Electrical Properties of Neurons

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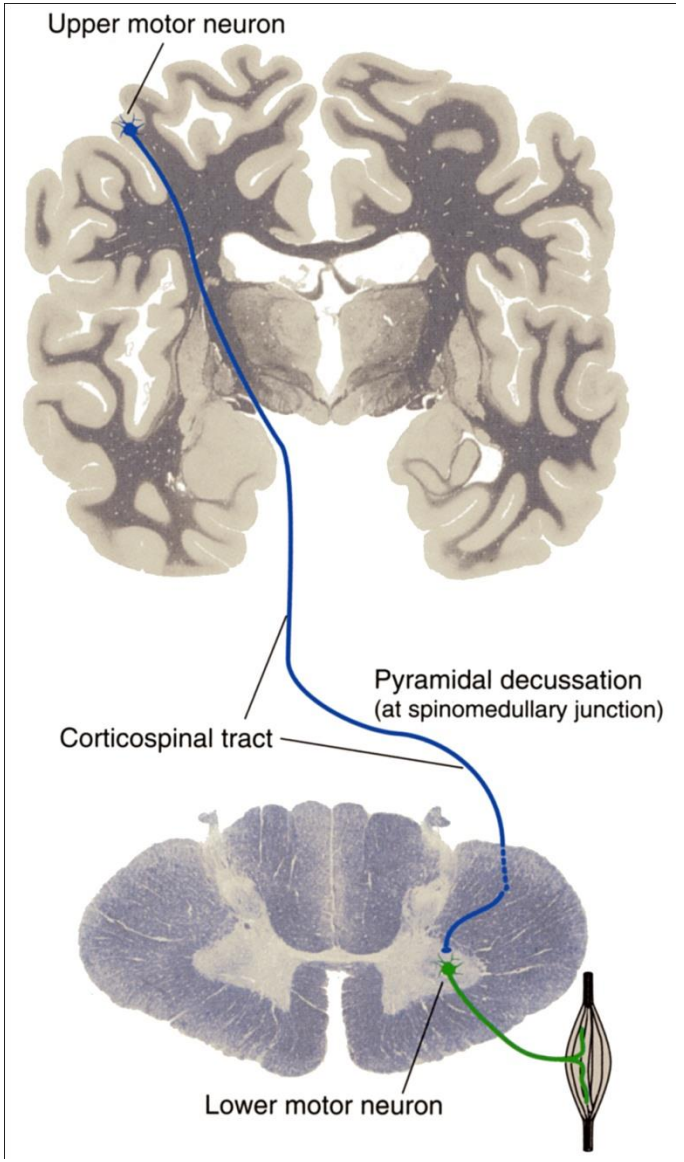
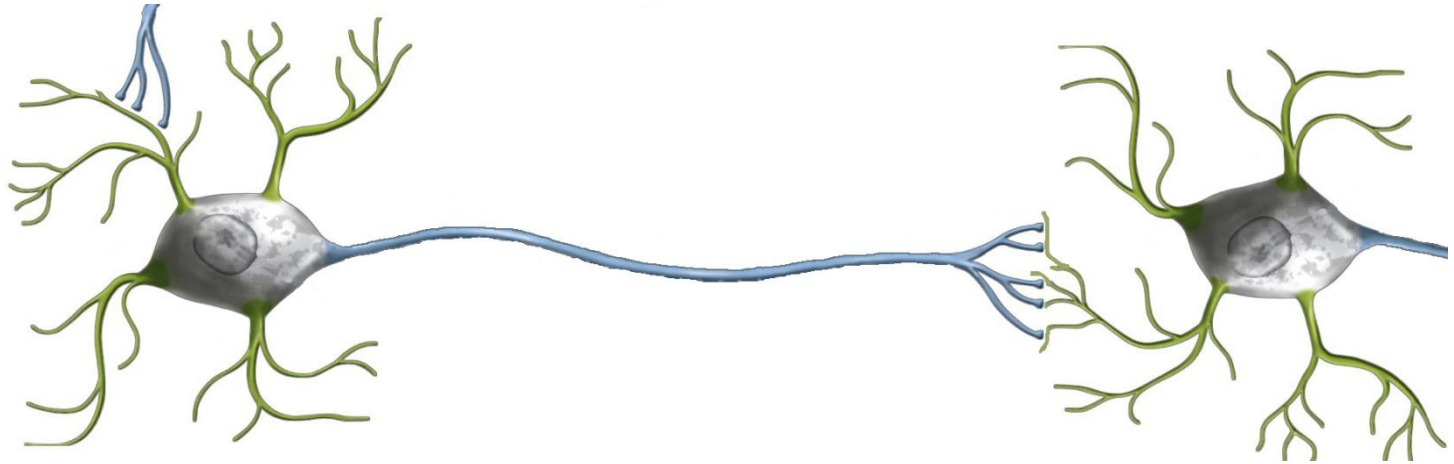
Neuronal Communication

- Neurons communicate with other cells, often over long distances.
- The electrical properties of neurons are essential for this process.



Neuronal Communication

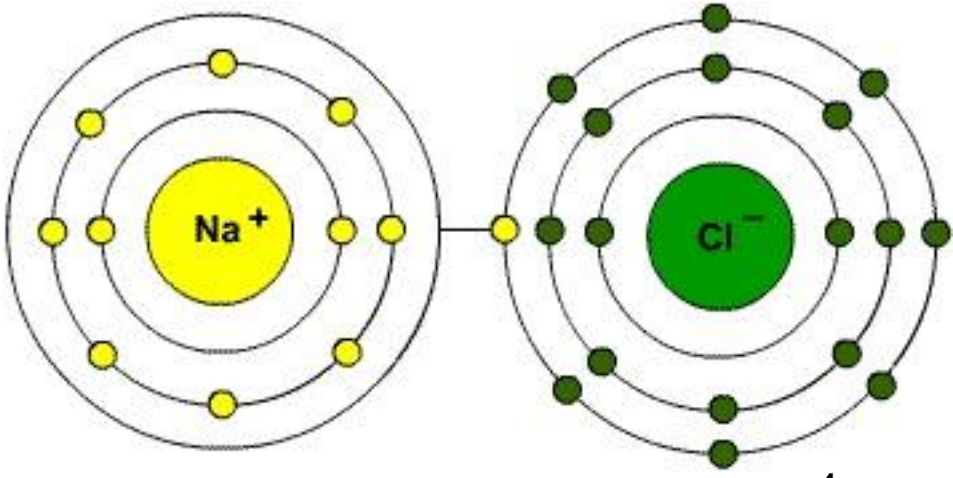


- Key features of these electrical properties include:
  - resting membrane potential
  - graded changes in the membrane potential in the dendrites and soma in response to excitatory and inhibitory inputs
  - action potentials that self propagate unchanged along the length of axons
  - action potentials initiate release of neurotransmitter at synapses
  - neurotransmitter initiates changes in the membrane potential of postsynaptic cells

Ions

- Atoms like to have complete rings of electrons.
- In ionic bonds, atoms can loan electrons to their partner atoms.
- In water, certain atoms can dissociate while maintaining the electron loan.
- Atoms with more electrons than protons have a negative charge.
- Atoms with fewer electrons than protons have a positive charge.

sodium chloride (NaCl)

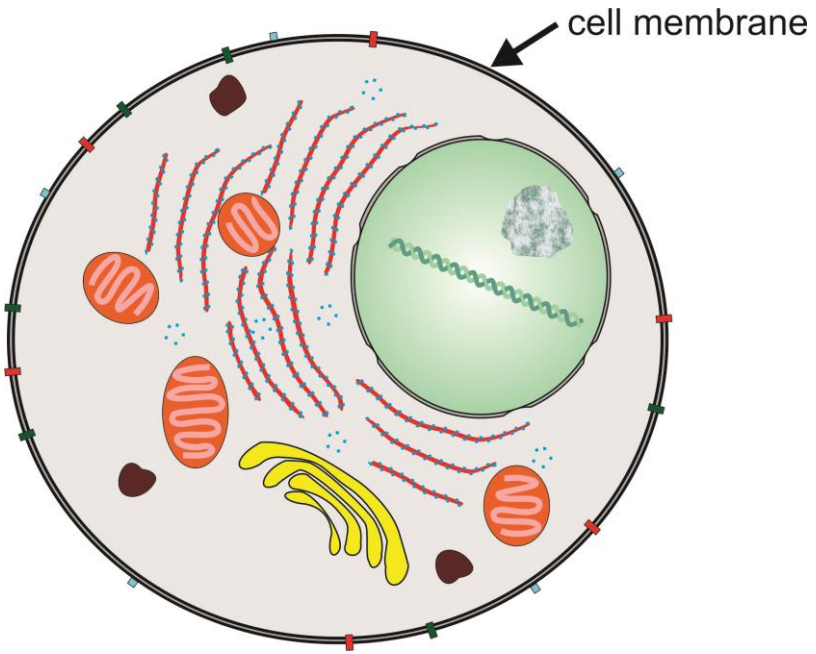


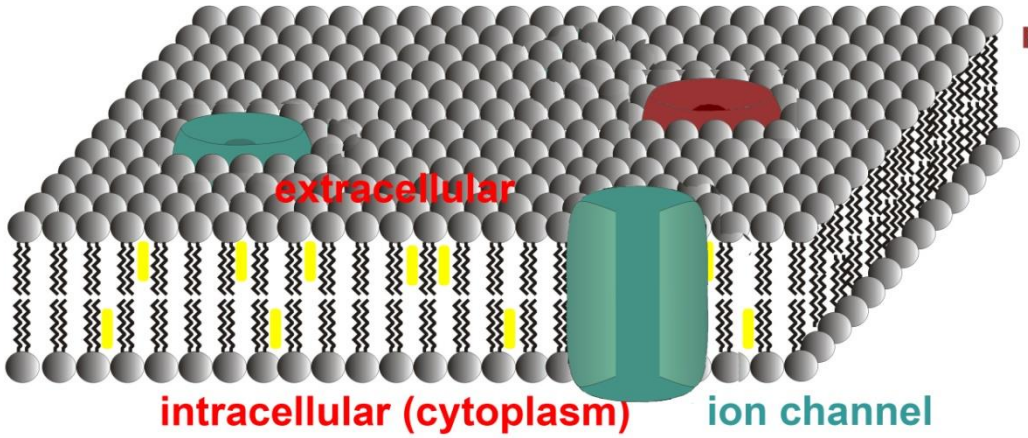
Ions

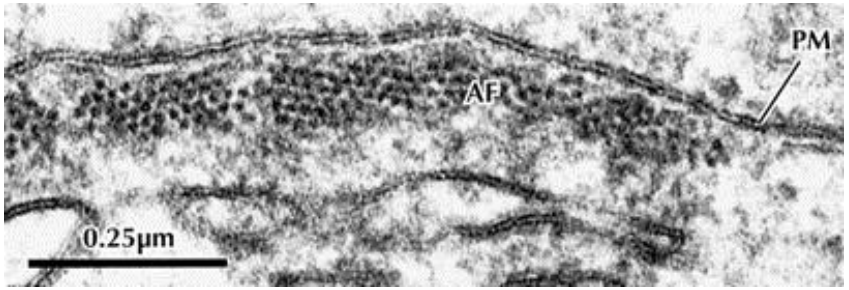
- Major ions in the body include:
  - chloride (Cl^-)
  - sodium (Na^+)
  - potassium (K^+)
  - magnesium (Mg^{++})
  - calcium (Ca^{++})

Resting Membrane Potential

- The lipid bilayer of the cell membrane is hydrophobic.
- The lipid bilayer is a barrier to movement of most molecules between the cytoplasm and the extracellular environment.
- Channels and transporters allow the movement of ions between the inside and outside of the cell.



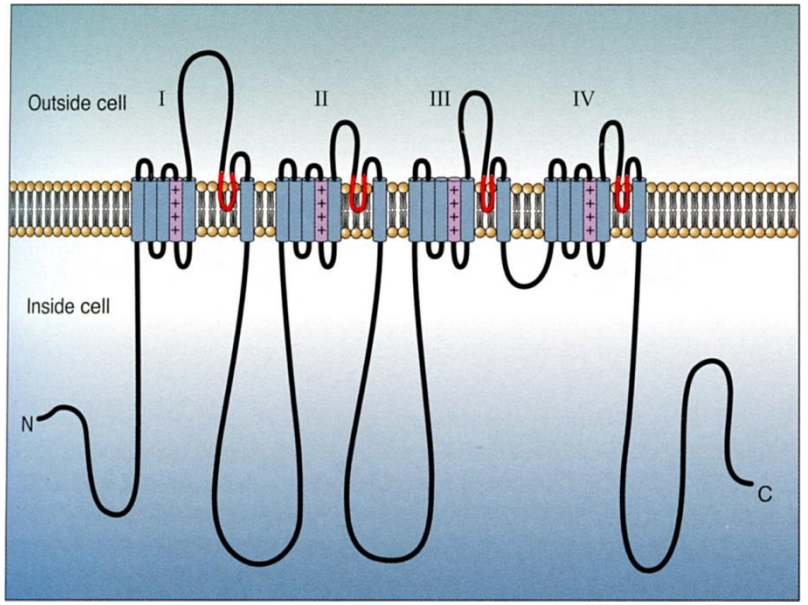


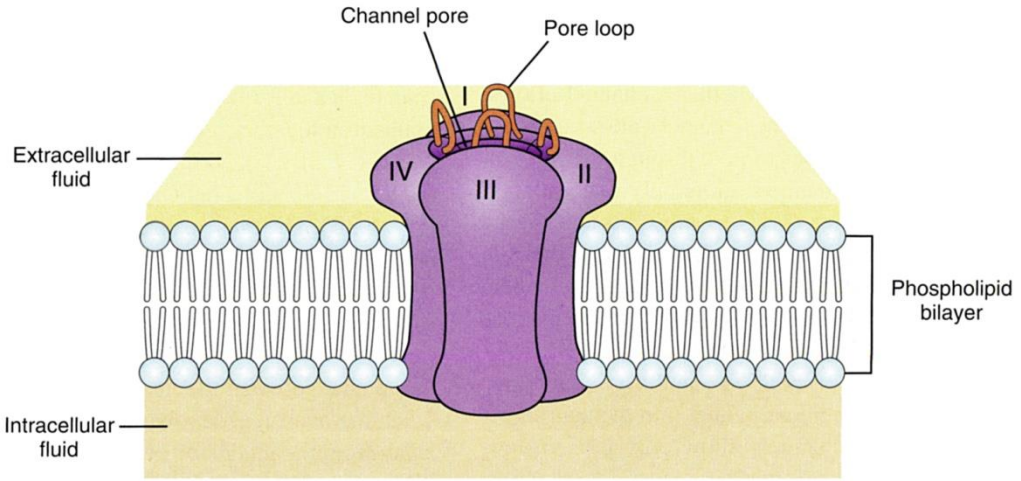


Resting Membrane Potential

- Channels and transporters are formed by proteins that pass through the cell membrane several times and arrange so as to form a pore.

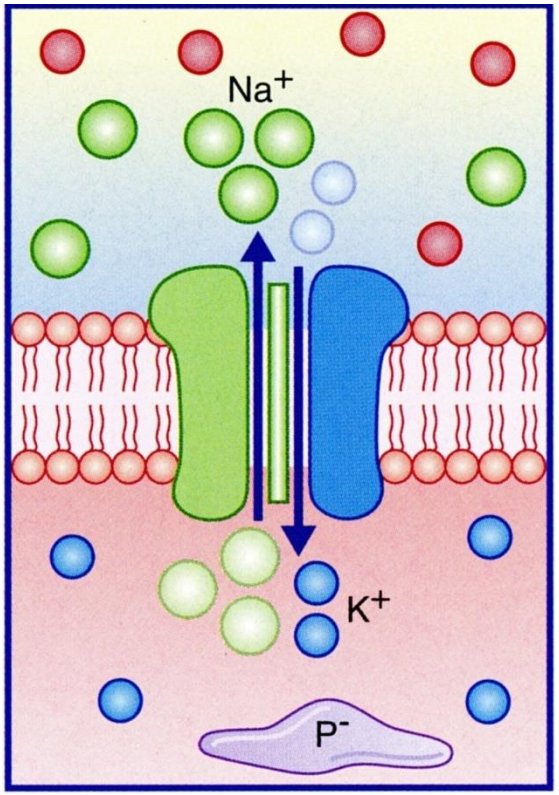
- They can be …
  - unregulated (passive).
    or
  - gated by the membrane potential, ligand binding, mechanical force or other stimuli.



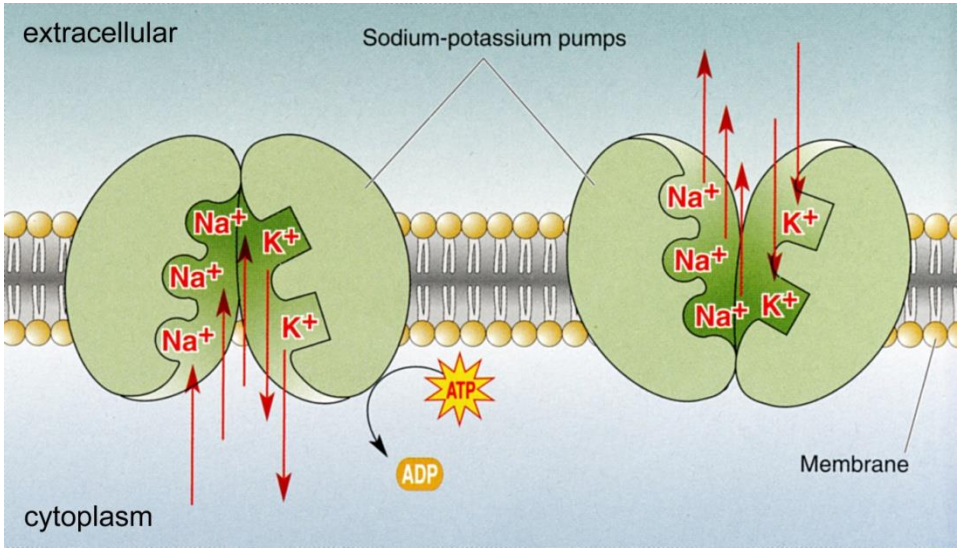


Resting Membrane Potential

- A neuron at rest, that is a neuron receiving no synaptic input, maintains a higher concentration of K^+ and a lower concentration of Na^+ and Cl^- in its cytoplasm than outside the cell.
- A sodium-potassium pump maintains this ion differential.
- Proteins on the inside of the cell mostly have a negative charge.



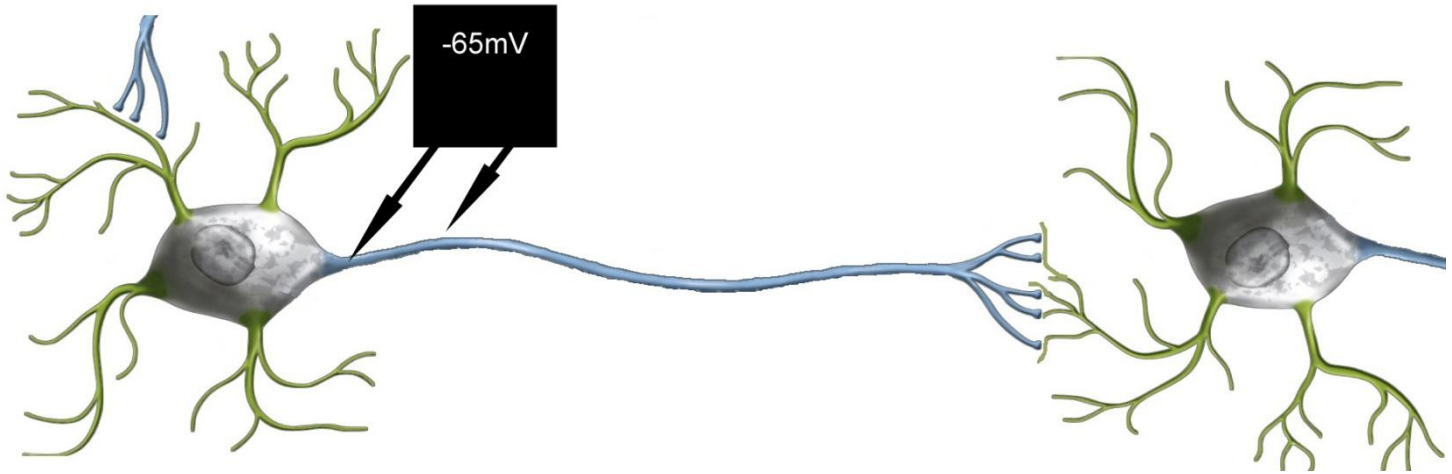
Resting Membrane Potential



The sodium-potassium pump…

- moves 3 sodium ions out of the neuron and 2 potassium ions into the neuron.
- requires energy in the form of adenosine triphosphate (ATP).

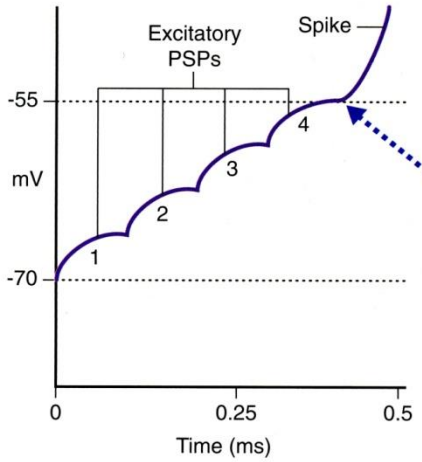
Resting Membrane Potential



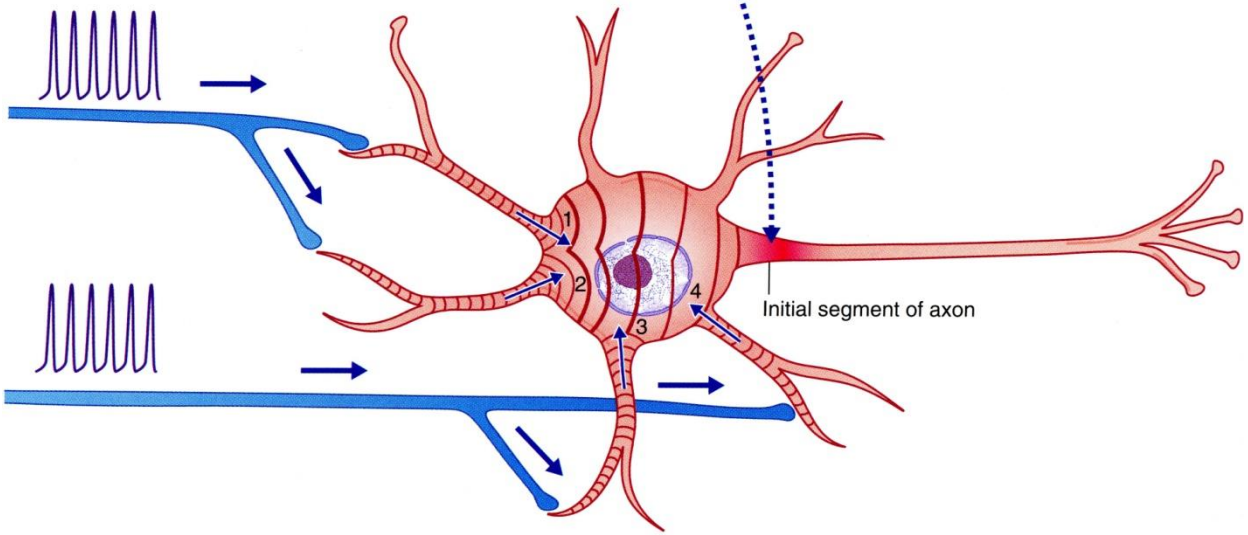
- The electrical charge from proteins, ions moving through unregulated channels and ion pumps reaches an equilibrium in a neuron at rest.

- The ‘resting membrane potential’ can be measured with a voltmeter with electrodes on the inside and outside of the cell; this is typically -65mV.

Graded Potentials in Dendrites & Soma



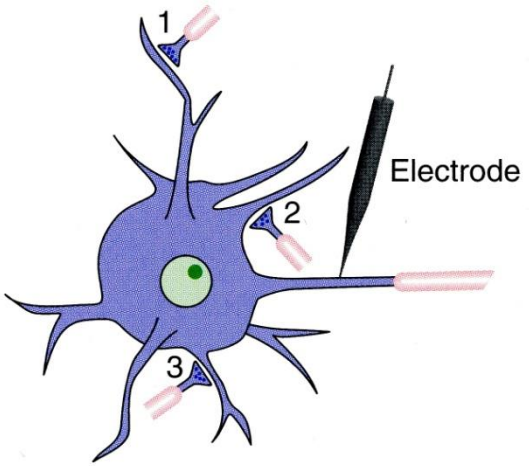
- Activation of neurotransmitter receptors causes changes in the ion conductance in the dendrites and soma.
- Inhibitory synaptic activity <u>hyperpolarizes</u> the neuron (i.e. the membrane potential becomes more negative).
- Excitatory synaptic activity <u>depolarizes</u> the neuron (i.e. makes it more positive).

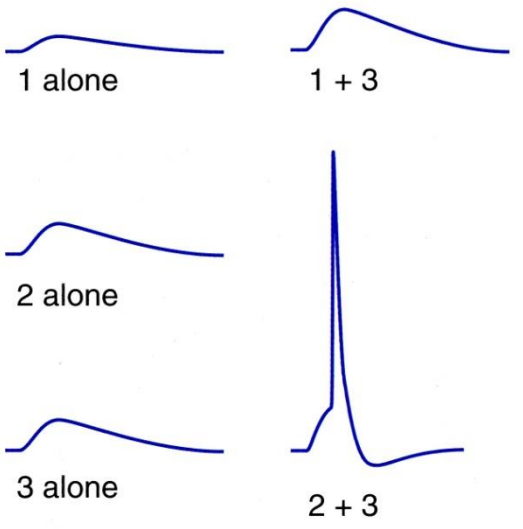


Action Potentials in the Axon

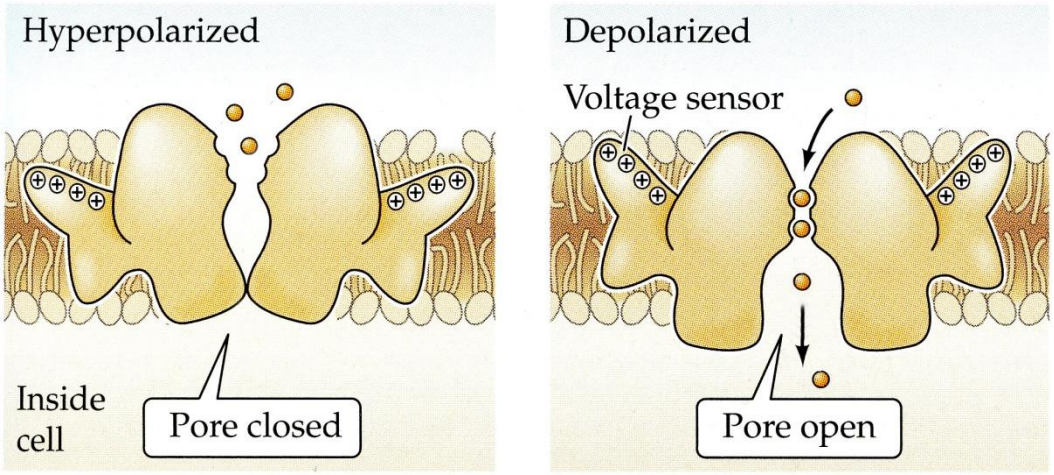
- The sum of all excitatory and inhibitory inputs to the cell is monitored by the initial segment of the axon.

- When the initial segment reaches threshold (i.e. when it is sufficiently depolarized) an action potential is generated.





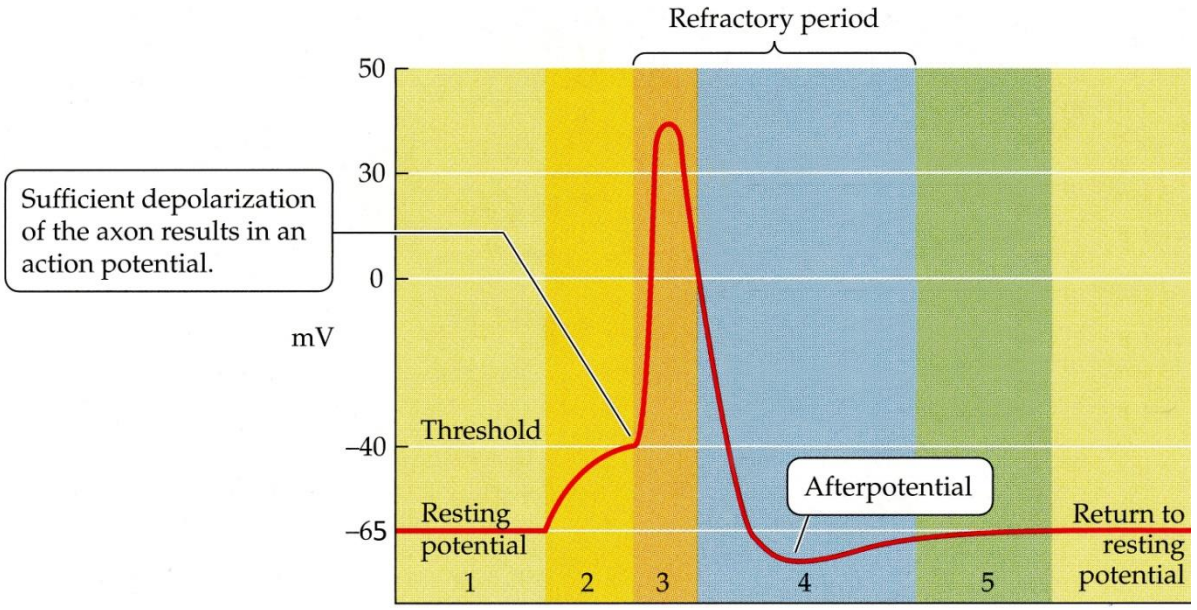
Action Potentials in the Axon



- Voltage-gated sodium (Na^+) channels monitor the neuron's level of activity.

- When threshold is reached in the initial segment, the voltage-gated Na^+ channels open allowing Na^+ to enter the axon.

Action Potentials in the Axon

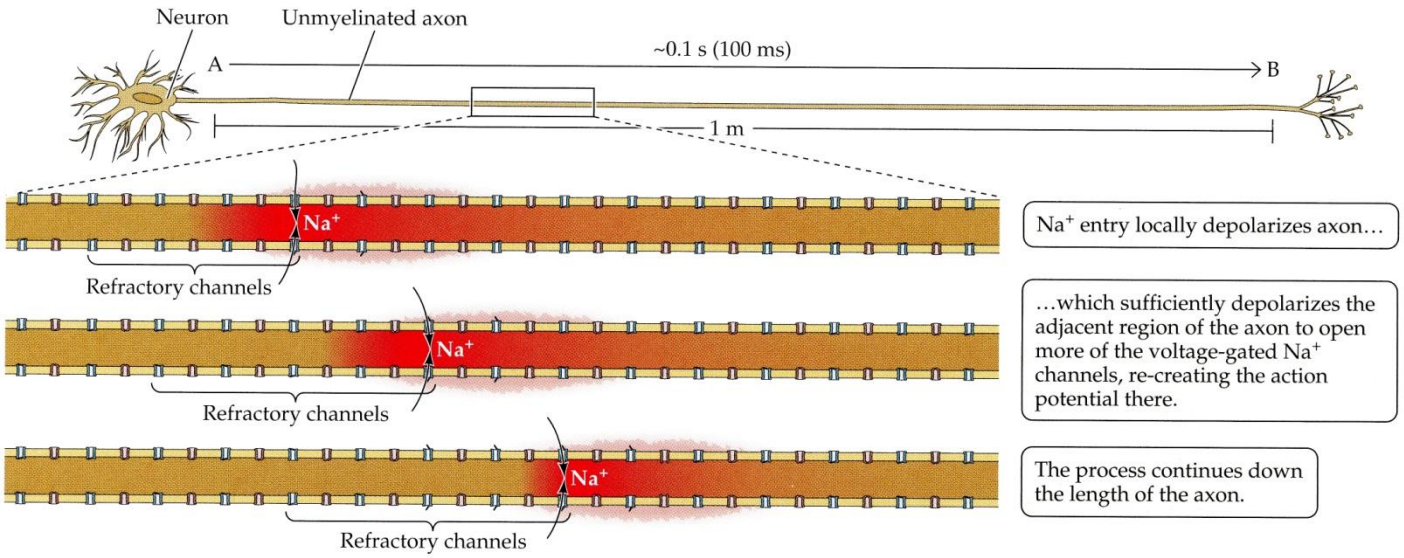


- Opening the voltage-gated Na^+ channels further depolarizes the axon and is the start of the action potential.

- Later voltage-gated K^+ channels open and voltage-gated Na^+ channels close, which starts repolarizing the cell.

- Repolarization slightly overshoots making the axon briefly hyperpolarized until it finally returns to the resting membrane potential.

Action Potentials in the Axon

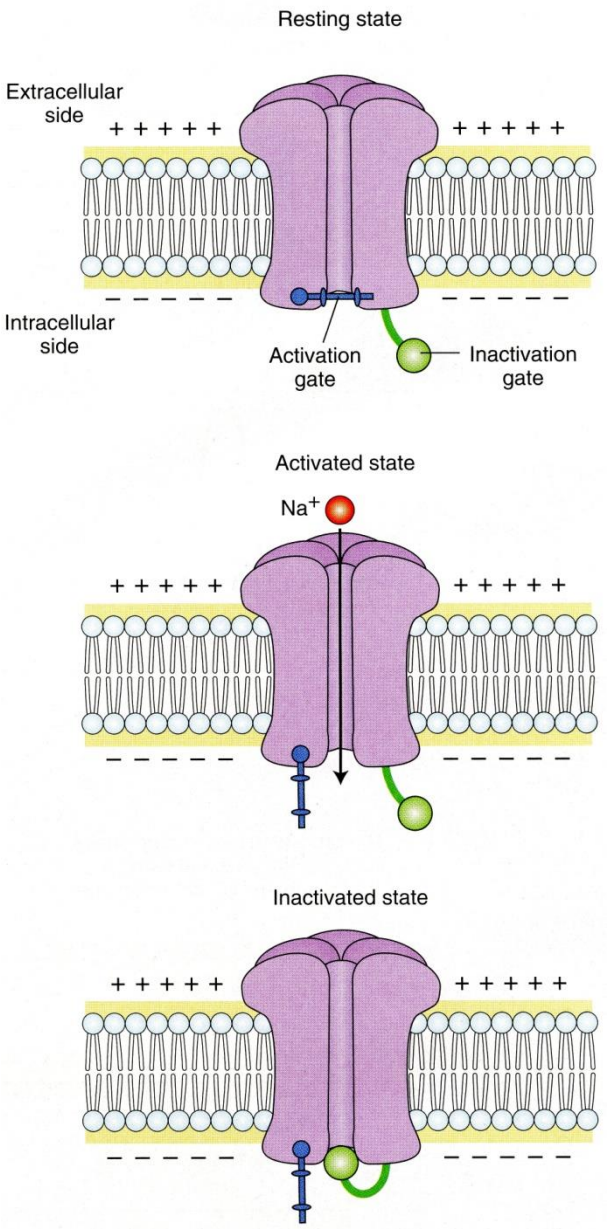


- Opening of the voltage-gated Na^+ channels in one segment of the axon causes depolarization of the voltage-gated Na^+ channels further down the axon.

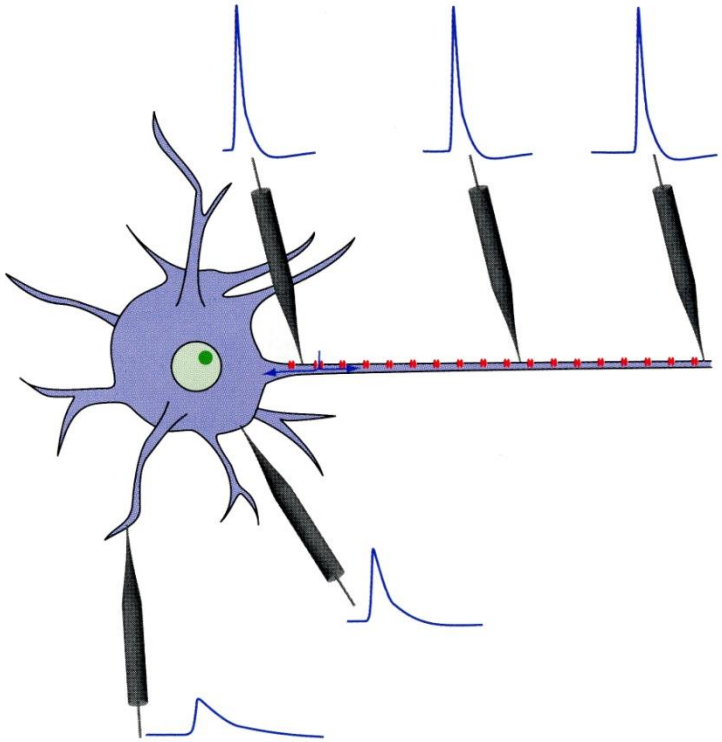
- This results in the action potential self-propagating down the entire length of the axon.

Action Potentials in the Axon

- After opening, voltage-gated Na^+ channels have a brief period in which they are blocked and cannot be activated.
- A new action potential cannot be generated during this period, the refractory period.
- This limits the potential frequency of action potentials.
- This also prevents the strength (i.e. voltage) of the action potential from increasing.



Action Potentials in the Axon



- The level of depolarization reached is the same along the entire length of the axon. (Thus, there is no decrement in the strength of the action potential along the length of the axon.)

- The action potential is described as an all-or-none event. (That is once started in the initial segment, it is destined to go to the end of the axon.)

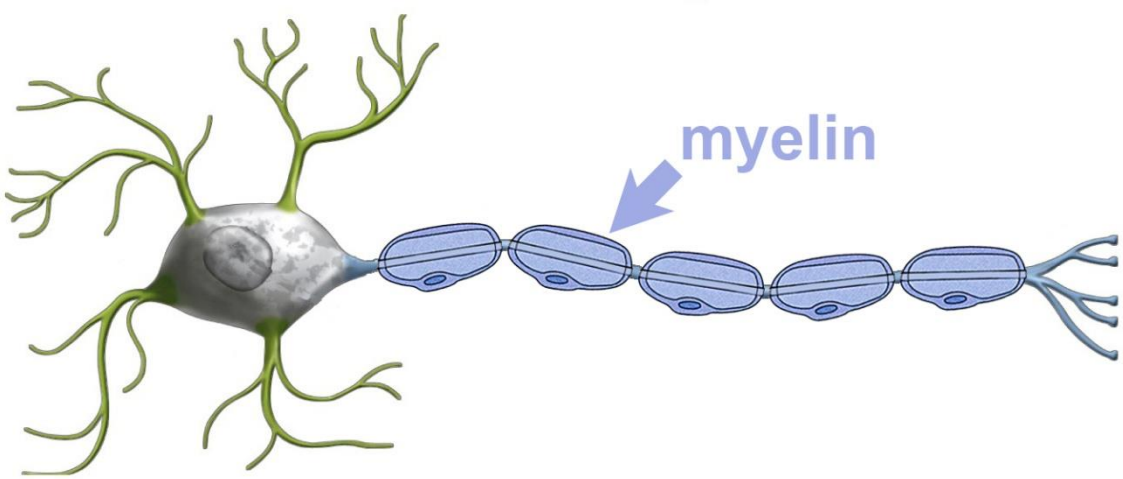
Channelopathy

- Channelopathies are a family of diseases caused by abnormal function of an ion channel.

- Many of these are due to a mutation in a gene for a channel protein. Several diseases are due to mutations in a gene for a protein that forms a voltage-gated sodium channel.

- These diseases often result in muscle weakness and slow responses.

Myelin

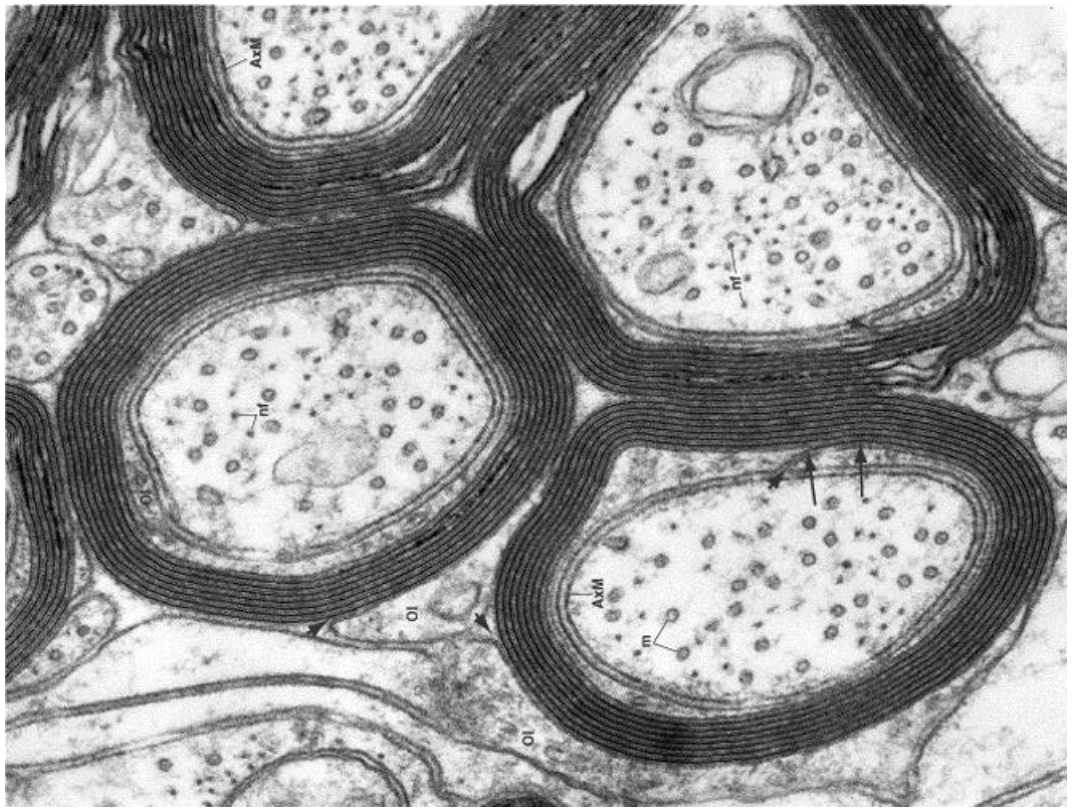


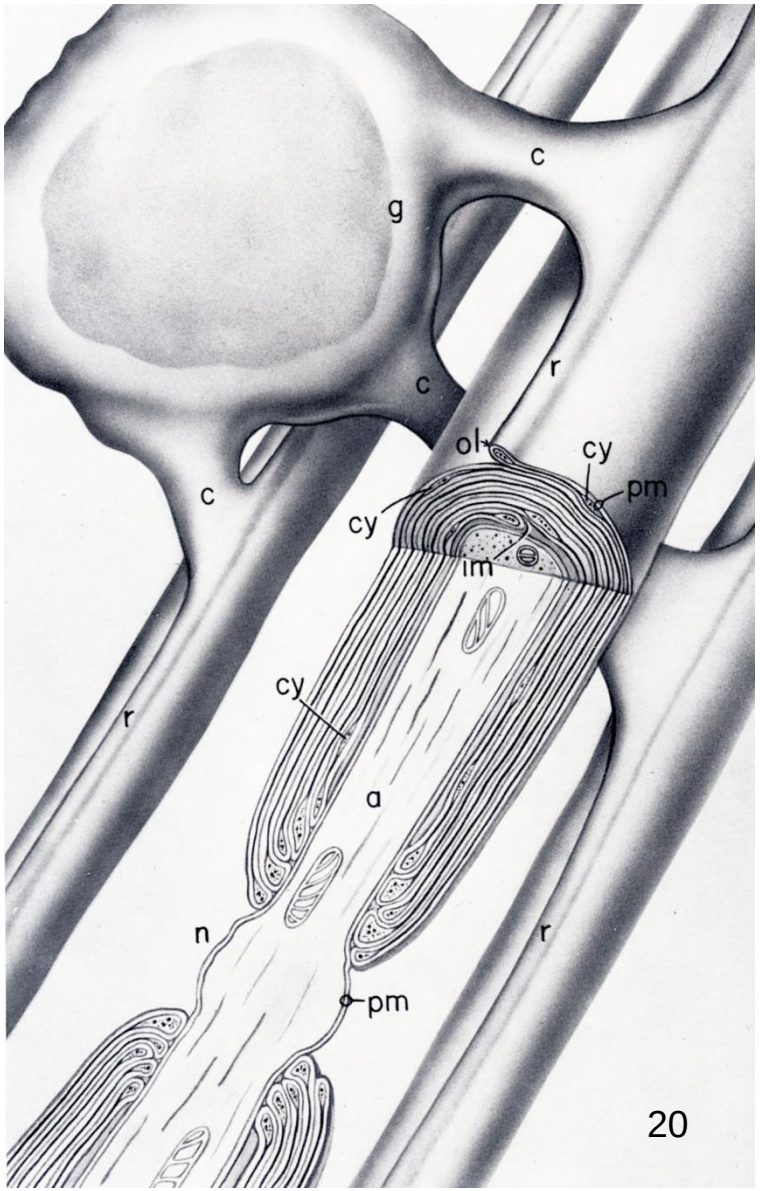
- Most axons have a covering of myelin.
- Myelin speeds the conduction of action potentials down the axon.

Myelin

Myelin is formed by glial cells wrapping their membranes around an axon:

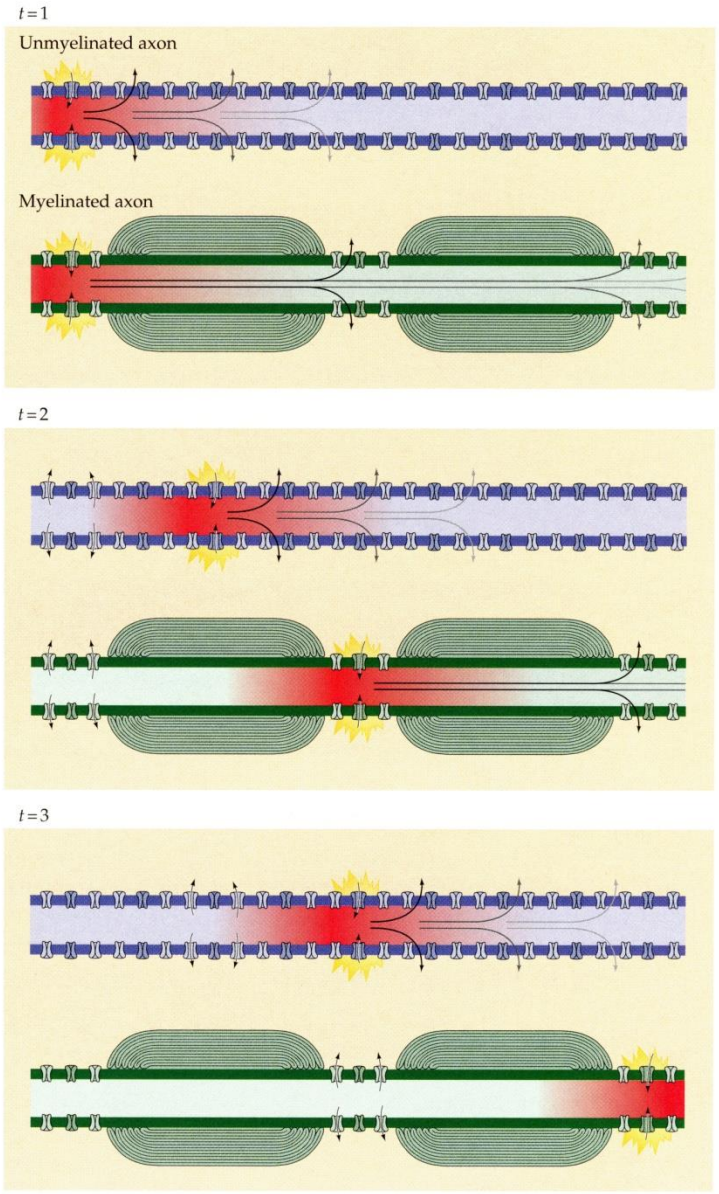
- Schwann cells in the PNS.
- Oligodendrocytes in the CNS.





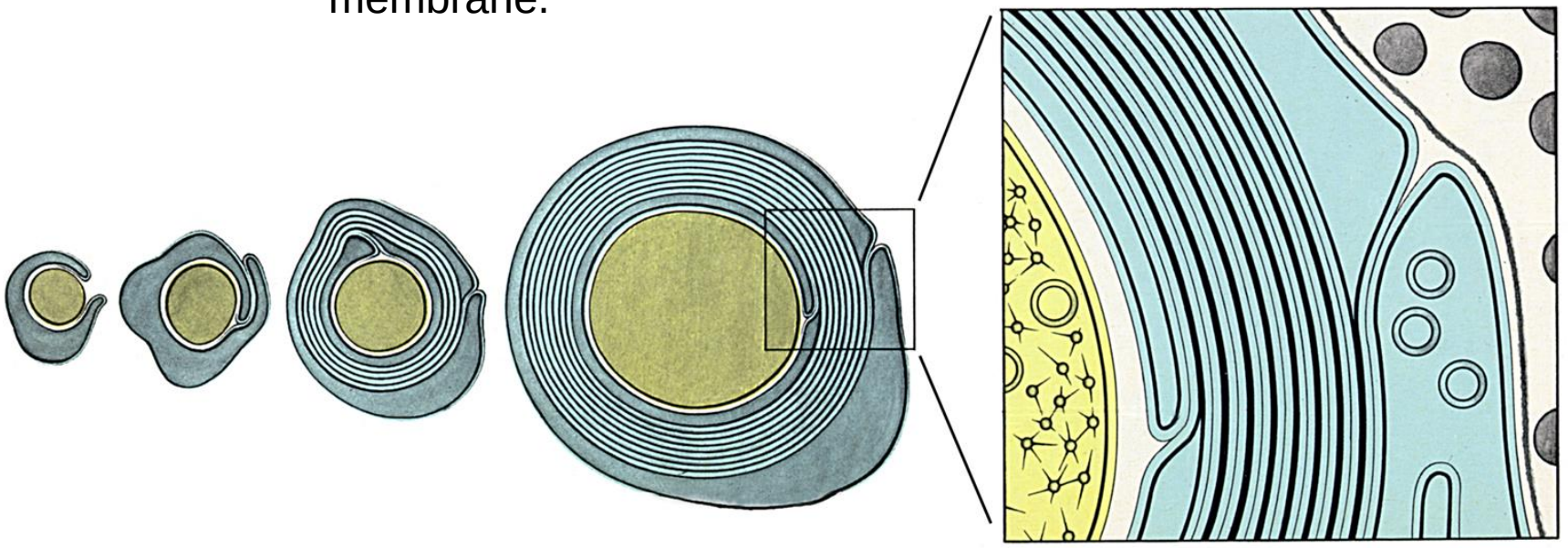
Saltatory Conduction

- The membrane wrapped by myelin is not excitable, and there is a high density of voltage-gated Na^+ channels in the nodes between the myelin.
- The action potential moves rapidly from node to node.
- Myelinated axons have a much faster <u>conduction velocity</u> than unmyelinated axons.



Development of Myelin

- Glial cells wrap around the axons, synthesize the molecules associated with myelin-type membrane, and exclude cytoplasm between the layers of membrane.

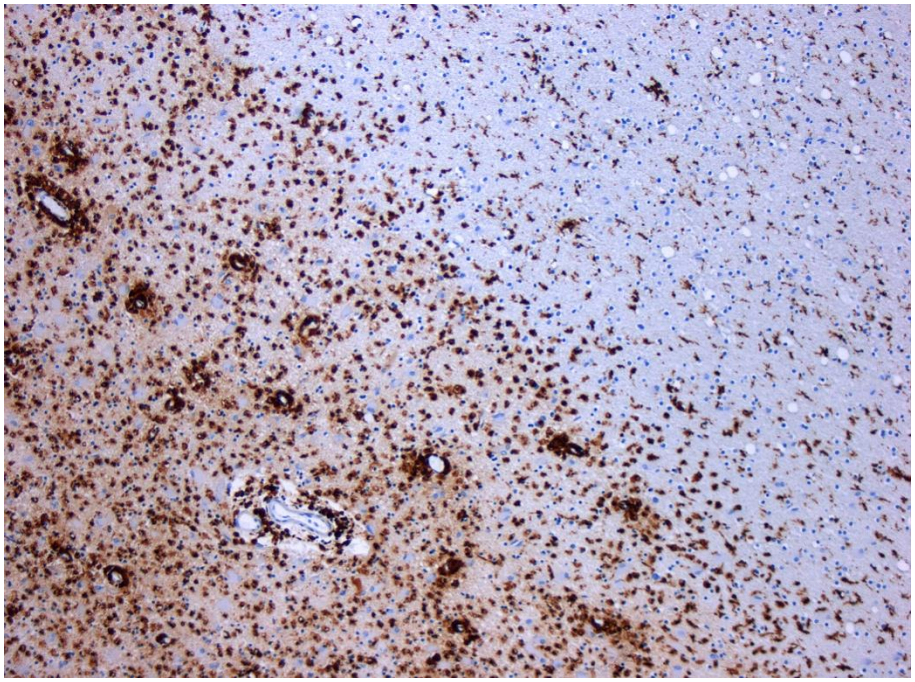


Development of Myelin

- Some tracts myelinate as early as 14wks of gestation; myelination continues until mid-adolescence.
- The Babinski sign is present in newborns and disappears as the pyramidal tract myelinates (4mos – 2yrs of age).
- Many factors can delay myelination including poor nutrition.
- In adults, the Babinski sign is indicative of upper motor neuron disease.

Multiple Sclerosis (MS)

- MS is a demyelinating disease of the CNS.
- MS results in a variety of neurological symptoms including loss of touch sensitivity, poor motor coordination and vision problems. Symptoms are variable from person to person. Symptoms often remit and relapse.
- Symptoms often appear in the mid-twenties, and MS is more common in women than men.
- Inflammation destroys the myelin.



Macrophages (brown) invading axon tracts.
[from Wikipedia]

Action Potentials in the Axon

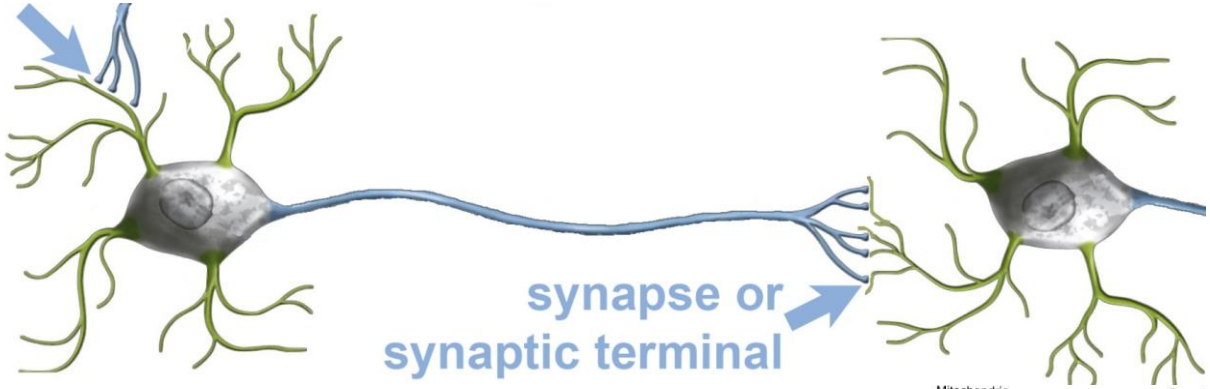
- The larger the diameter of the axon, the faster the conduction velocity.

Action Potentials in the Axon

- Lidocaine is a drug that blocks voltage-gated Na^+ channels and thus blocks action potentials.

- Lidocaine is used as a local anesthetic.

Neurochemical Communication



- When an action potential reaches the synapse, it initiates release of neurotransmitter into the synaptic cleft.