Resting Distribution of Ions in Mammalian Neurons

	Outside	Inside (mM)	E_{ion}	Permab.
K^+	5	100	-81	1.0
Na^+	150	15	+62	0.04
Cl^-	100	10	-62	0.045

V_m= -60 mV

V_m approaches the Equilibrium Potential of the most permeable ion, which at rest is K^+

Two ways to change the Membrane Potential:

1. Change the concentrations of an ion, e.g. increase extracellular K+ concentration
   Doesn't happen under normal circumstances, because body and neurons maintain constant environment.

2. Change the permeability of the membrane to an ion, which causes the Vm to move closer to Eion.
   Neuron regulates opening and closing of gated ion channels

Opening and Closing of Na+ and K+ channels is basis of Action Potential

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Change of Ion Concentration leads to change of V_m

	Outside	Inside (mM)	E_{ion}	Permab.
K^+	150	100	+11	1.0
Na^+	150	15	+62	0.04
Cl^-	100	10	-62	0.045

V_m= +11 mV

Two ways to change the Membrane Potential:

1. **Change the concentrations of an ion, e.g. increase extracellular K+ concentration**
   Doesn't happen under normal circumstances, because body and neurons maintain constant environment.

2. **Change the permeability of the membrane to an ion, which causes the Vm to move closer to Eion.**
   Neuron regulates opening and closing of gated ion channels

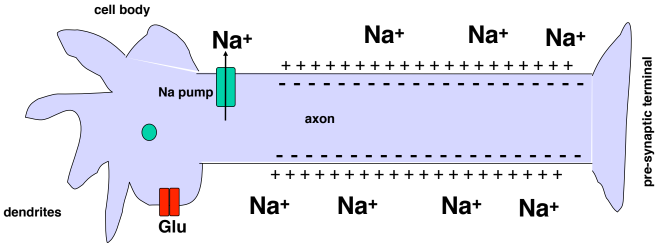
Opening and Closing of Na+ and K+ channels is basis of Action Potential

Change of Permeability leads to change of V_m

	Outside	Inside (mM)	E_{ion}	Permab.
K^+	5	100	-81	1.0
Na^+	150	15	+62	20
Cl^-	100	10	-62	0.045

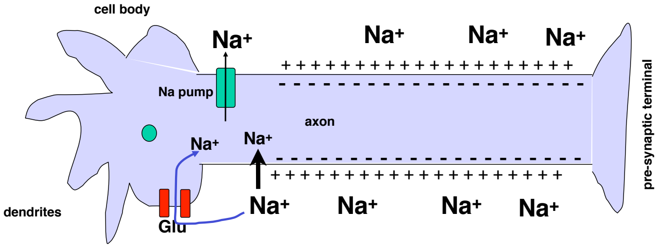
V_m = +54 mV

Membrane Potential of Neuron



Neurotransmitters cause Na^+ channels to open and let Na^+ into the neuron.

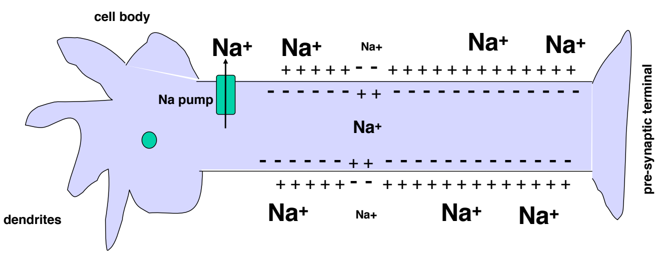
Membrane Potential of Neuron



Neurotransmitters cause Na+ channels to open and let Na+ into the neuron. *Change of Vm causes more Na+ channels to open.*

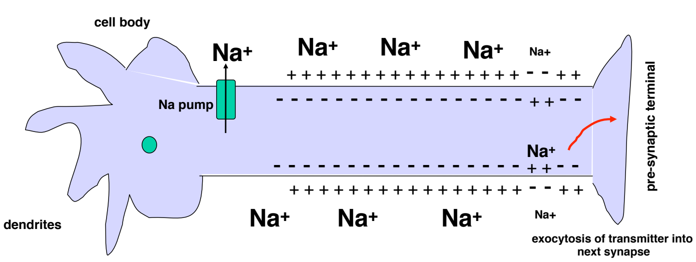
(could also be artificial injection of positive current -- anything that raises Vm from -70 mV -> -30mV)

Membrane Potential of Neuron



When Na+ moves into the neuron, the neuron fires an action potential (a wave of changing potential)

Membrane Potential of Neuron



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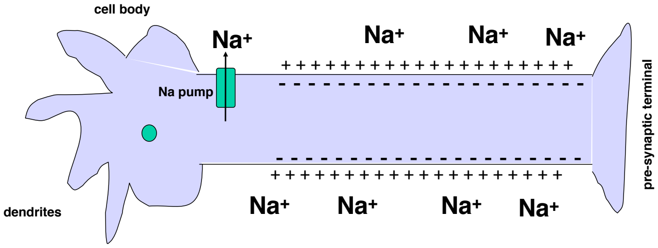
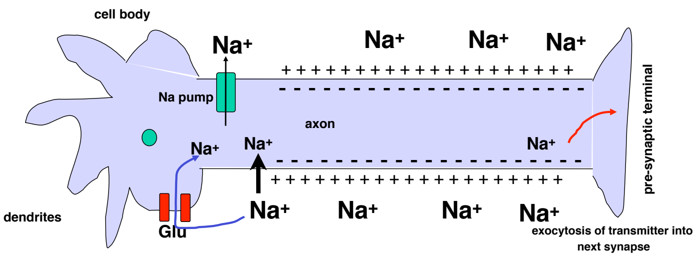
Membrane Potential of Neuron



K+ channels and Na+/K+ pump restore balance of ions -> return to -70 mV membrane potential

Membrane Potential of Neuron (summary)



Neurotransmitters cause Na^+ channels to open and let Na^+ into the neuron.

Change of Vm causes more Na+ channels to open.

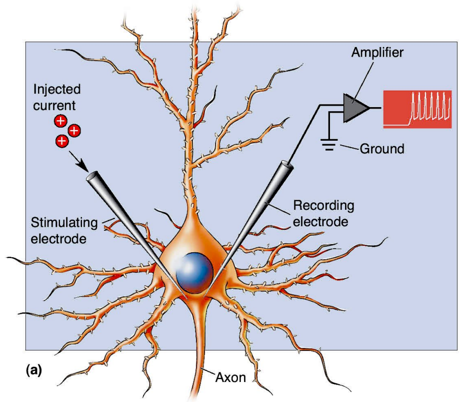
When Na^+ moves into the neuron, the neuron fires an action potential (a wave of changing potential)

K^+ channels open slowly behind Na^+ wave, so neuron returns to -70 mV V_m

Na^+/K^+ ATPase pump restores balance of ions

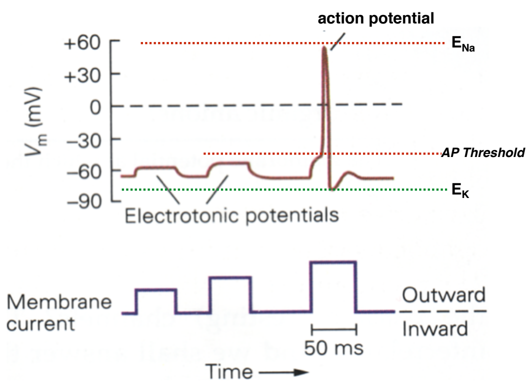
https://www.youtube.com/watch?v=qNvtlW8LPRw

depolarization -> Action Potential



- Electrode injecting current
- Stimulus causing Na+ channels to open (e.g. pain, red pepper)

depolarization -> Action Potential



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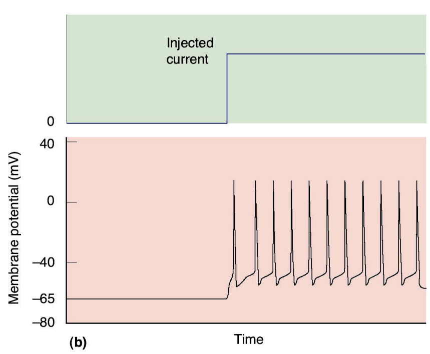
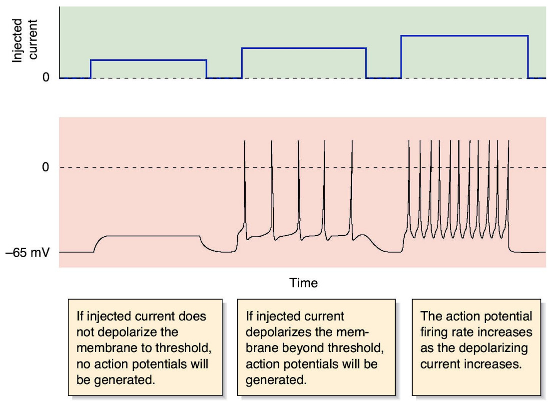




Summary of Action Potential (AP)

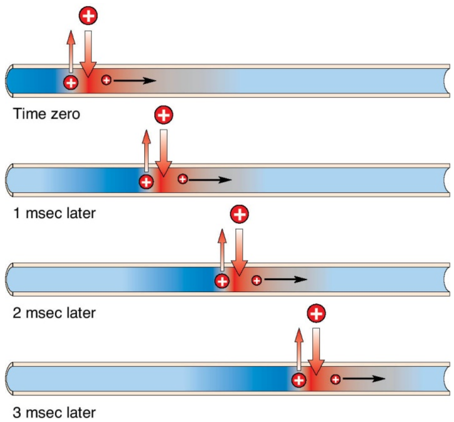
0. At rest, resting K+ channels open, so Vm is close to E_K
1. Depolarization by electrical stimulation or neurotransmitter
2. V_m rises above AP threshold (depolarization)
3. Voltage-gated Na^+ channels open: V_m moves to E_{Na}
4. Rising V_m depolarizes neighboring membrane: AP starts moving down axon (speed depends on cable properties)
5. Voltage-gated Na^+ channels inactivate; Voltage-gated K^+ channels open; V_m moves to E_K
6. Voltage-gated K^+ channels close
7. V_m returns to resting potential, only resting K+ channels open

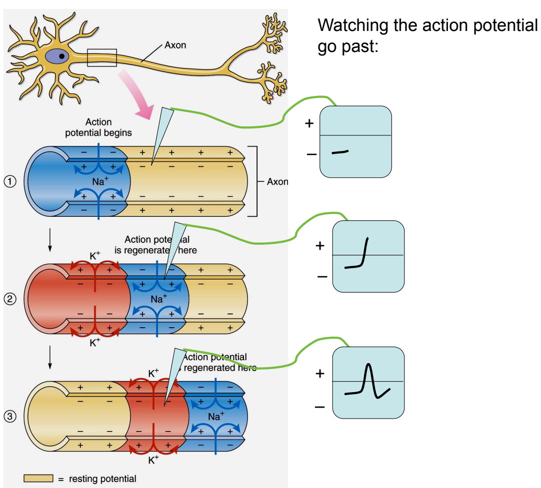
Three Types of Ion Channels play a role in Action Potential:

1.Resting K+ channels:
always open, keep resting Vm of neuron close to E_{K+}

2.Voltage-Gated Na+ Channels:
when neuron Vm becomes less negative (depolarizes),
-65 mV —> -40 mV
many Na+ channels open very quickly (< 1 msec)

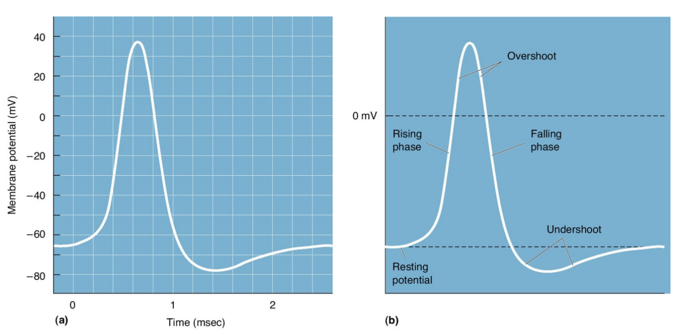
3.Voltage-Gated K+ Channels:
also open when neuron depolarizes,
but more slowly (5 msec) than Na+ channels;
restore Vm to -65 mV





Fox Figure 7.19

Parts of the Action Potential

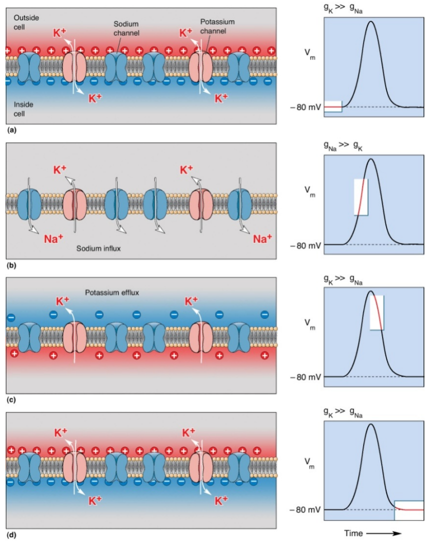


At rest, K+ channels are open (Na+ are closed). V_m close to E_{K+}

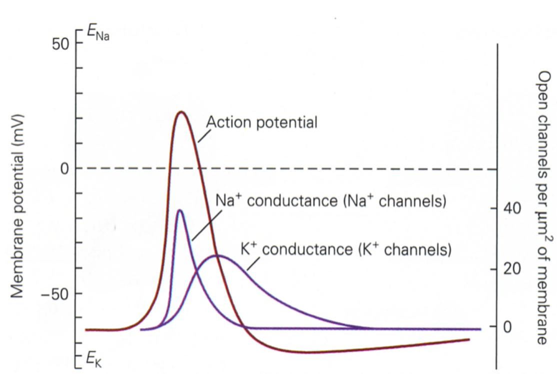
If neuron deploarizes, many Na+ channels open. V_m rises towards E_{Na+}

With deplorization, slower K+ channels open. V_m falls towards E_{K+}

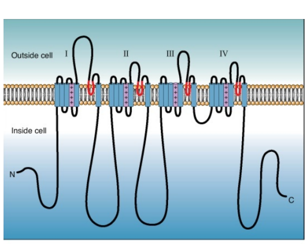
Back at rest, only resting K+ channels are open (Na+ and K+ are closed). V_m close to E_{K+}

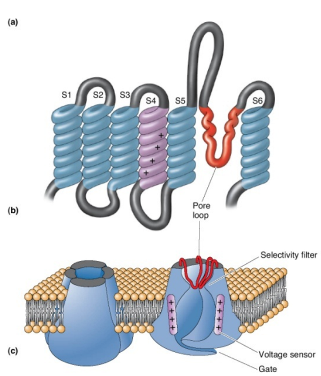


Action Potential



Voltage-Gated Sodium (Na+) Channel

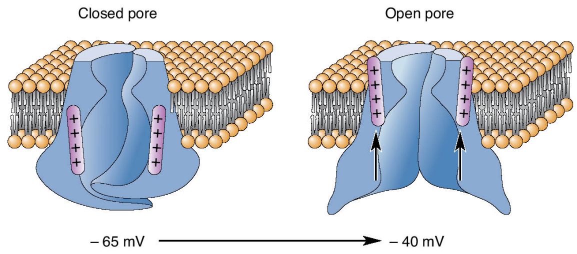




Voltage-Gated Sodium (Na+) Channel

3 Properties:

1. Selective for Na+ ions only
2. Opens when Vm rises above -40 mV (depolarizes)
3. Shortly after opening, inactivates and channels is blocked



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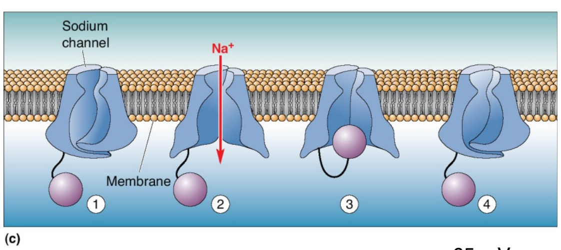
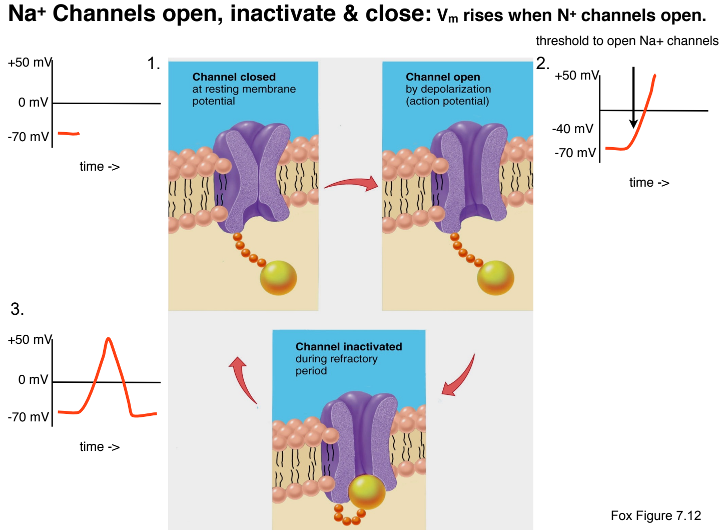


(c)

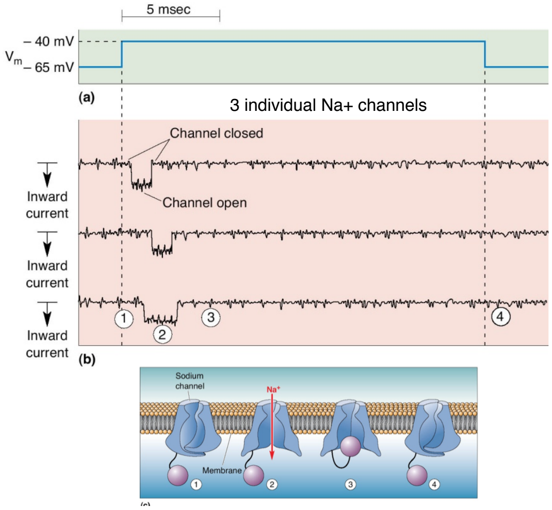
-65 mV | > -40 mV → *1 msec* | -65 mV

closed | open | inactivates | closed

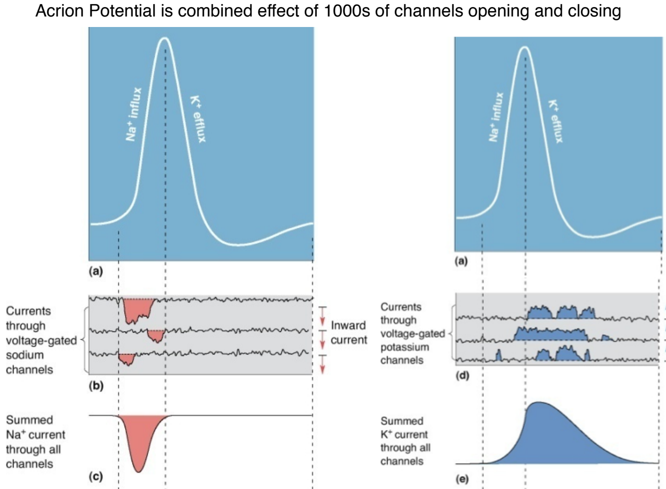
Na^+ Channels open, inactivate & close: V_m rises when N^+ channels open.

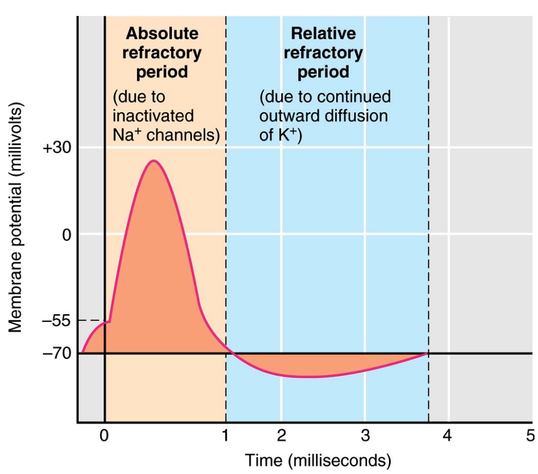


Fox Figure 7.12



Acrion Potential is combined effect of 1000s of channels opening and closing

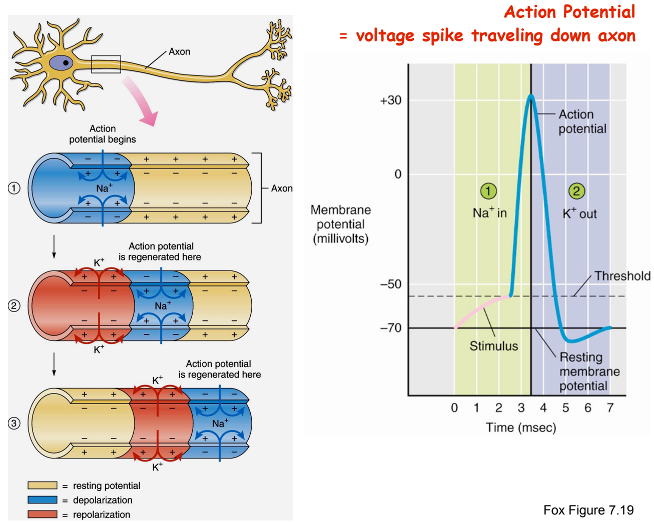




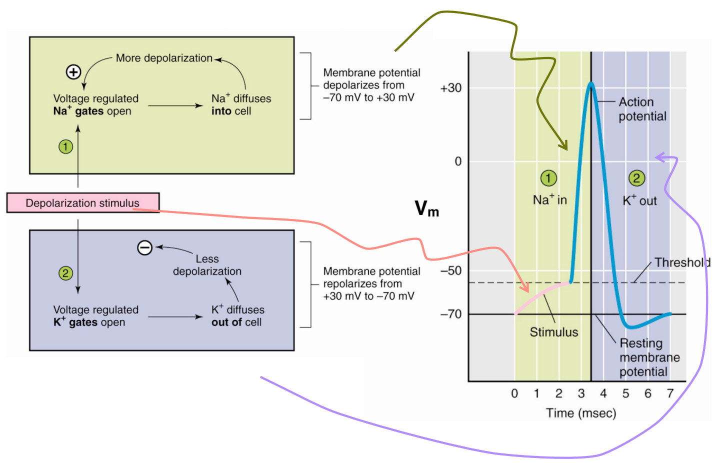
Fox Figure 7.17

Action Potential

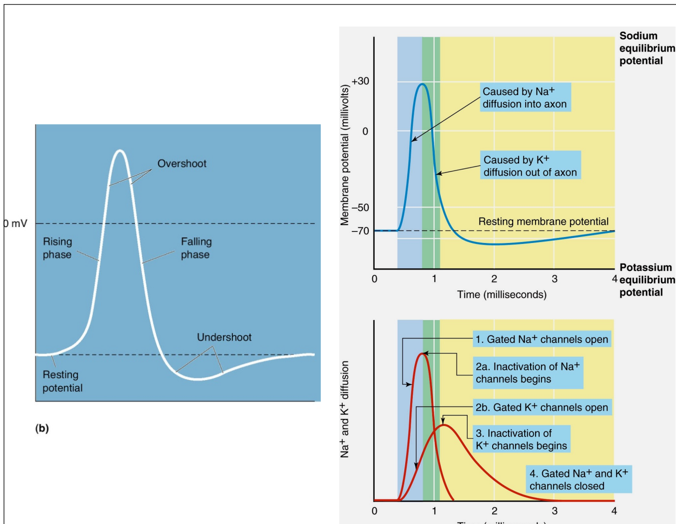
= voltage spike traveling down axon



Fox Figure 7.19



Fox Figure 7.13



Fox Figure 7.14

https://www.youtube.com/watch?v=Sa1wM750Rvs

Cable Properties of Axons

1. **Insulated myelinated axons have higher capacitance, so current is not dissipated and travels further**

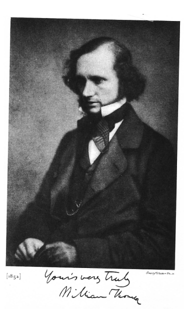
   With myelin sheath, charge is conducted to the next gap in the insulation; action potential jumps from one node of Ranvier to the next node very quickly = **saltatory** (jumping) **conduction**

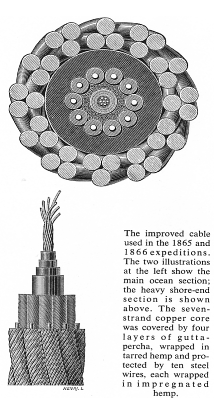
2. **Wider diameter axons have lower resistance, so wave of depolarization spreads faster**

   Because ions flow more easily to next segment of membrane in wider axons, action potentials move faster down wider axons.

Cable Properties

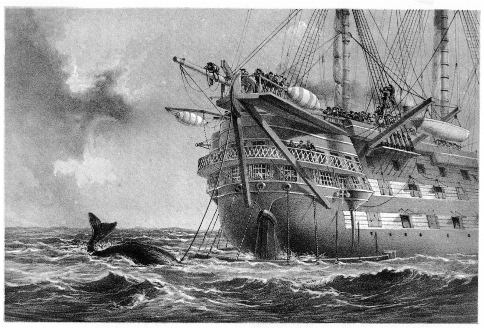
Lord Kelvin





The improved cable used in the 1865 and 1866 expeditions. The two illustrations at the left show the main ocean section; the heavy shore-end section is shown above. The seven-strand copper core was covered by four layers of gutta-percha, wrapped in tarred hemp and protected by ten steel wires, each wrapped in impregnated hemp.

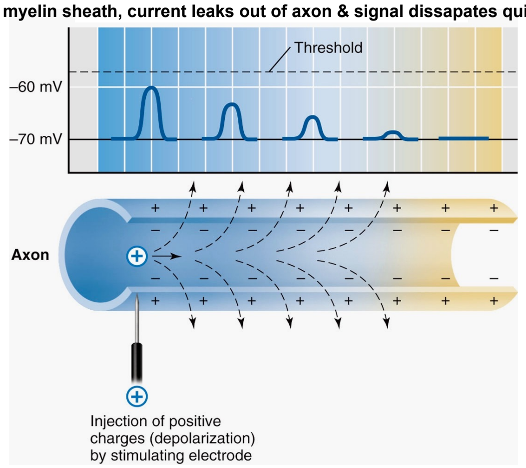
TransAtlantic Cable in 1850-60s



The stern of the Agamemnon with the cable issuing from the sheaves. The crew watches anxiously as a whale crosses the line. The "crinoline" about the rudder post was to keep the cable from being injured by the ship's propeller.

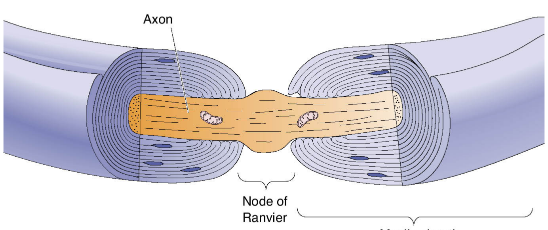
Dissipation of current (depolarization) with distance

Without myelin sheath, current leaks out of axon & signal dissapates quickly

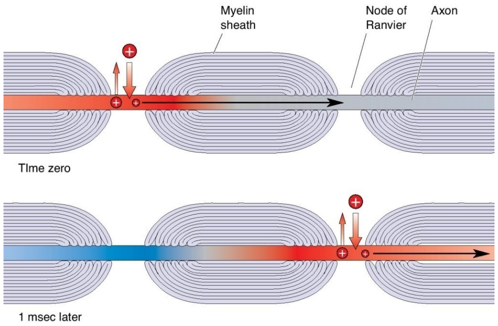


Myelination extends depolarization

- Myelin: Layers of myelin sheath facilitate current flow.
  - Schwann cells in the PNS
  - Oligodendroglia in CNS

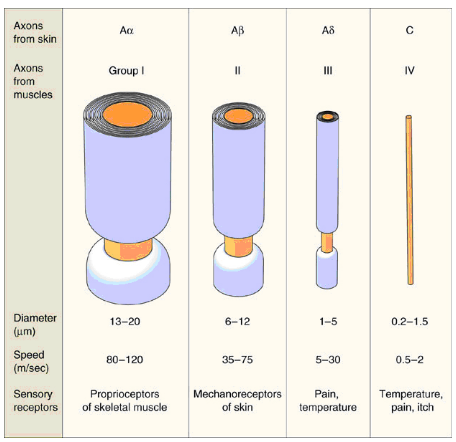


Saltatory (jumping) conduction



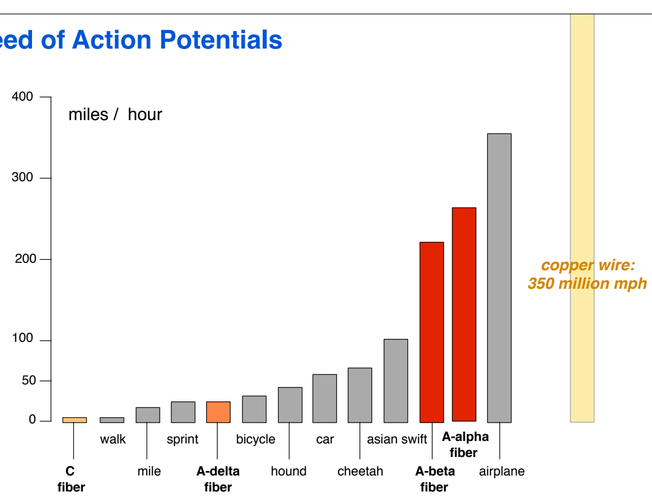
Nerves can have Axons of different diameters:

wider axons are faster, because ions flow more easily to next segment of membrane



http://alexandria.healthlibrary.ca/documents/notes/bom/unit_6/Lec%2024%20Peripheral%20mechanisms.xml

Speed of Action Potentials



redrawn from http://faculty.washington.edu/chudler/cv.html

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