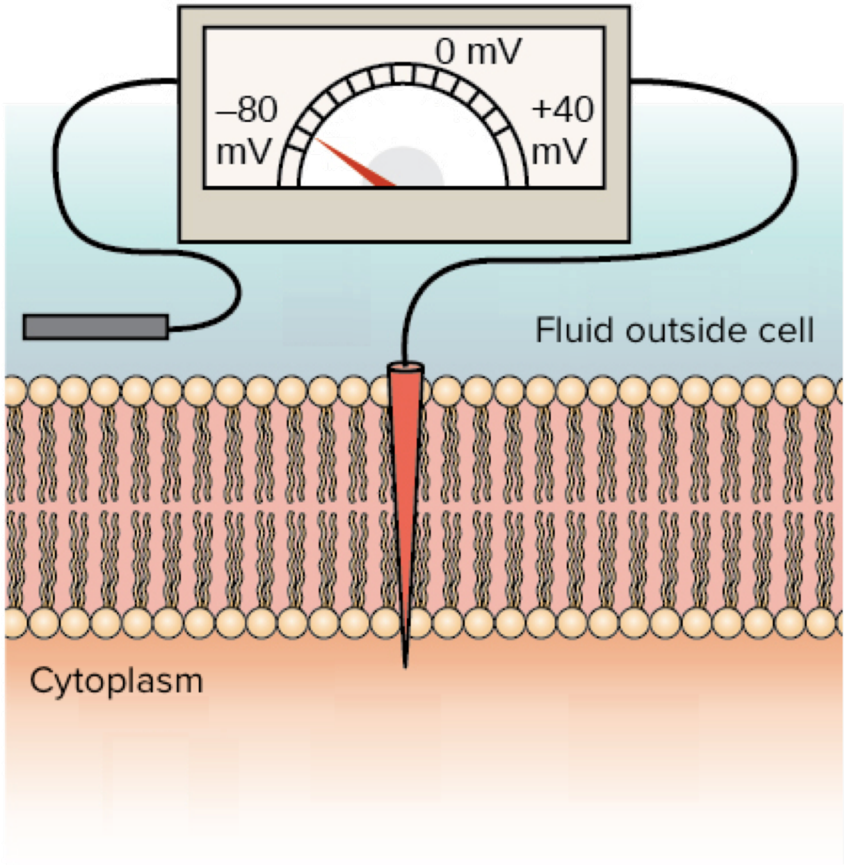
- When a neuron is not sending a signal, it is ***at rest***.
- When a neuron is at rest, the inside of the neuron is negative relative to the outside.
- Although the concentrations of the different ions attempt to balance out on both sides of the membrane, they cannot because the cell membrane allows only some ions to pass through channels (ion channels).
- At rest, potassium ions (K+) can cross through the membrane easily. Also at rest, chloride ions (Cl-) and sodium ions (Na+) have a more difficult time crossing. The negatively charged protein molecules (P-) inside the neuron cannot cross the membrane.

	Na^+	K^+	Cl^-	Ca^{2+}	Proteins
Outside cell	many	few	many	many	few
Inside cell	few	many	few	few	many



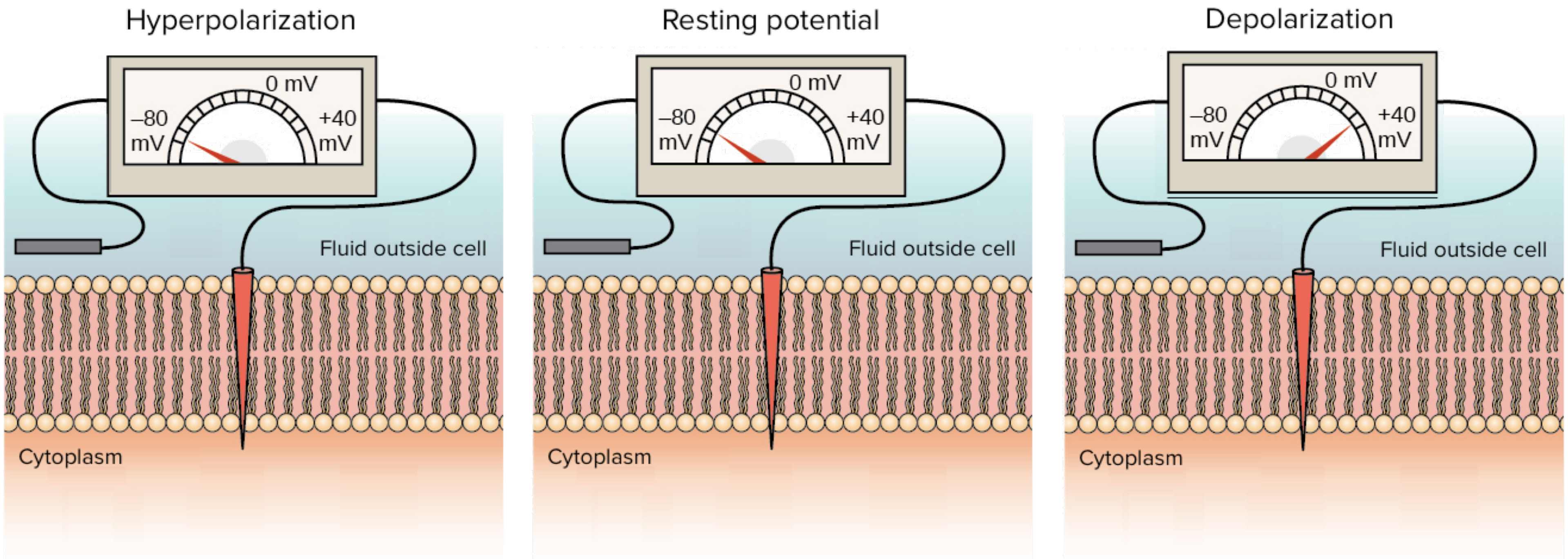
Resting membrane potential of neuron

- There is a pump that uses energy to move three sodium ions out of the neuron for every two potassium ions it puts in.
- Finally, when all these forces balance out, and the difference in the voltage between the inside and outside of the neuron is measured, you have the resting potential. The resting membrane potential of a neuron is about **-30 mV** to **-90 mV**.
- At rest, there are relatively more sodium ions outside the neuron and more potassium ions inside that neuron.



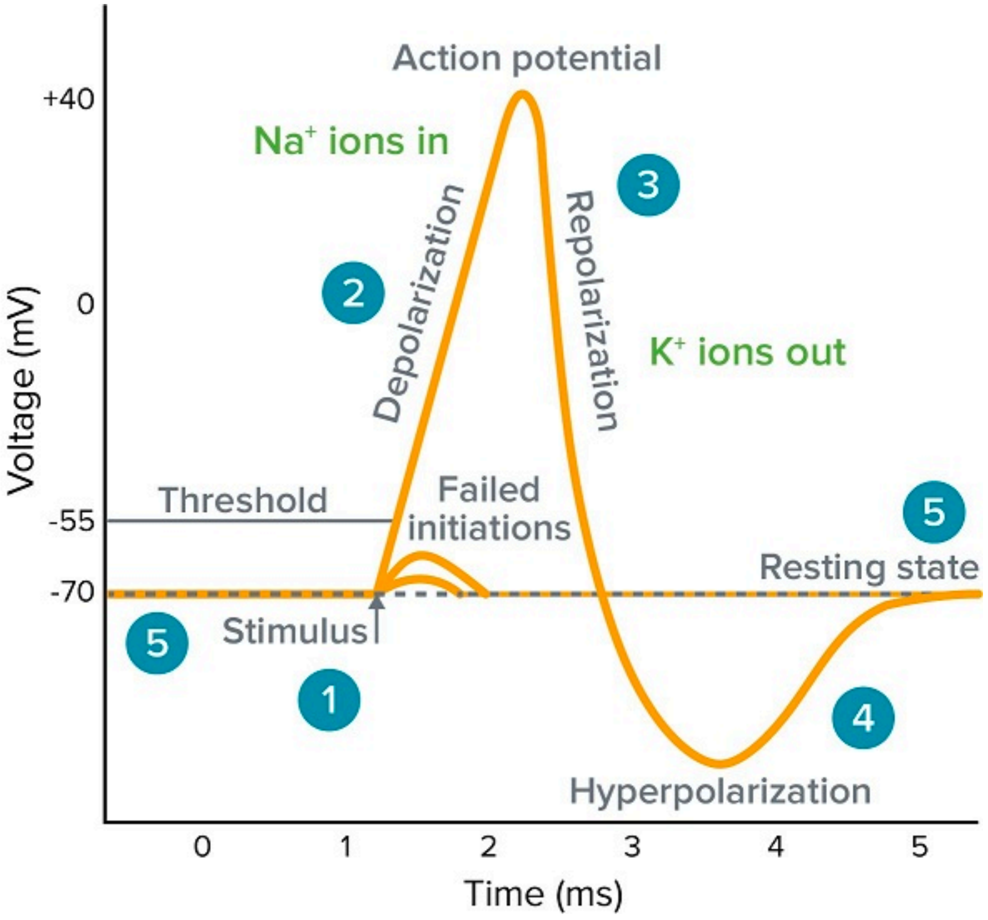
Membrane polarization

- Because there is a potential difference across the cell membrane, the membrane is said to be **polarized**.
- If the membrane potential becomes more positive than it is at the resting potential, the membrane is said to be **depolarized**.
- If the membrane potential becomes more negative than it is at the resting potential, the membrane is said to be **hyperpolarized**



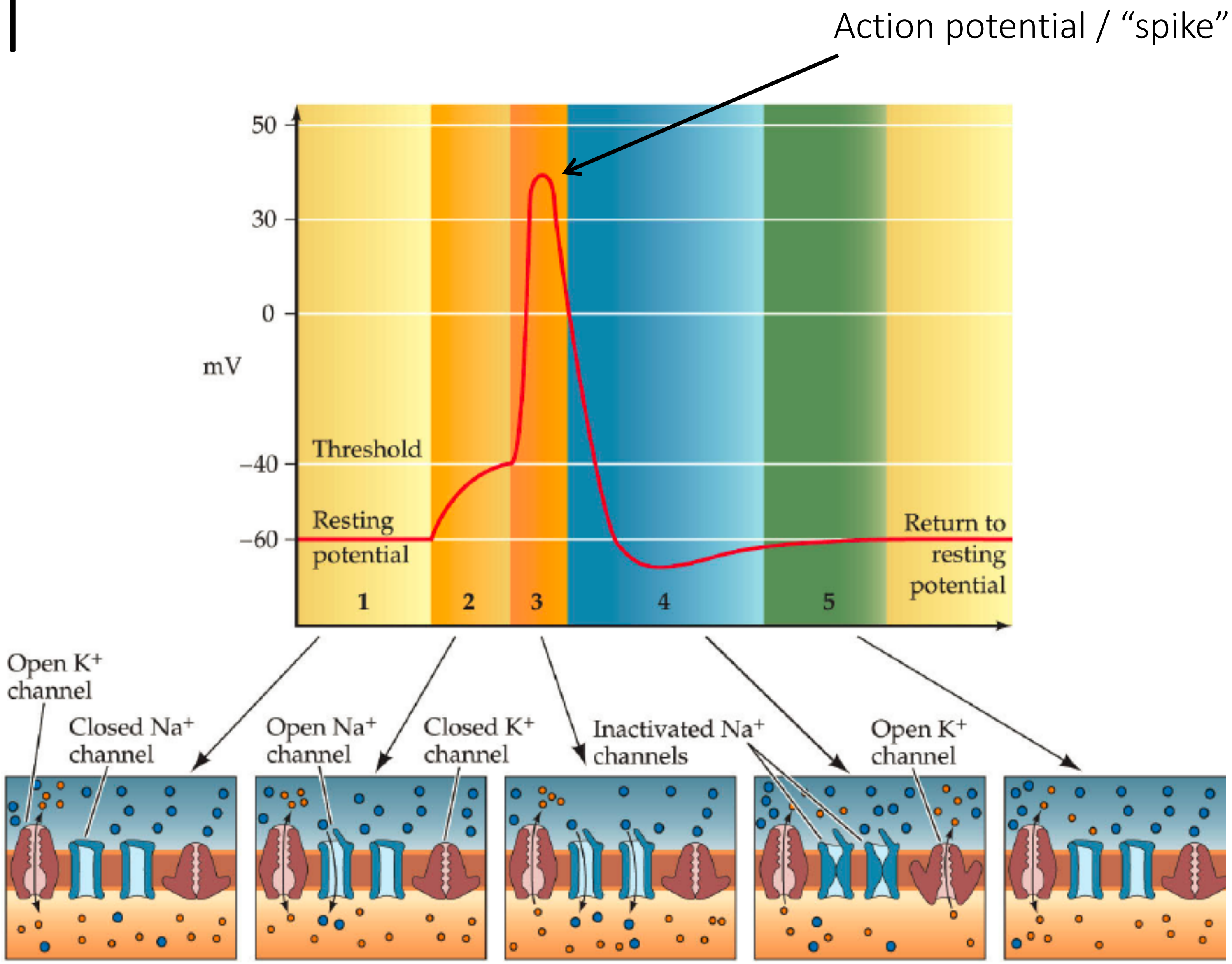
Action potential

- An adjacent presynaptic neuron sends neurotransmitters that bind to the dendrites of the neuron
- If these neurotransmitters are excitatory, then gated ion channels will open up to permit ambient sodium ions (Na+) into the cell (making the potential more positive).
- If these neurotransmitters are inhibitory, then gated ion channels will open up to permit internal potassium ions (K+) out of the cell (making the potential more negative)



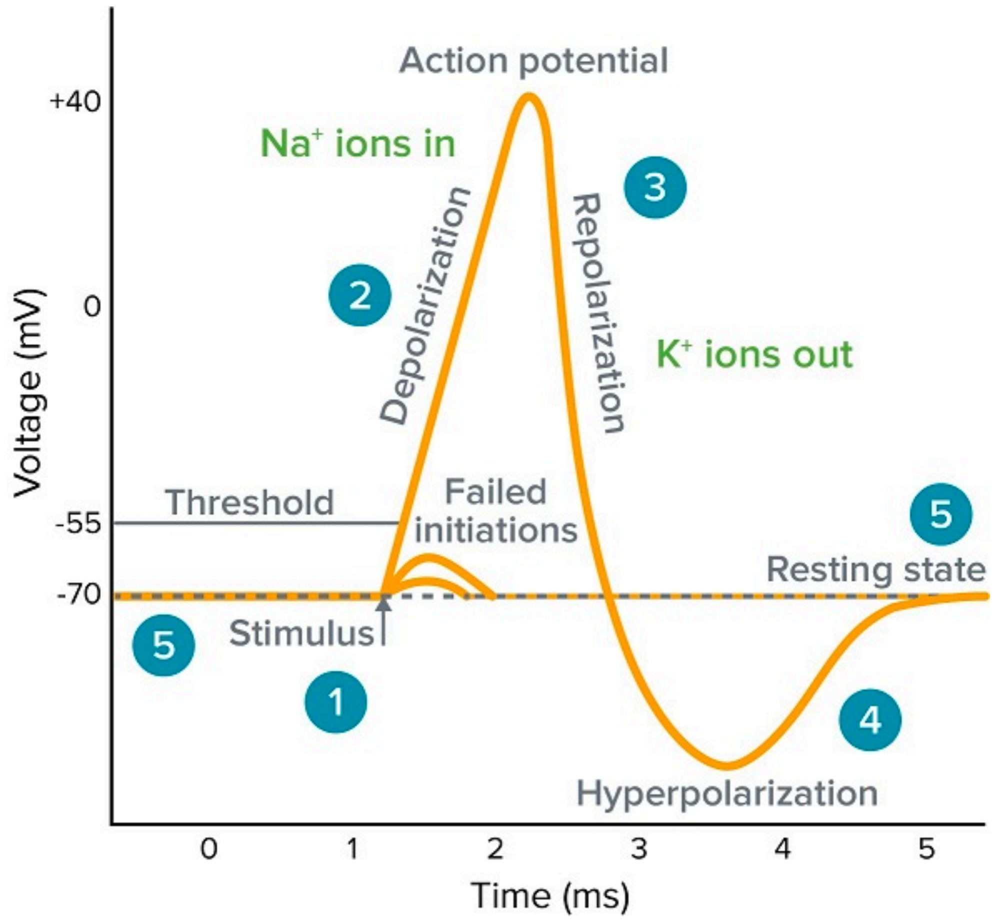
Action potential

It takes longer for potassium channels to open. When they do open, potassium rushes out of the cell, reversing the depolarization.
Also at about this time, sodium channels start to close. This causes the action potential to go back toward rest potential (a repolarization)



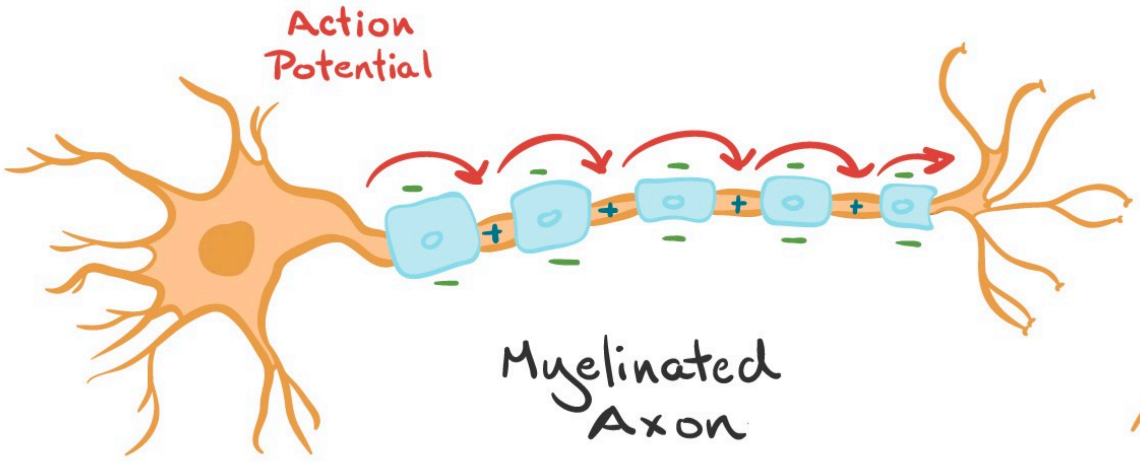
Action potential

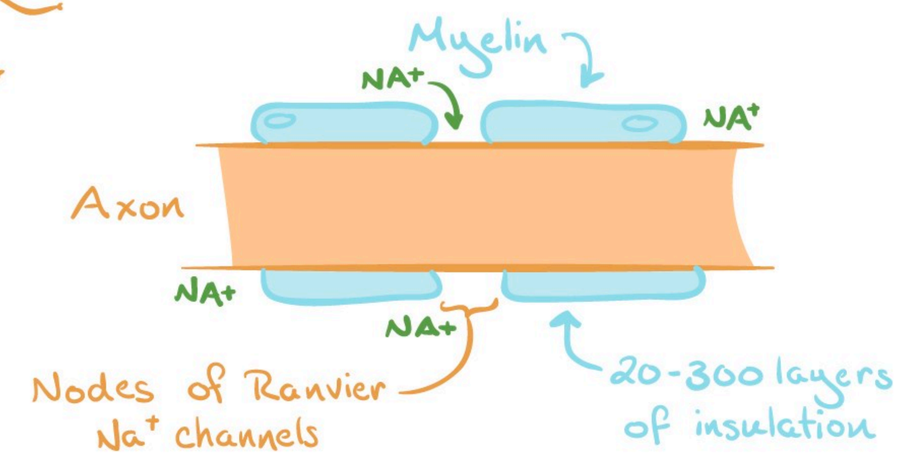
- For an action potential to be generated, enough excitatory neurotransmitters must be present to raise the charge above a certain threshold level. Once this level is exceeded, an **all-or-none electrical potential** is sent down the length of the axon
- After depolarizing, the neuron's ion pumps begin working to reestablish the resting potential. While the neuron is doing so, it enters a refractory period during which no further action potentials can be generated. (hyperpolarization)
- Once the potential has been restored, the neuron is ready for a new stimulus



Velocity of spike propagation

- After the spike is generated, it is propagated along the axon
- **Fast (the so-called saltatory) spread**

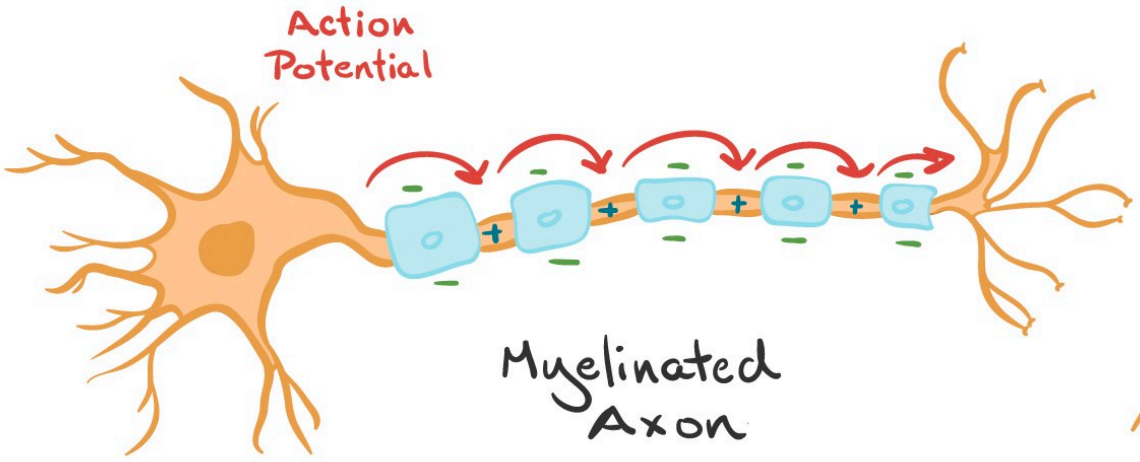


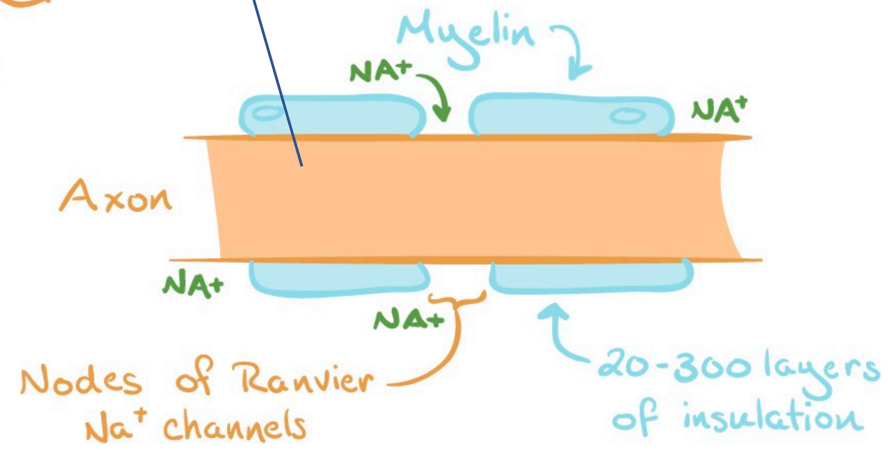


Velocity of spike propagation

- After the spike is generated, it is propagated along the axon
- **Saltatory spread**

A myelin sheath decreases the capacitance of the neuron in the area it covers. So, the neurons get a lot of agitated negative ions which need to be balanced out.

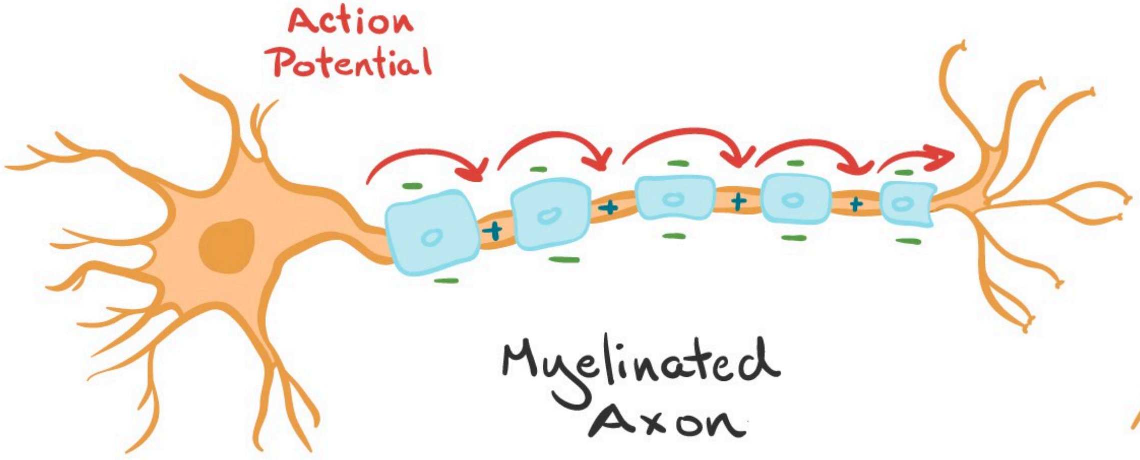


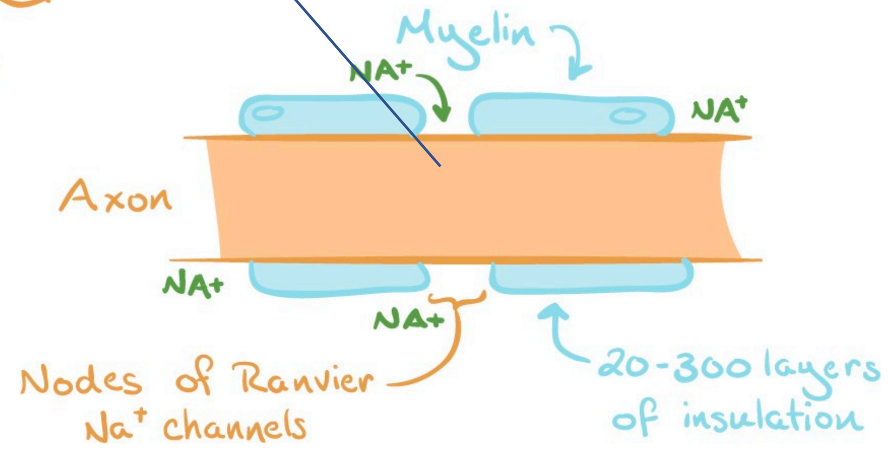


Velocity of spike propagation

- After the spike is generated, it is propagated along the axon
- **Saltatory spread**

They spread out to the end of the membrane, in a hope to find the positive ions. The positive ions then approach these to calm them down.

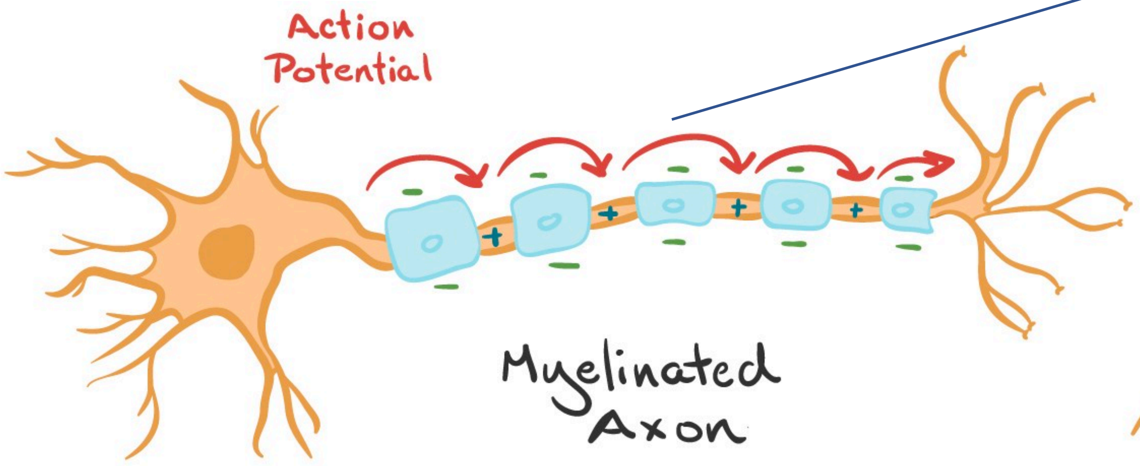


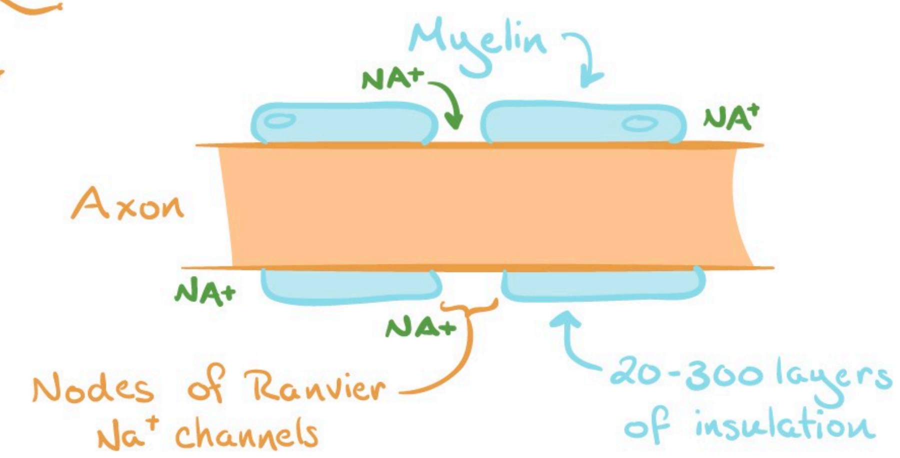


Velocity of spike propagation

- After the spike is generated, it is propagated along the axon
- **Saltatory spread**

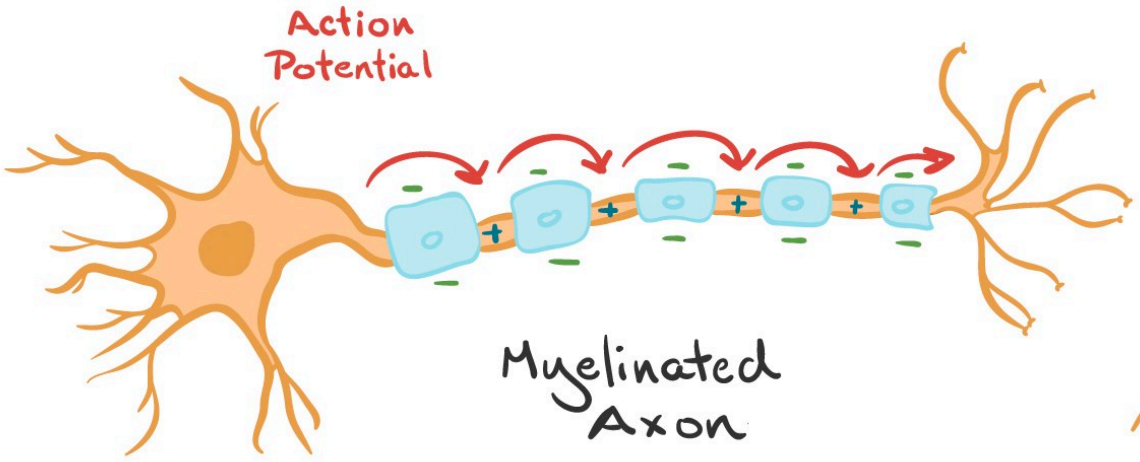
This leads to the formation of thin layers of positive ions on the outside and the negative ions on the inside.



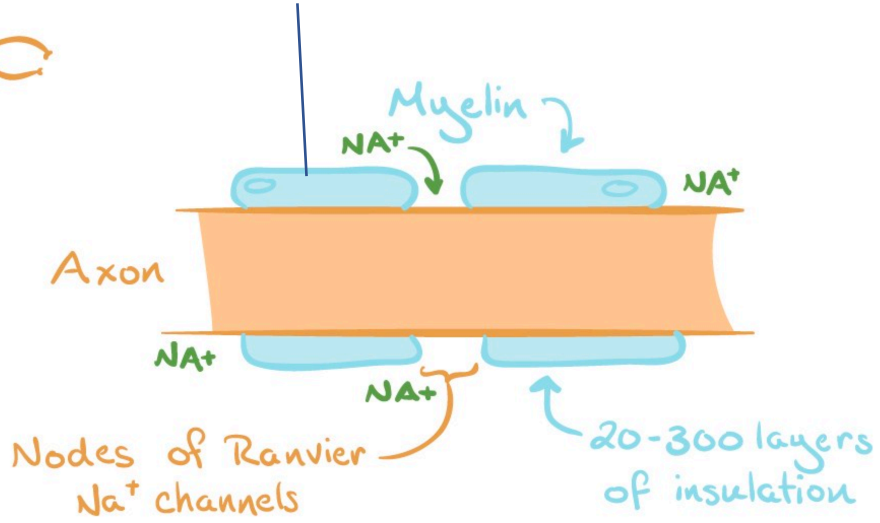


Velocity of spike propagation

- After the spike is generated, it is propagated along the axon
- **Saltatory spread**

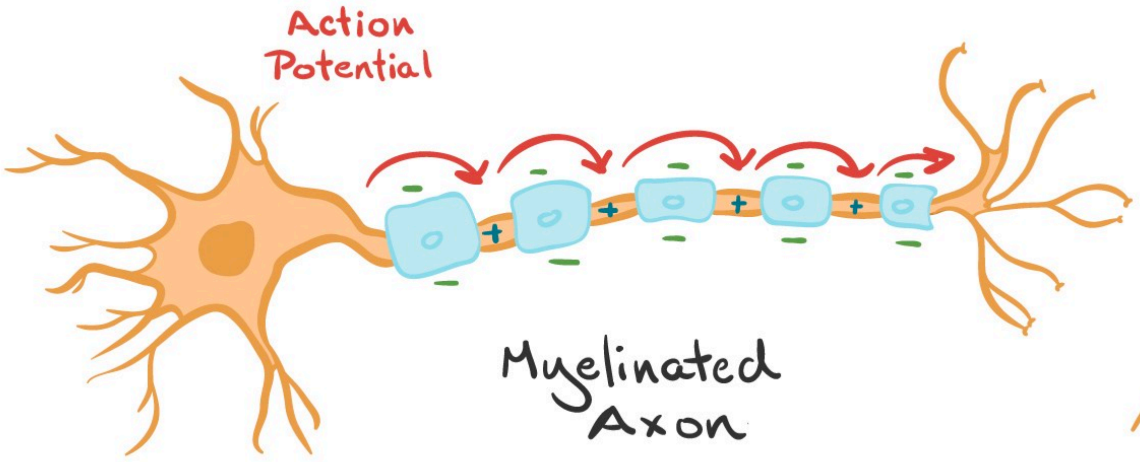


Fewer negative ions accumulate at the myelin wrapped parts of the axon, since then, they won't be able to access the positive ions with ease.

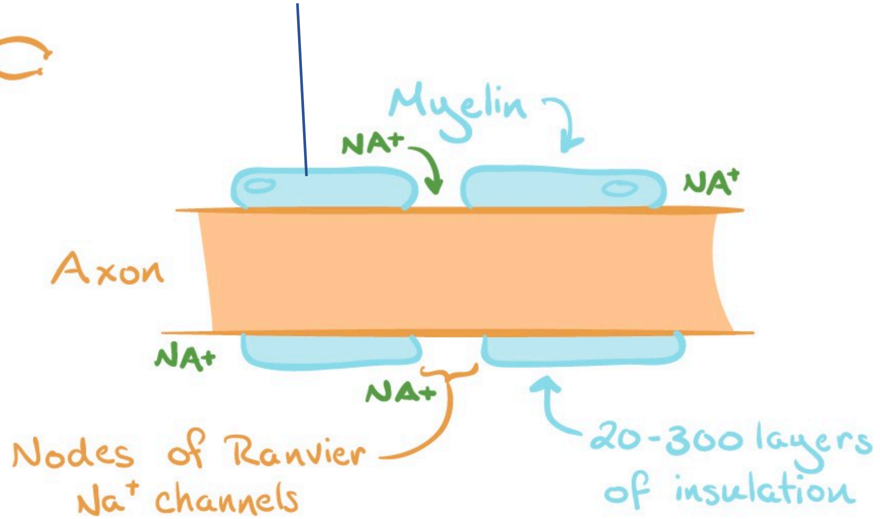


Velocity of spike propagation

- After the spike is generated, it is propagated along the axon
- **Saltatory spread**



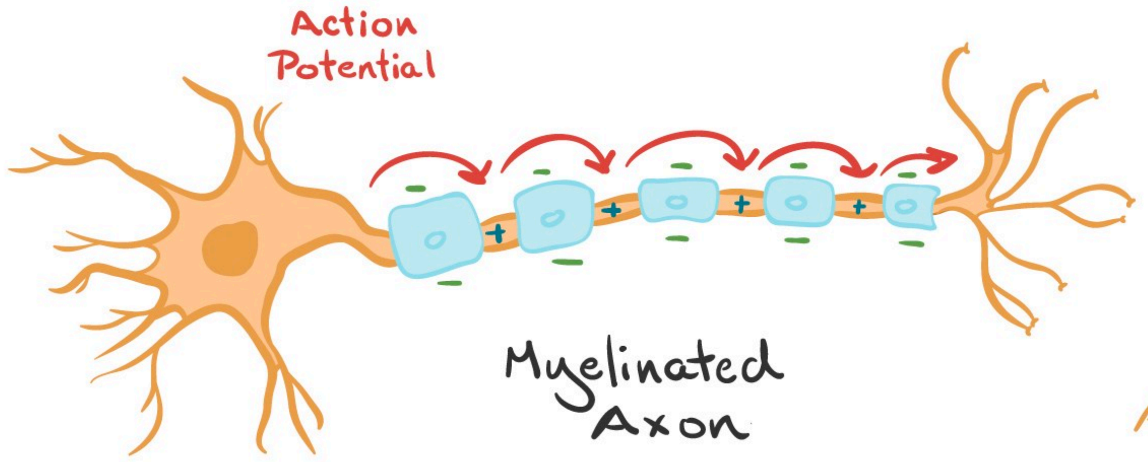
The action potential comes rushing by, it is easier to depolarize the areas that are sheathed because there are fewer negative ions to counteract

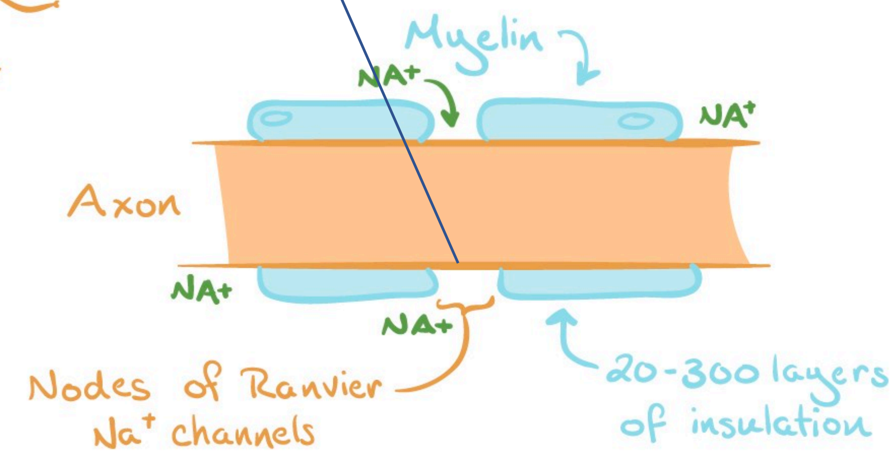


Velocity of spike propagation

- After the spike is generated, it is propagated along the axon
- **Saltatory spread**

The nodes of Ranvier have these positive gated voltage channels, where the positive ions form a swarm since they are the uncovered areas.

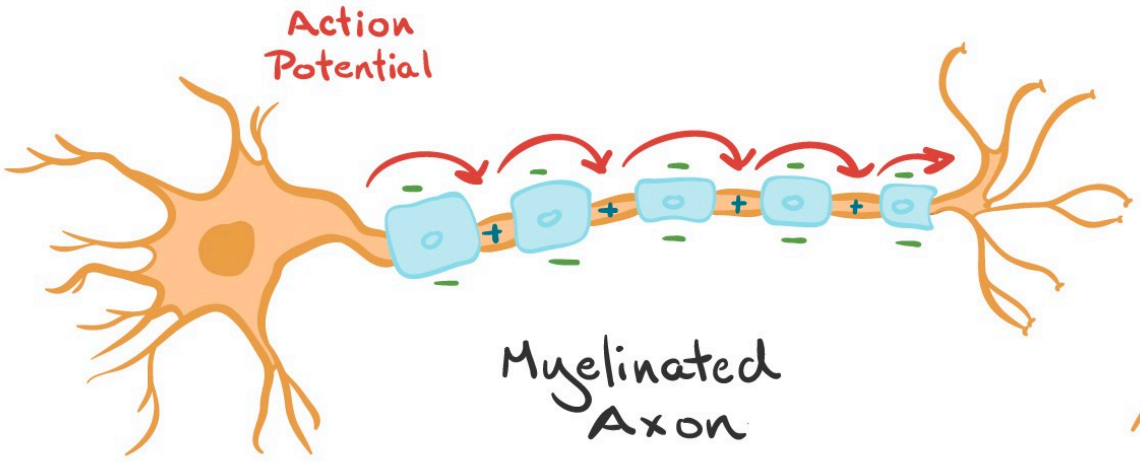


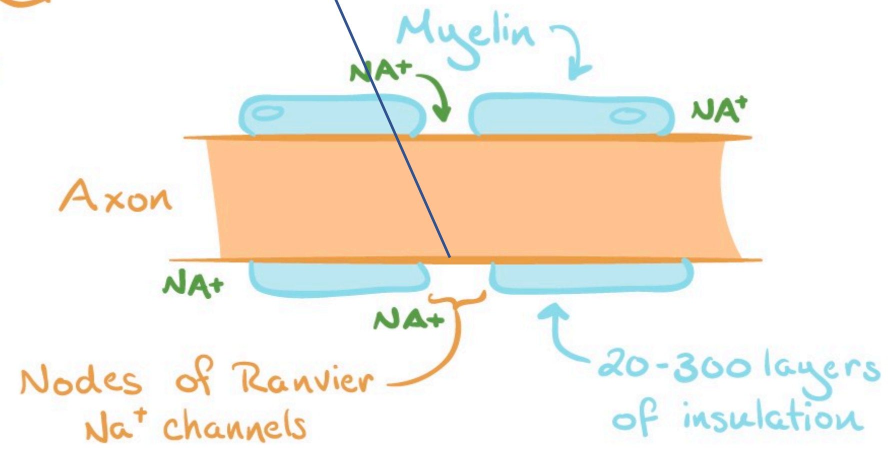


Velocity of spike propagation

- After the spike is generated, it is propagated along the axon
- **Saltatory speed**

The negative ions in the axons want to reach the nodes of Ranvier to balance themselves.

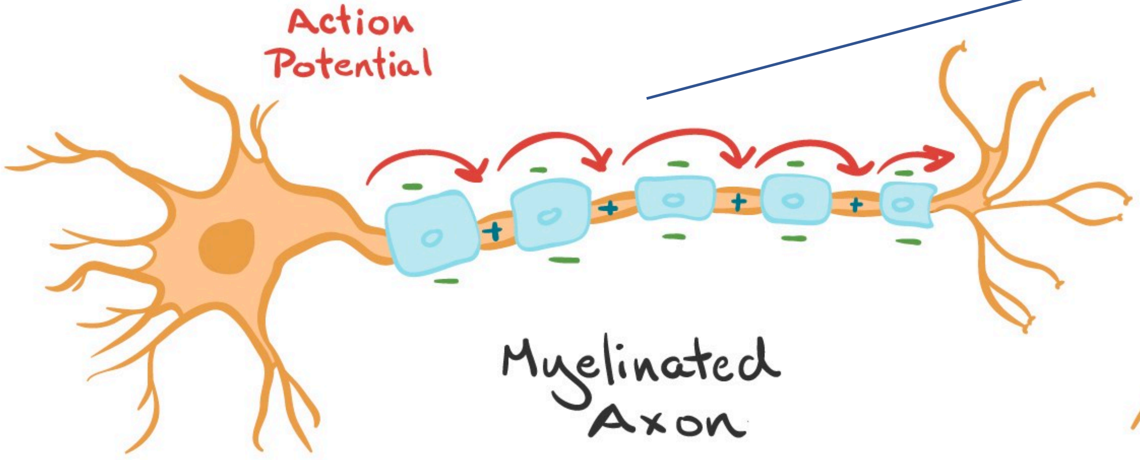


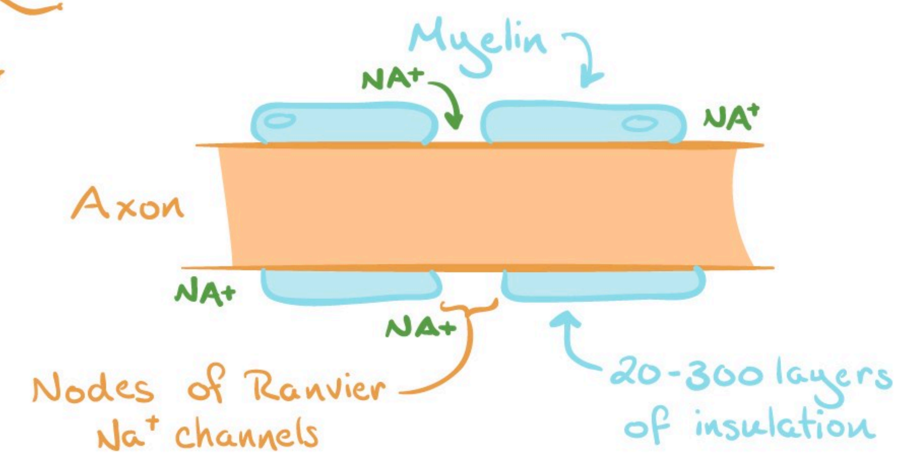


Velocity of spike propagation

- After the spike is generated, it is propagated along the axon

Saltatory conduction





Velocity of spike propagation

- After the spike is generated, it is propagated along the axon

Slow spread