BIO-311 Neuroscience

Unit 2: Action Potentials

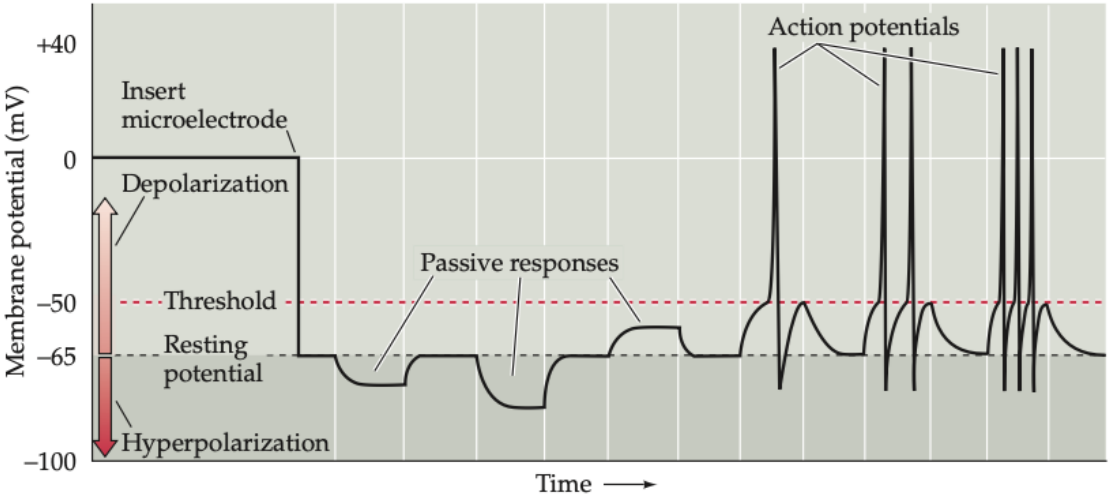
Summary

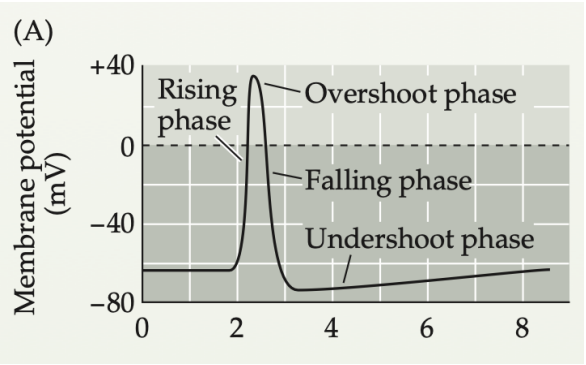
Action potential and electrical excitability

- Early & late currents, reconstruction of the action potential
- Experimental techniques: voltage clamp & current clamp
- The ionic basis: all-or-none voltage-gated Na^+ and K^+ channels
- Passive current and long-distance signal propagation
- Topology of Na^+ and K^+ channels

Action potential

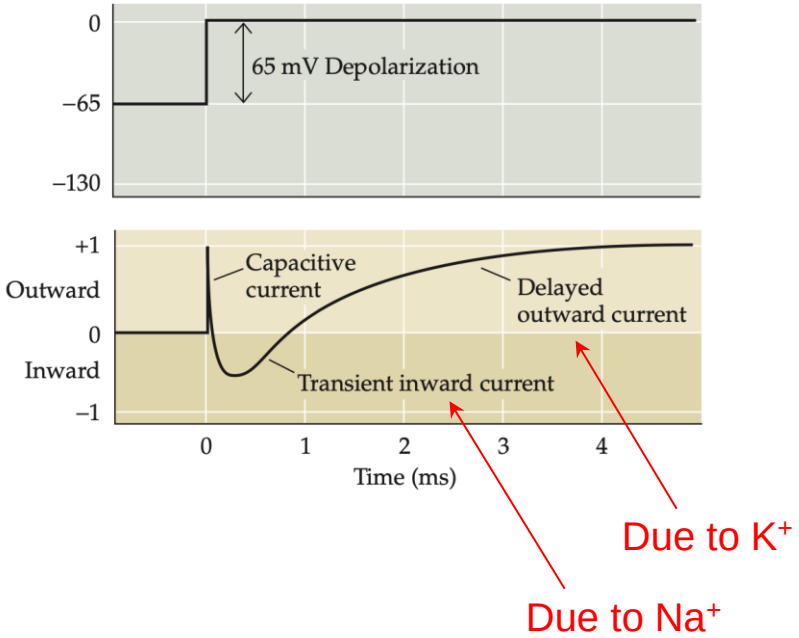
- Excitation (input) beyond threshold level → cell depolarizes above threshold potential → a spike is generated
- This is is the basis for the long-distance transmission of information





Let's look at the current flow across the cell membrane.

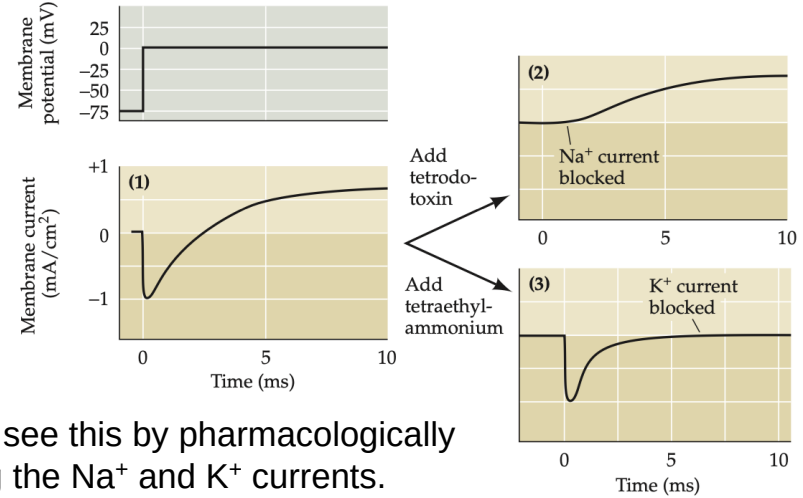
What happens if we artificially depolarize the cell to 0mV?



After a very short capacitive response, **current flows first into, and then out of the cell.**

How does this happen?

The movement of Na^+ and K^+ in and out of the cell!



We can see this by pharmacologically blocking the Na^+ and K^+ currents.

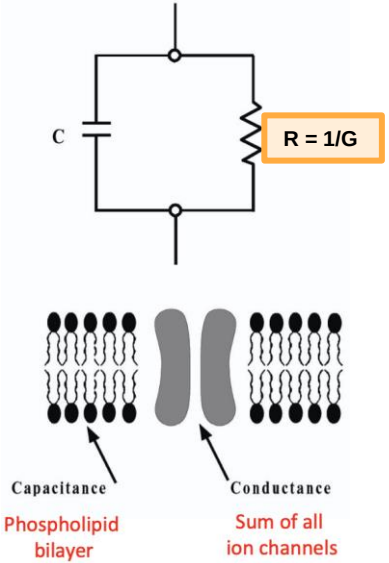
But why do Na^+ and K^+ currents behave the way they do?

Because of the properties of their respective channels!

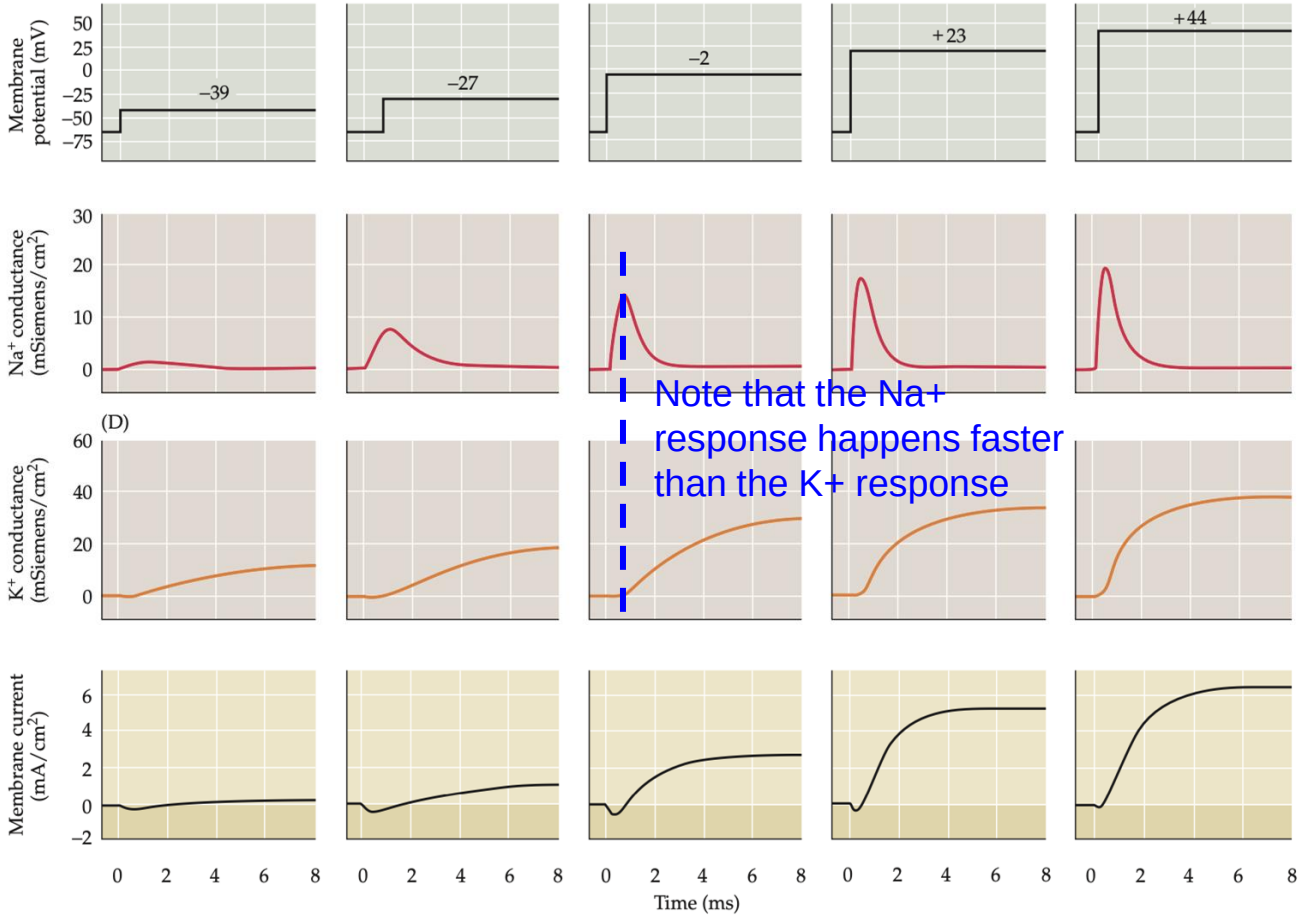
There are ion channels that are selectively permeable to Na^+ and K^+	→	This allows Na^+ and K^+ flows to be controlled separately
These ion channels are voltage-gated	→	This allows the input flow to vary depending on the membrane potential
These ion channels are also time-dependent	→	This allows Na^+ current to happen before the K^+ current
The Na^+ channels have an inactivation mechanism, unlike the K+ channels	→	This explains why the early inward current diminishes quickly

The voltage-gated, time-sensitive permeabilities can be modeled as conductances.

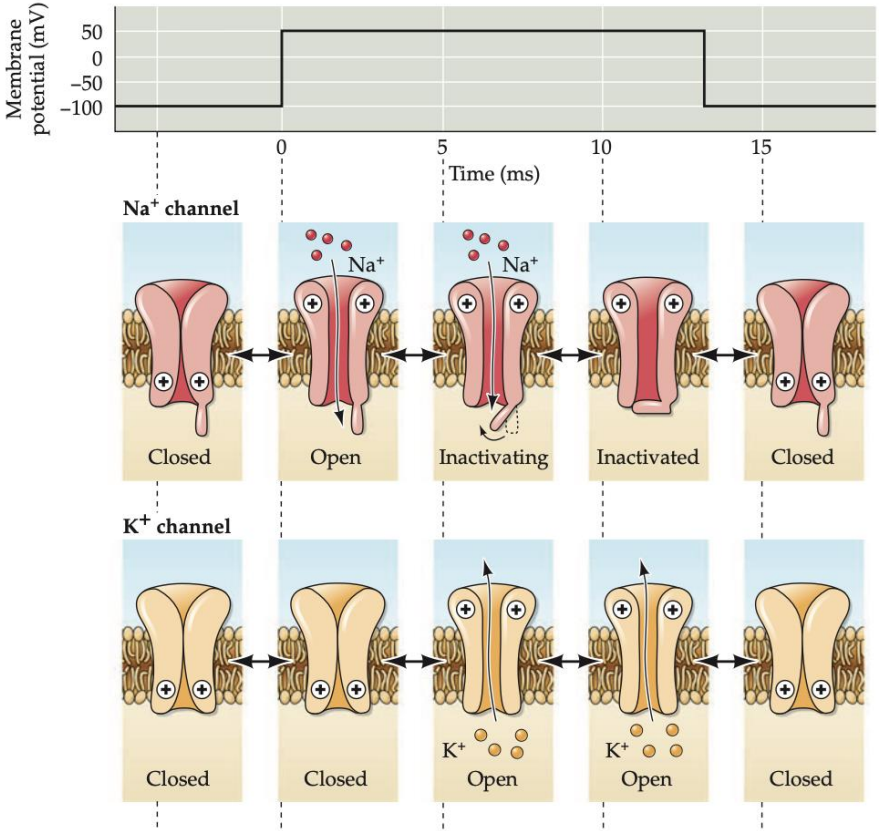
Recall from Unit 1:



$$\text{Conductance} = \frac{1}{\text{Resistance}}$$



A closer look at ion channels and their time-/voltage-dependent activities

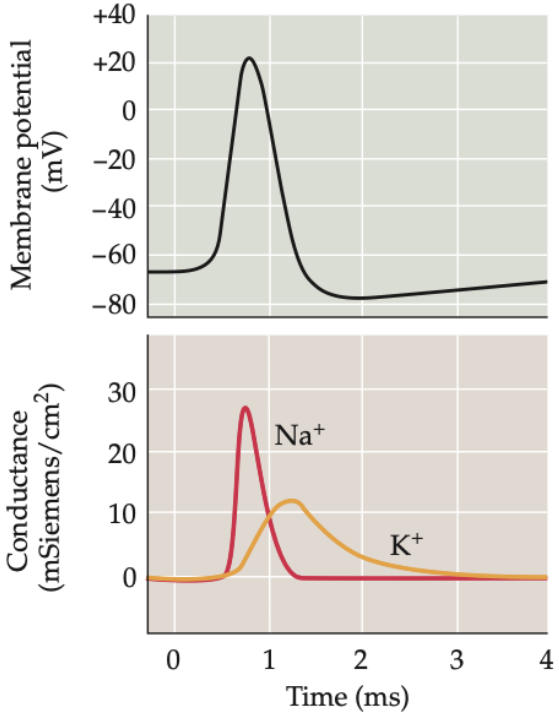


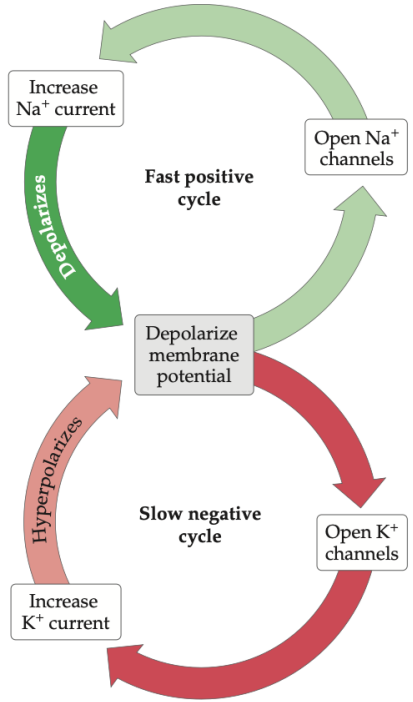
Note that:

- Na^+ channels have an inactivation mechanism
- There is a time difference between Na^+ and K^+ channel opening

From there, we can reconstruct membrane potential as a function of time

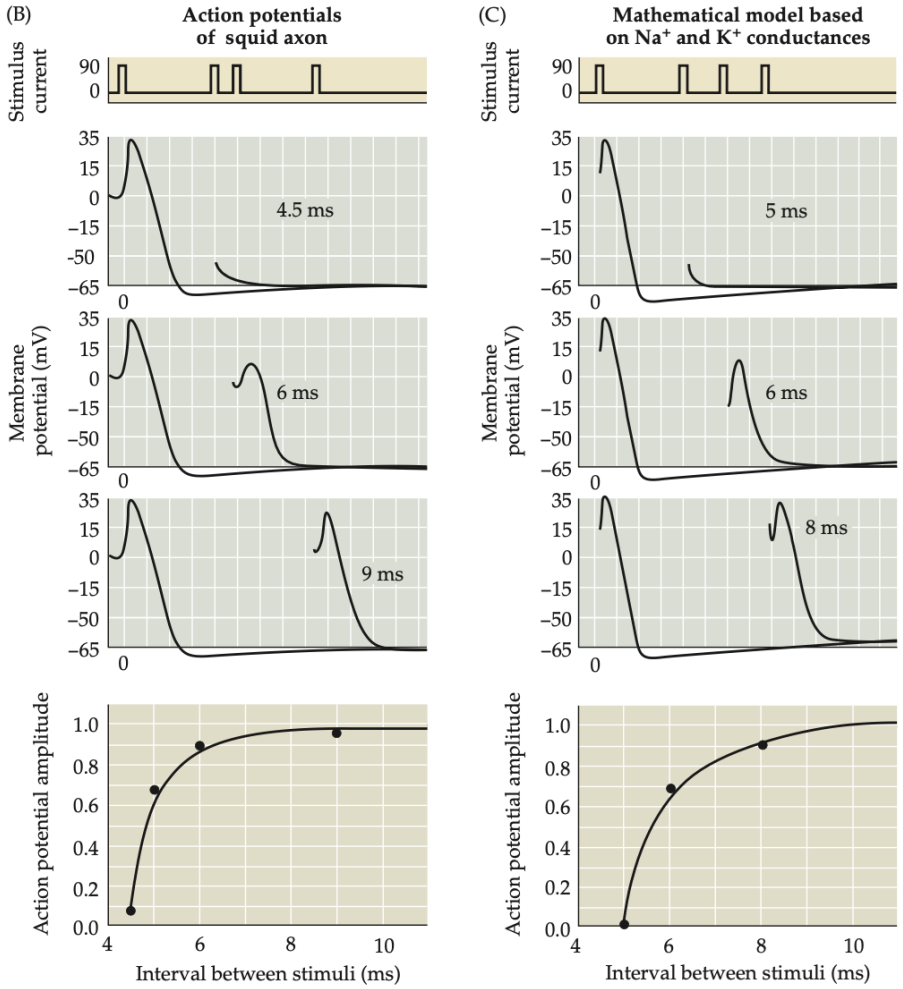
→ ***Action Potential***





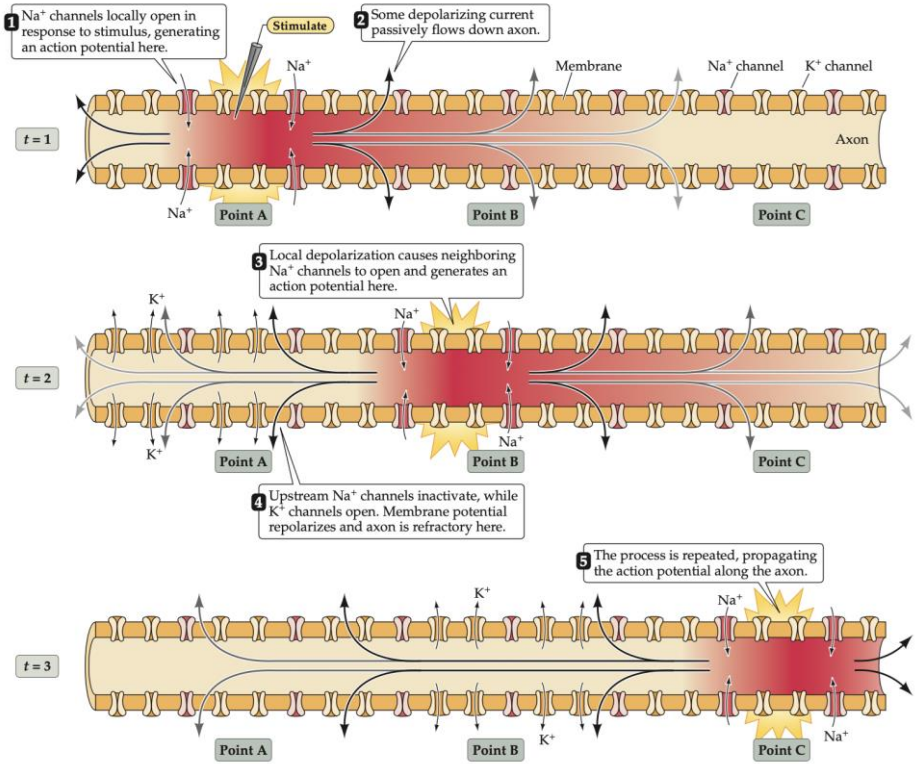
Positive and negative feedback loops: This explains the all-or-none nature of action potentials.

The model also predicts the refractory periods: inability to form a second action potential for a period of time after the first one.



Long-distance signaling by means of Action Potentials

- Active current: flow of ions in and out of the cell
- Passive current: current flows passively along the axon

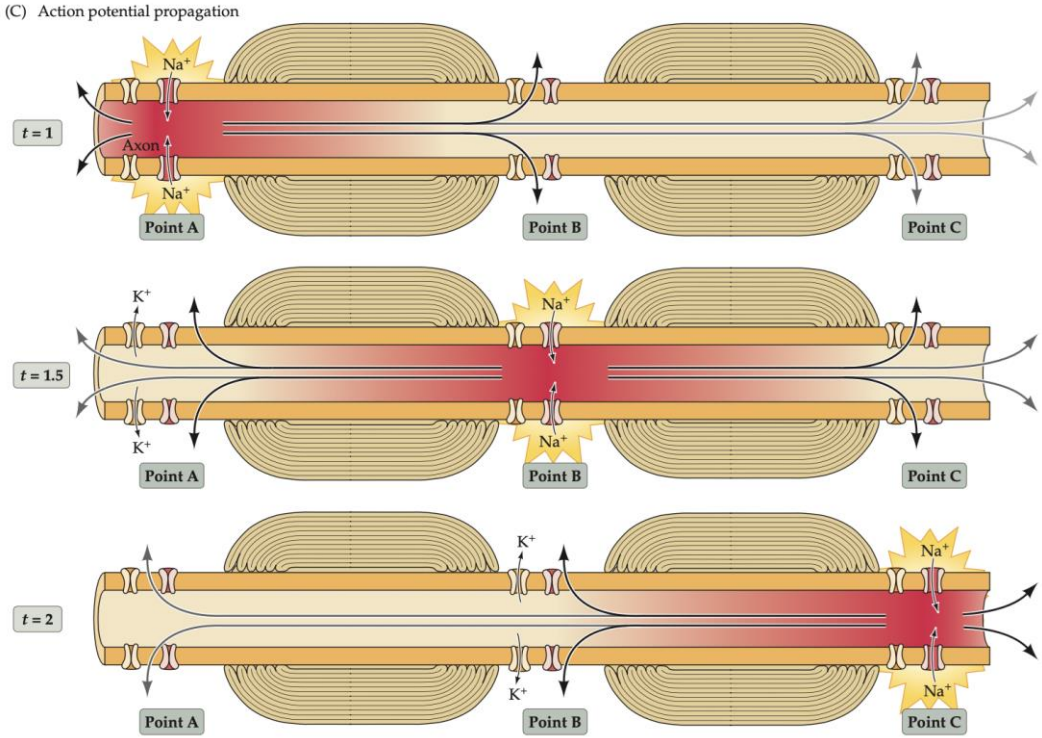


The passive current flow triggers the same positive feedback loop and carries the action potential down the axon.

Why does action potential not travel backward?

→ Inactivation of Na+ channels leads to **Refractory period**

Faster propagation: Saltatory conduction of action potentials in myelinated axons



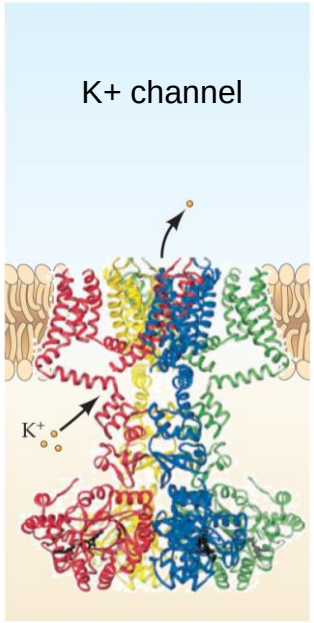
Insulating layers around the axons called myelin sheath. These are glial cells.

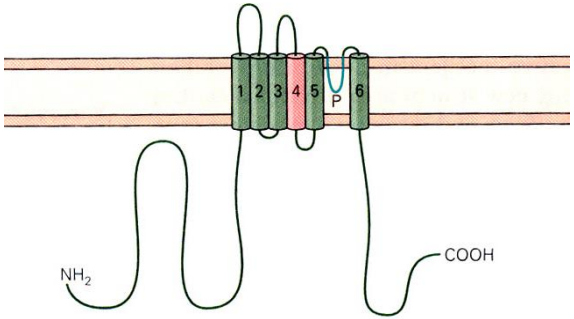
No ion channels along the axon except at gaps called Nodes of Ranvier.

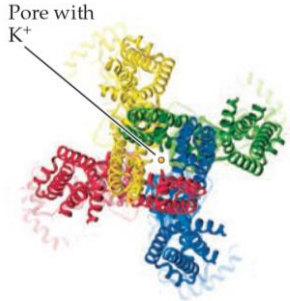
Faster propagation because:

- Effectively thicker membranes → lower capacitance
- Less current leak through the membrane → passive current can trigger action potential further down the axon (at the next Node of Ranvier)

voltage-gated K+ ion channels





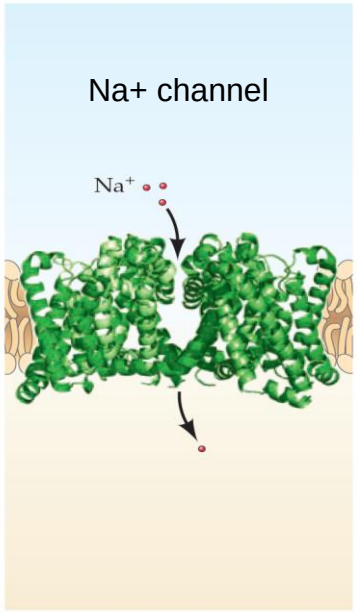


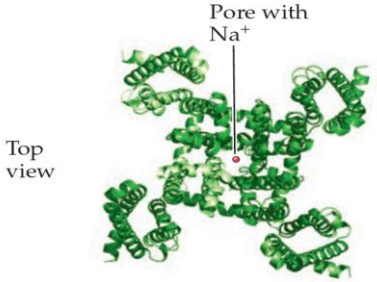
- tetramers (4 subunits form a channel)
- Voltage gating: S4 domain

Kandel, Figure 7-14

Purves, Figure 4.6

voltage-gated Na+ ion channels





- 4 "repeats" of K^+ channel-like structure
- Separate activation and inactivation gates