Neurons and Electrical Signalling

Lecture 18

Neurons

Neurons

- What are they?
- What is their structure?
- How do they send a signal along their length?
- How can this signal be disrupted?

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- The nervous system is made of specialized cells called neurons
    - What makes them special? They are capable of creating and transmitting electrical impulses.

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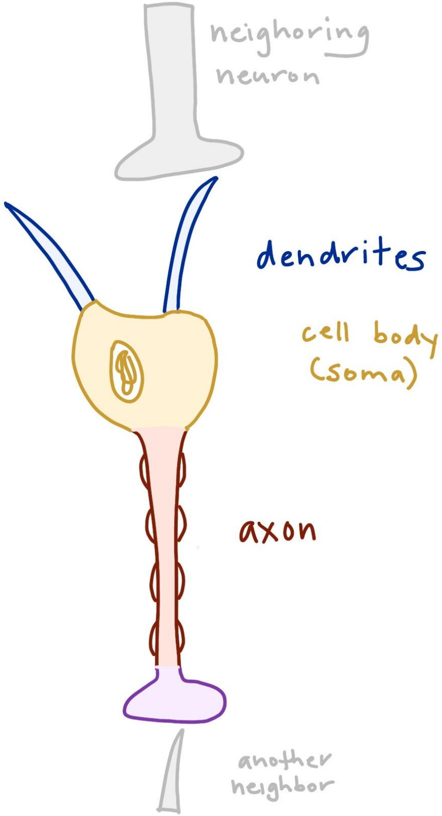

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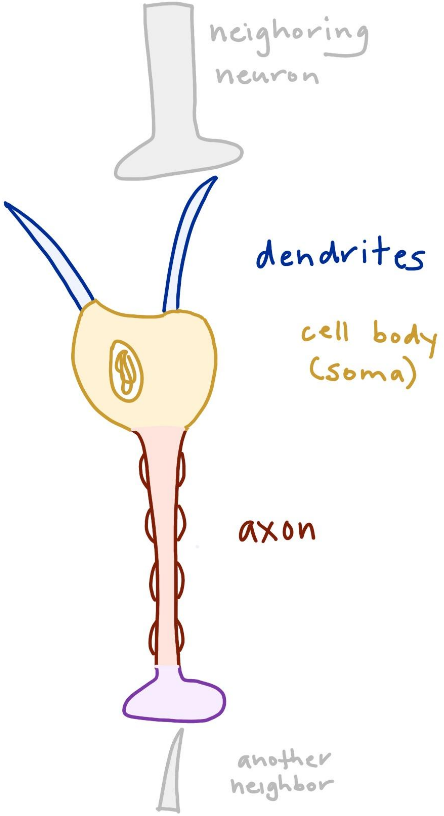

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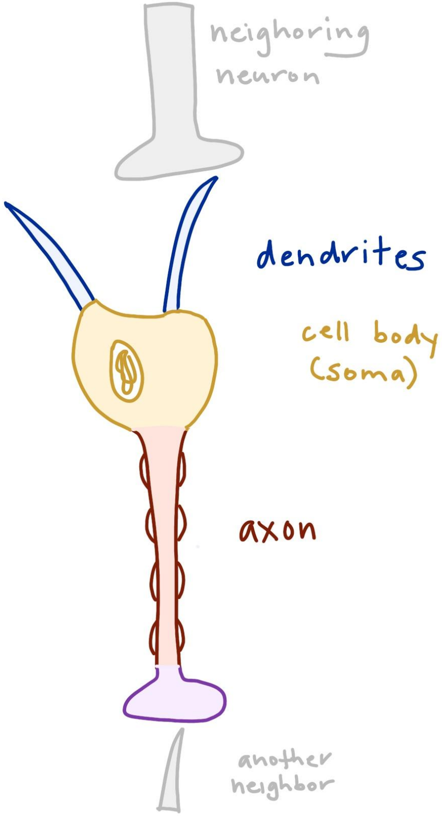

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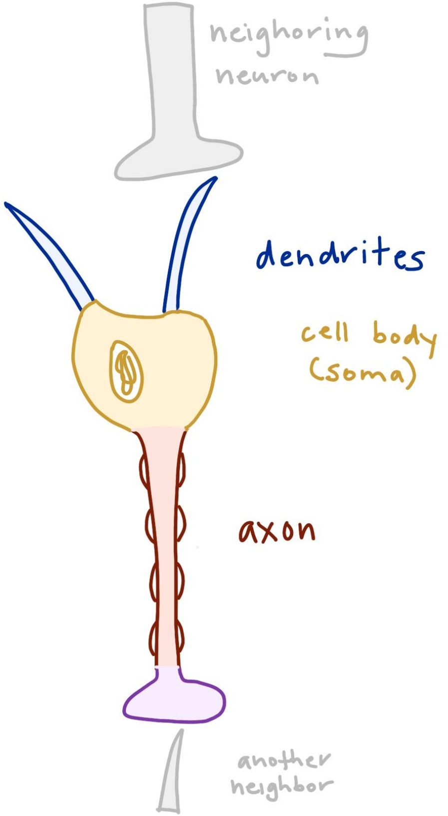

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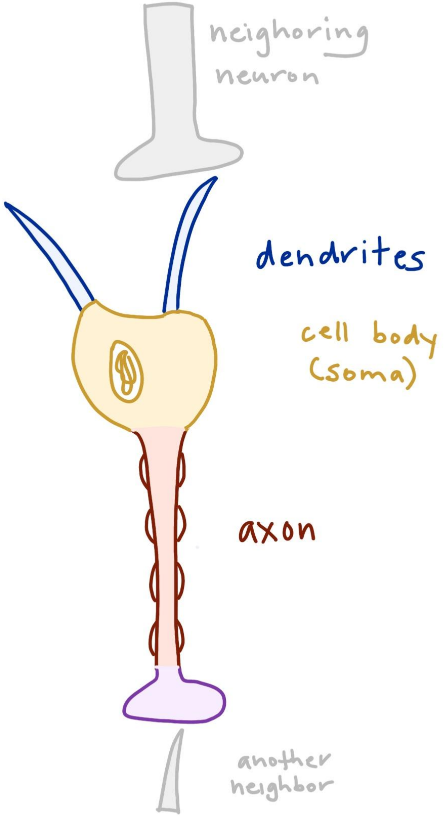

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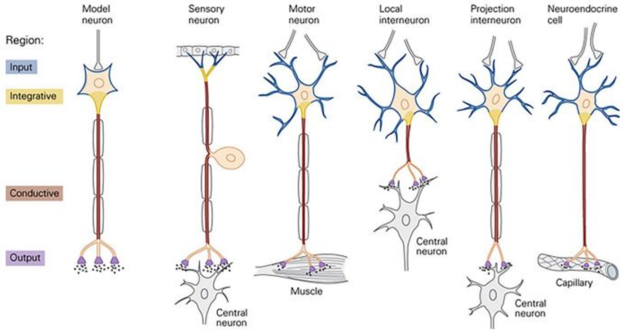

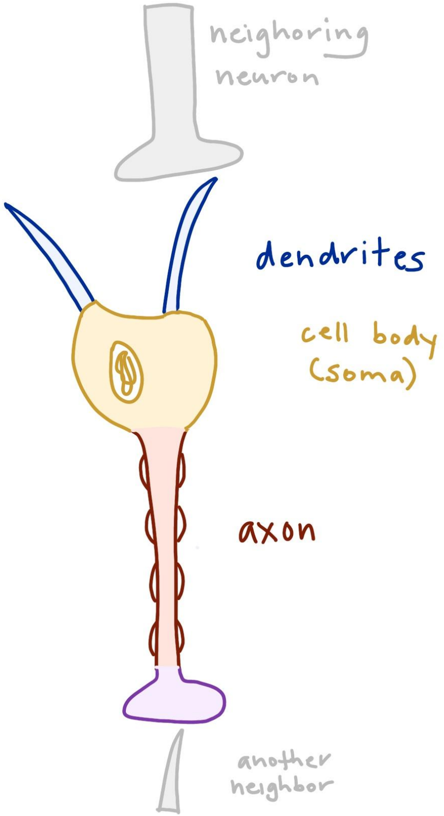

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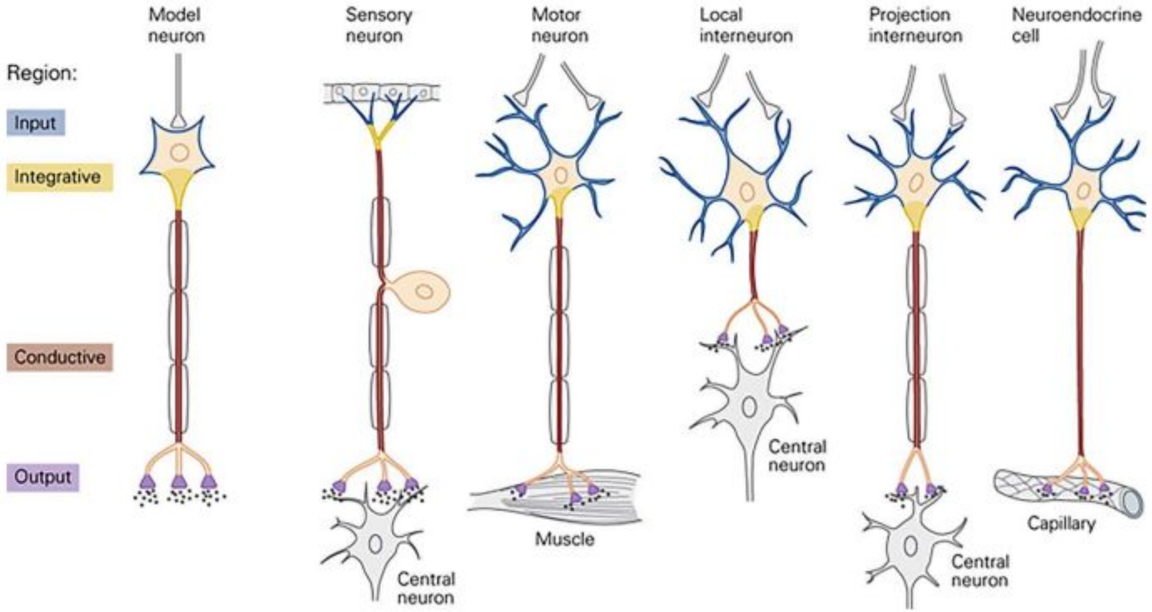

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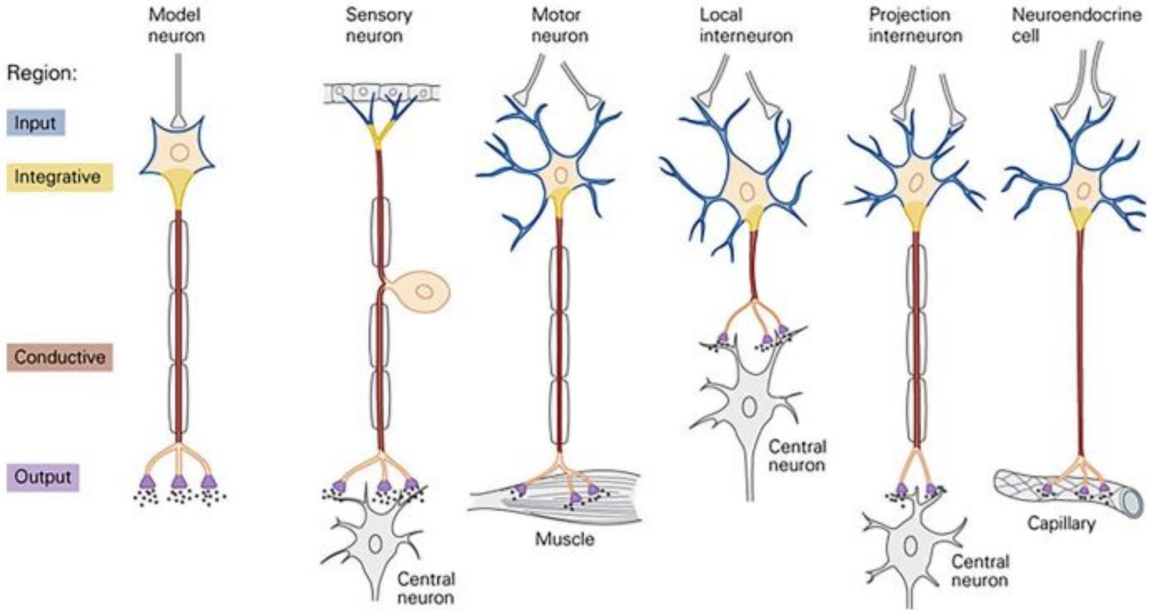

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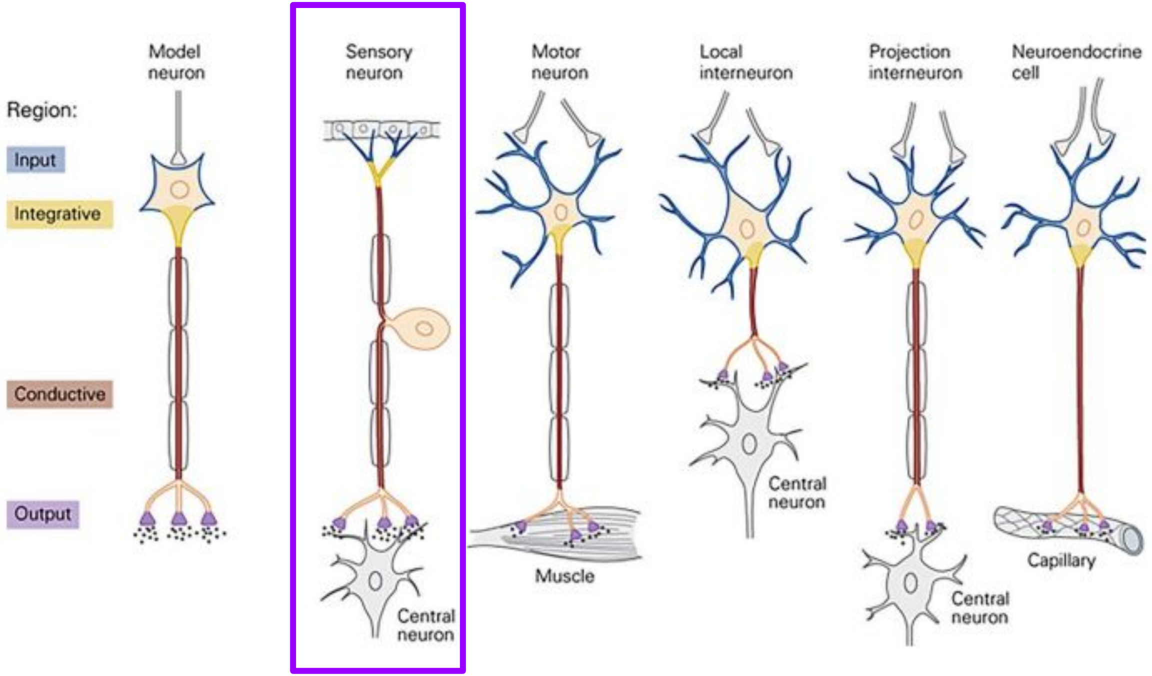

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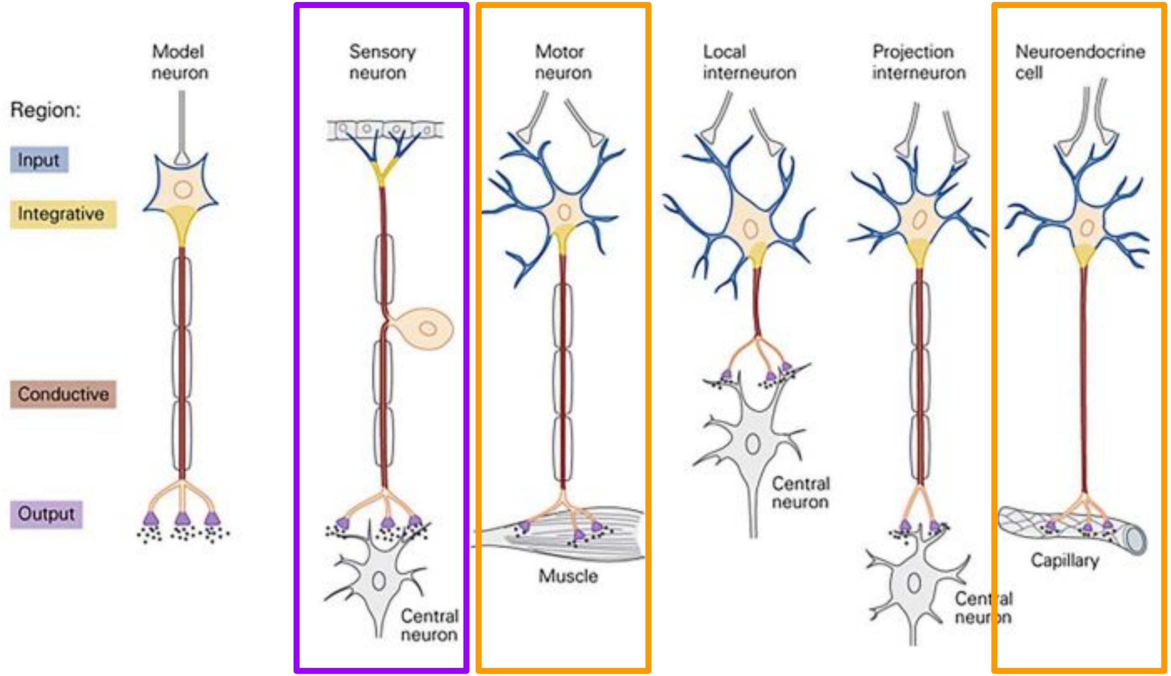
    - **Others** connect the nervous system and endocrine systems or muscles



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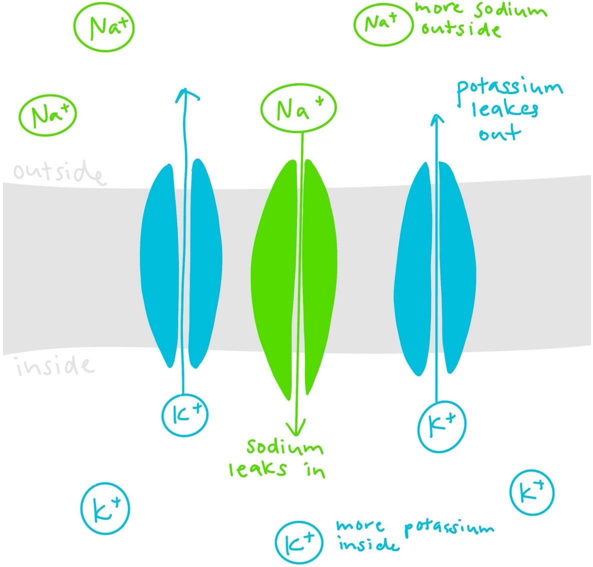

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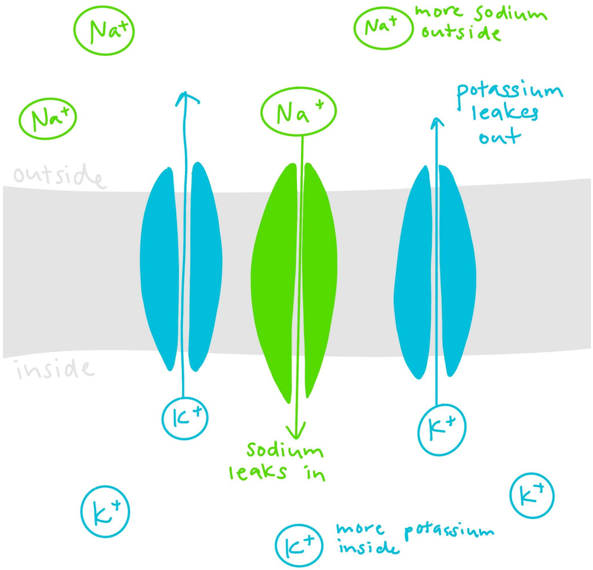

Note that there are **more** potassium leak channels, so more potassium leaves compared to the amount of sodium coming in

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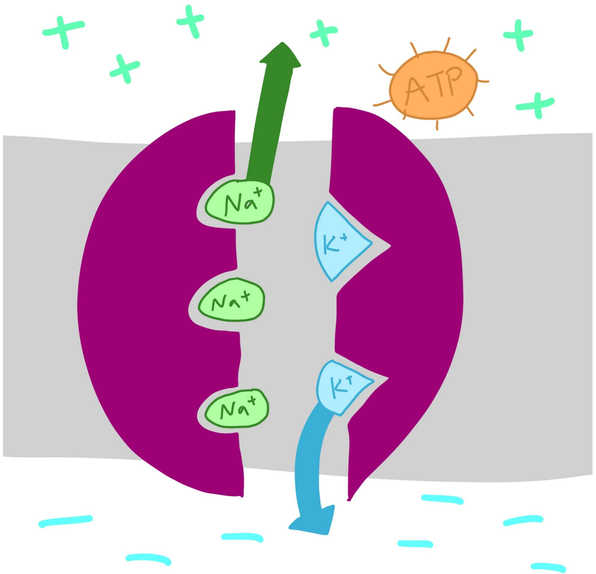

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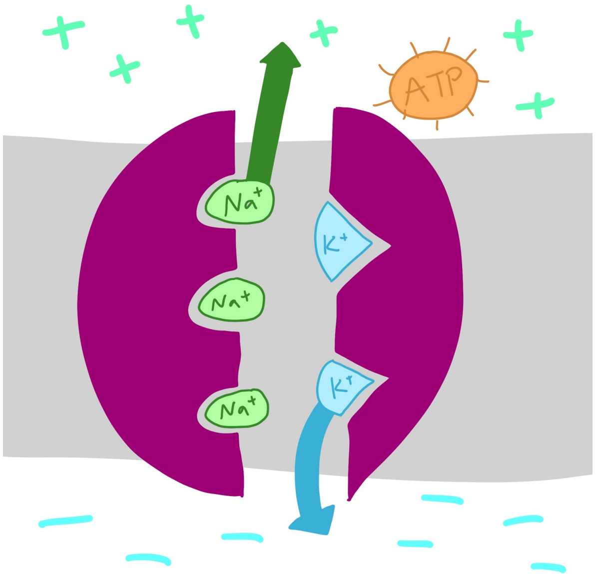

Note this produces a net **loss of one positive charge** out of the cell.

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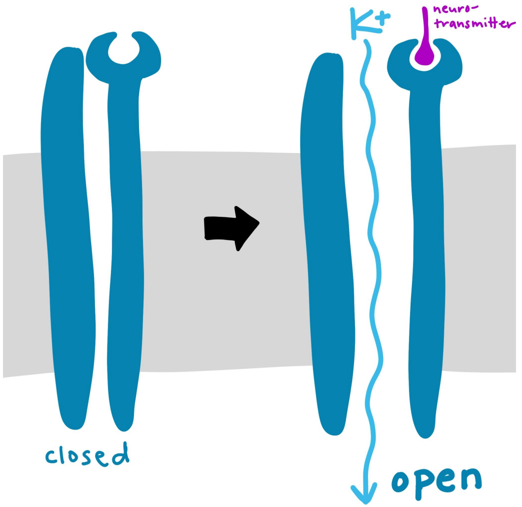

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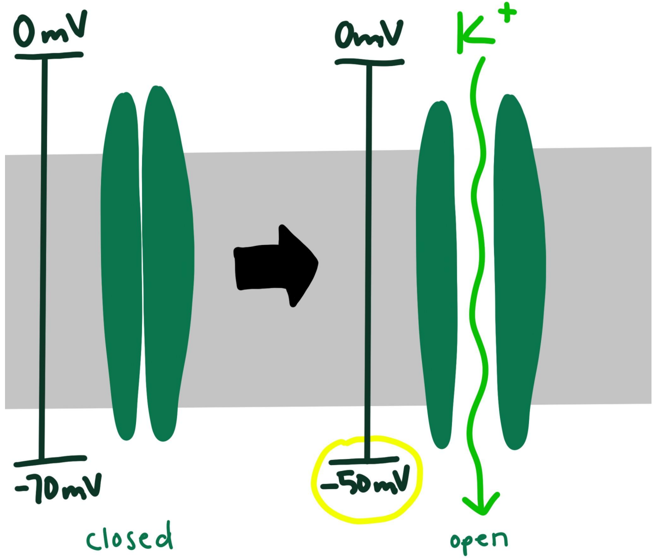

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You should understand how these work together to create 1) resting potential and 2) action potentials. We will cover that next.

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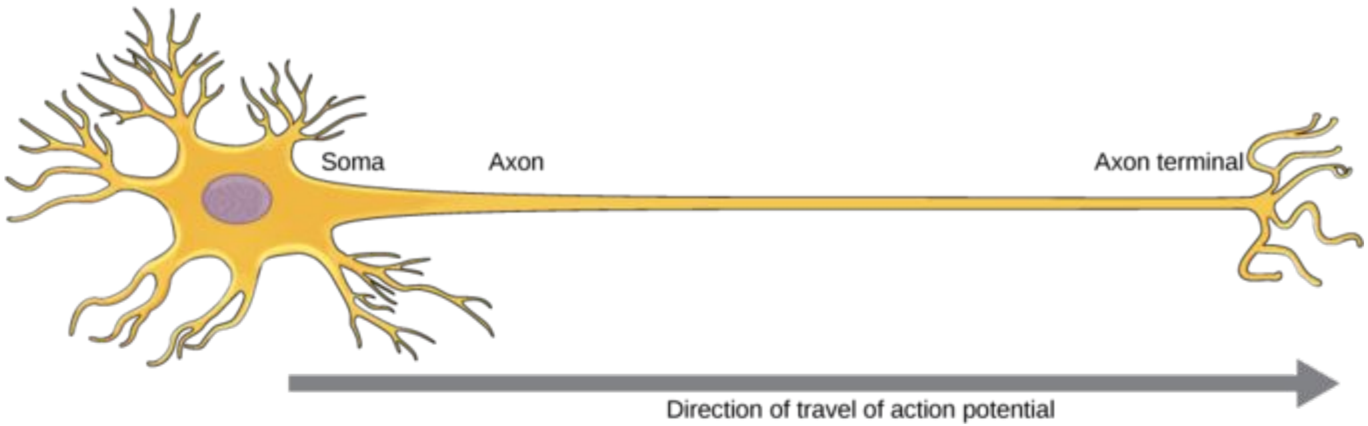

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First, we must understand what is happening when a neuron is at rest.

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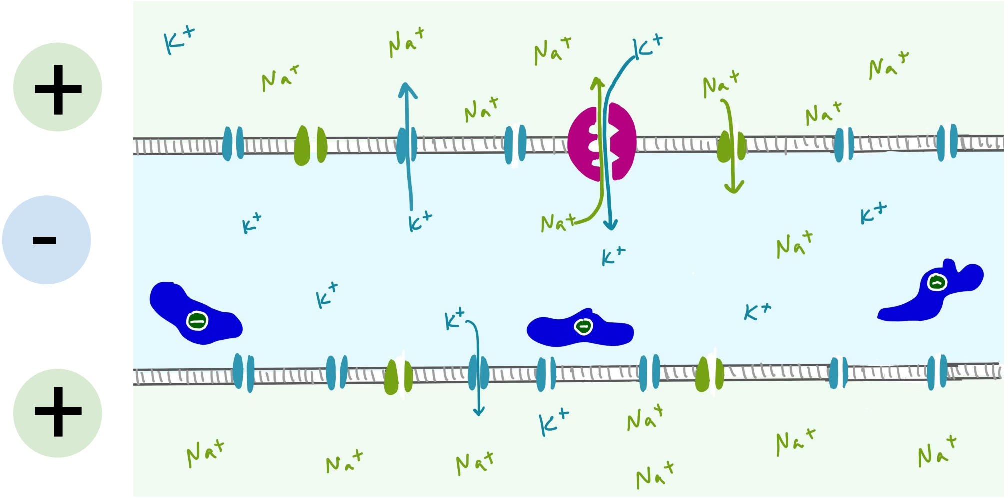

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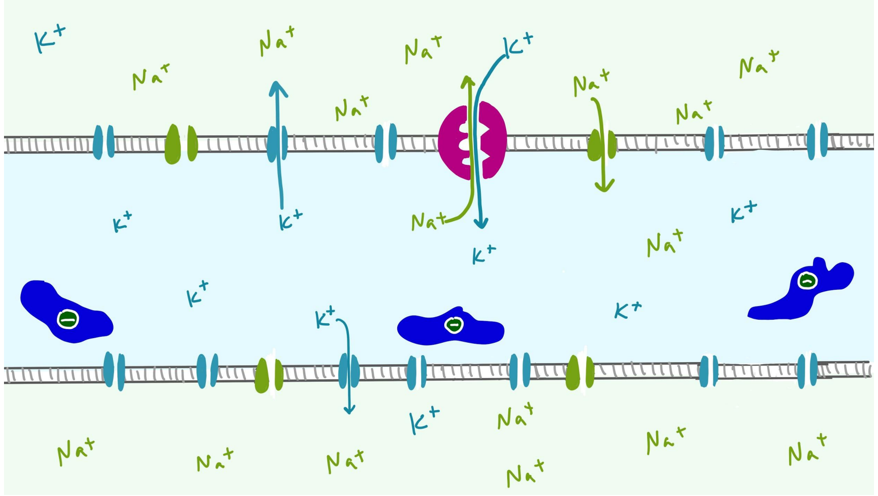

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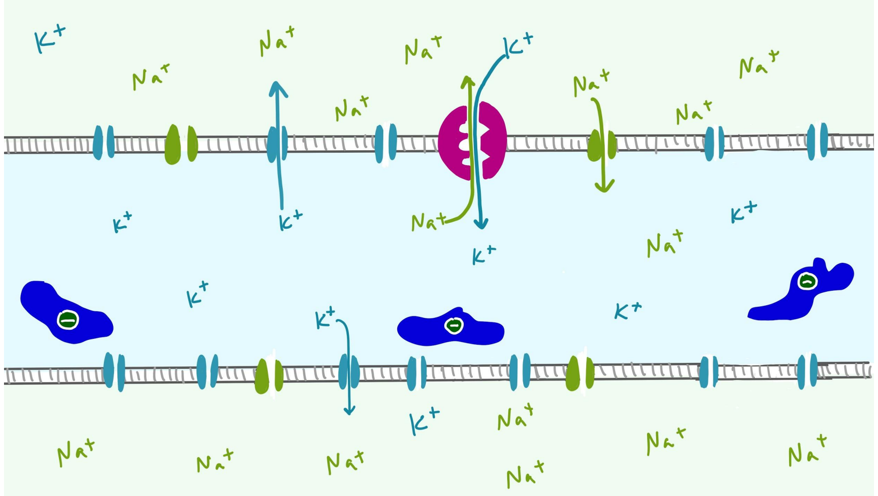
        - There are **more** potassium channels for potassium to leak out and fewer sodium channels for sodium to leak in



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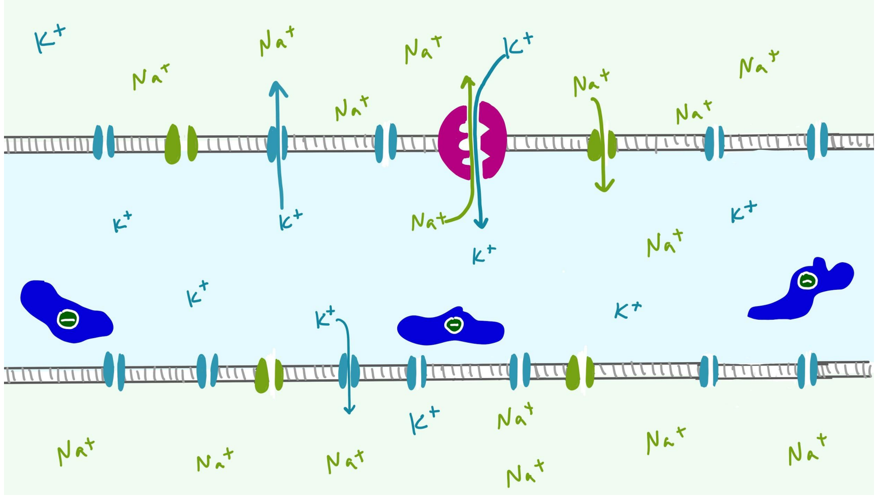
        - There are **more** potassium channels for potassium to leak out and fewer sodium channels for sodium to leak in
        - The sodium-potassium ATPase **pumps 3 sodiums out but only 2 potassiums in**
            - This is probably the most important factor.



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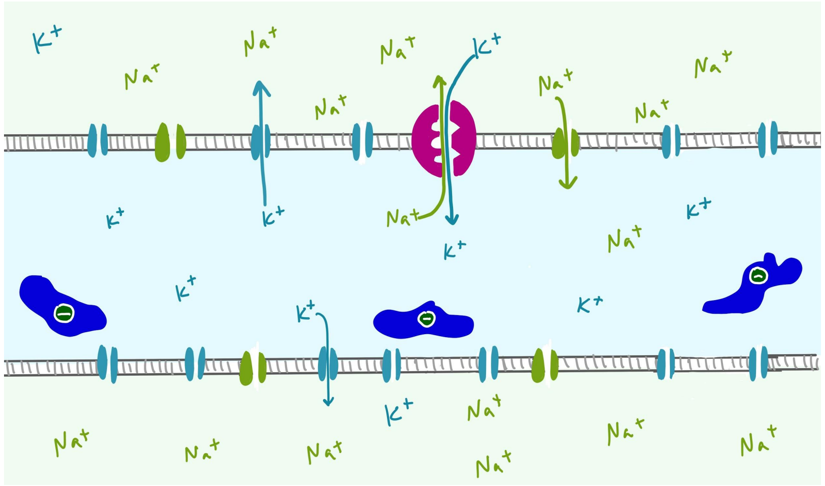
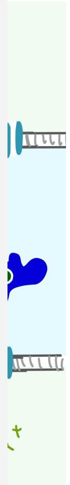


- All together, this makes the inside of the neuron 70 mV **more negative**:
    - Meaning a resting potential of -70 mV

How do neurons make these electrical i

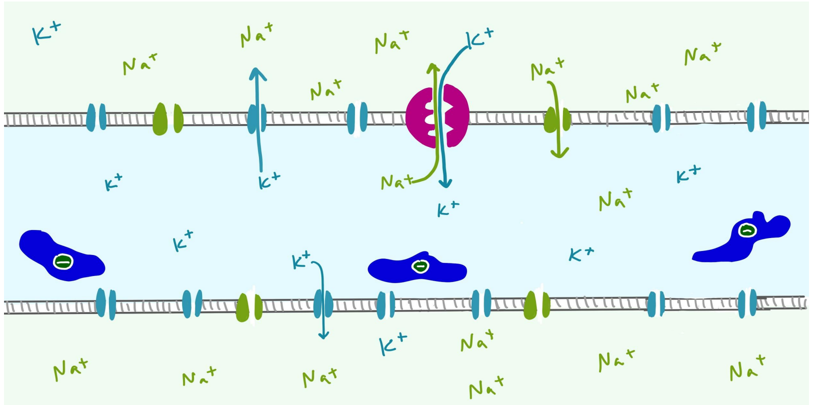
At this point in the lecture, they covered
1) the Nernst Equation and
2) graded hyper- and depolarizations.
I will talk about those later, because it will make more sense later.



Meaning a resting potential of -70 mV

How do neurons make electrical impulses?

- As we just saw, at rest, a neuron has a resting potential of -70 mV.



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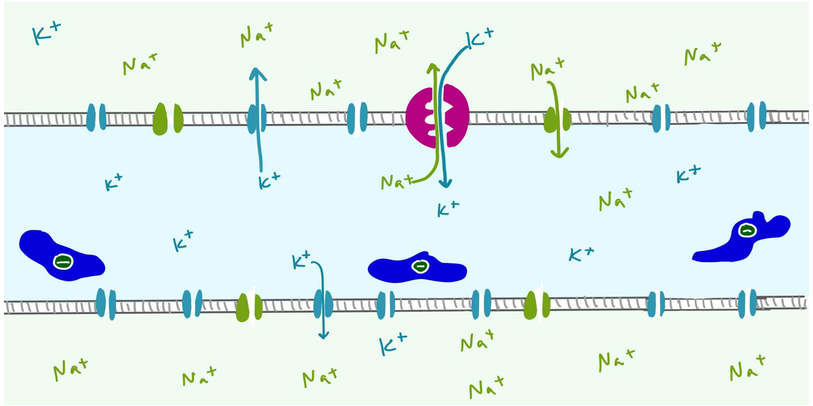

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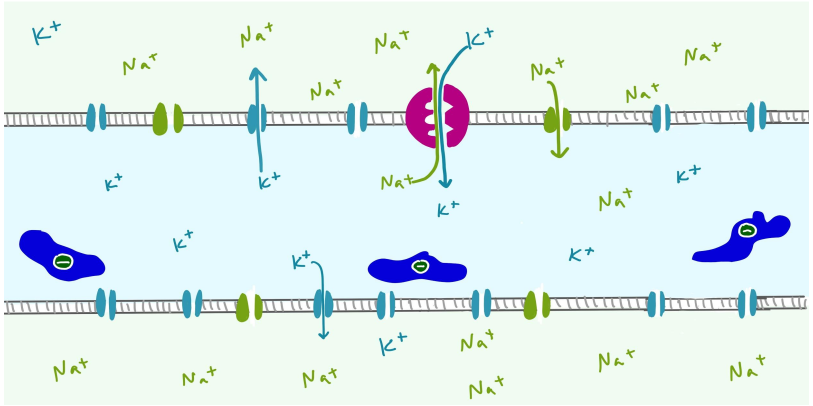
- As we just saw, at rest, a neuron has a resting potential of -70 mV.
- To send a signal, there must be a change in this potential.
- There are two ways the potential can change:
  - Graded potentials
  - Action potentials



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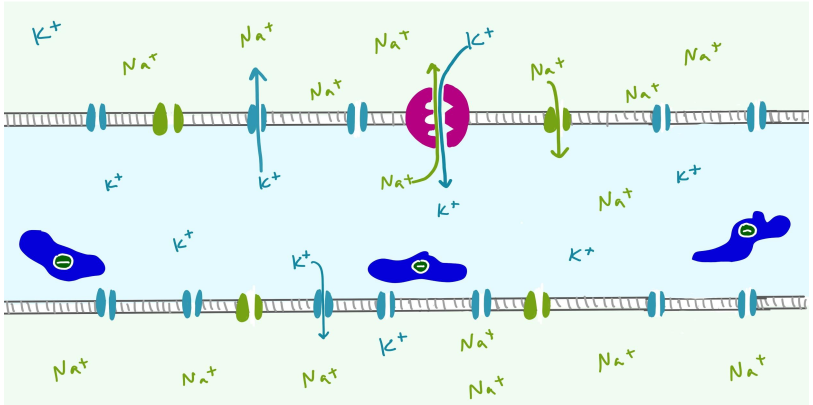
- We will talk about **action potentials** first.



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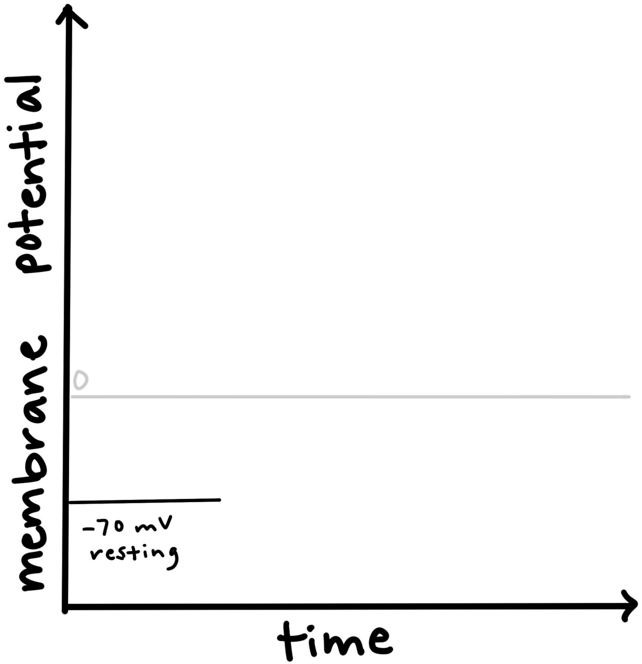

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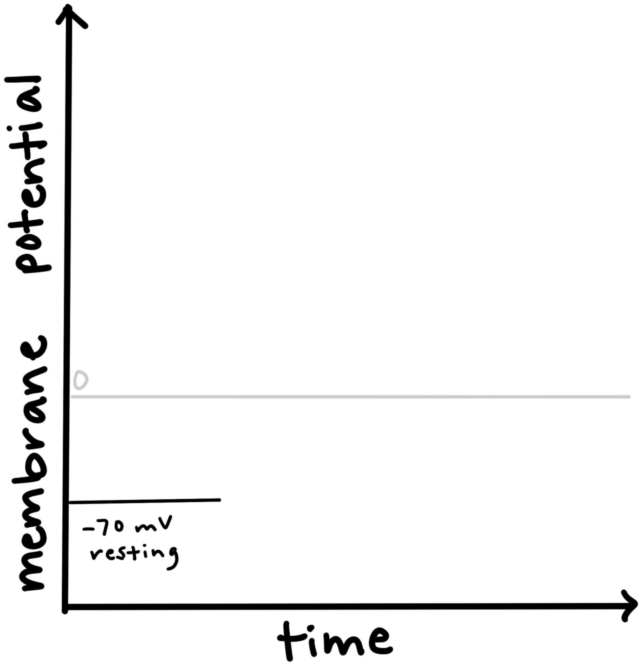
There is:

More sodium outside the neuron

More potassium outside the neuron



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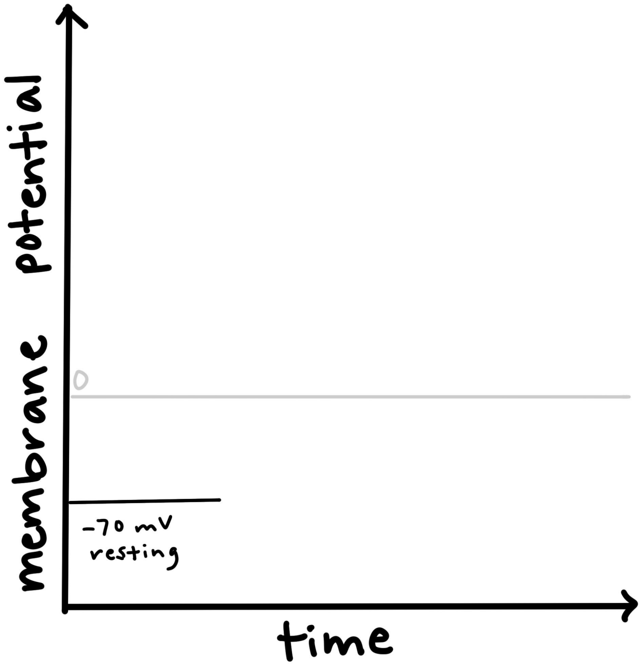
Ligand-gated channels are closed

Voltage-gated channels are closed



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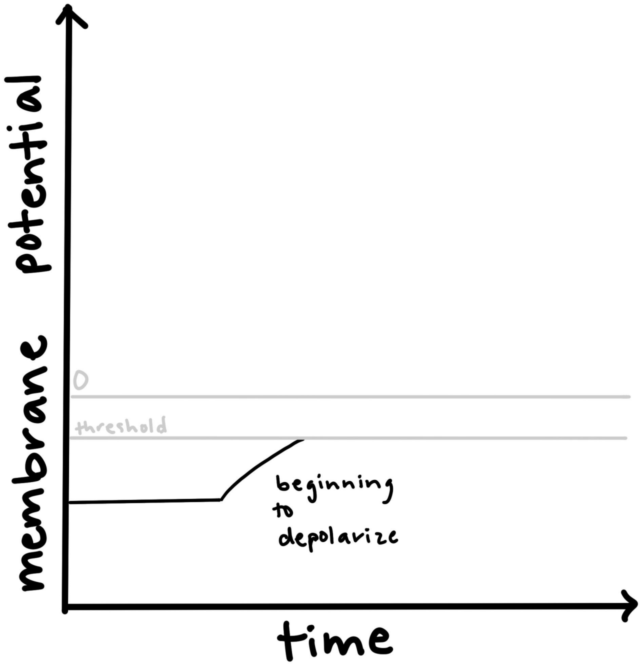
Now a stimulus causes **ligand-gated sodium channels** in the patch to open.



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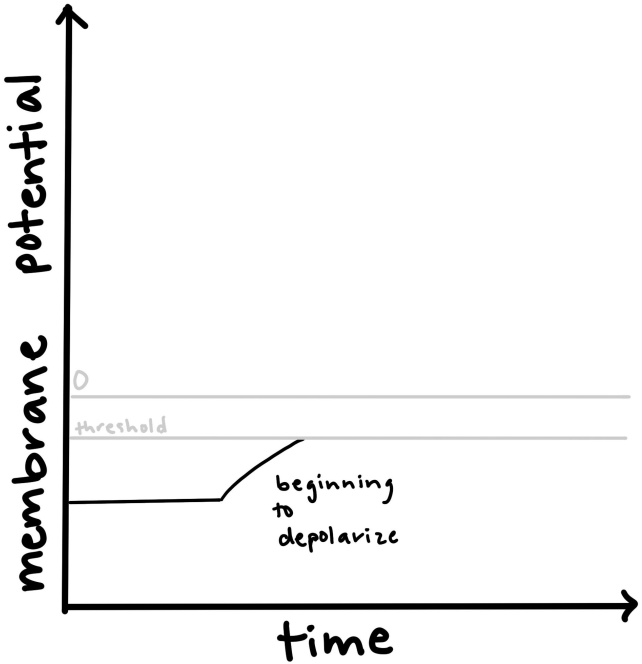

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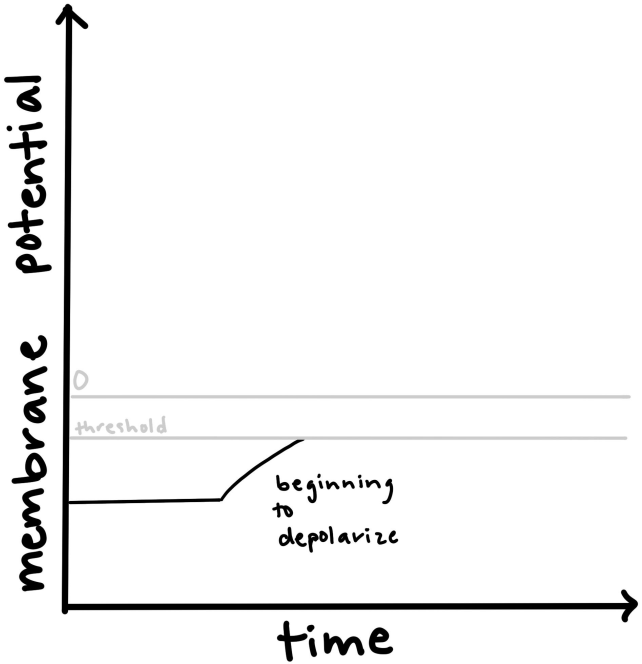
Some sodium comes into this neuron patch

This begins to depolarize this neuron patch



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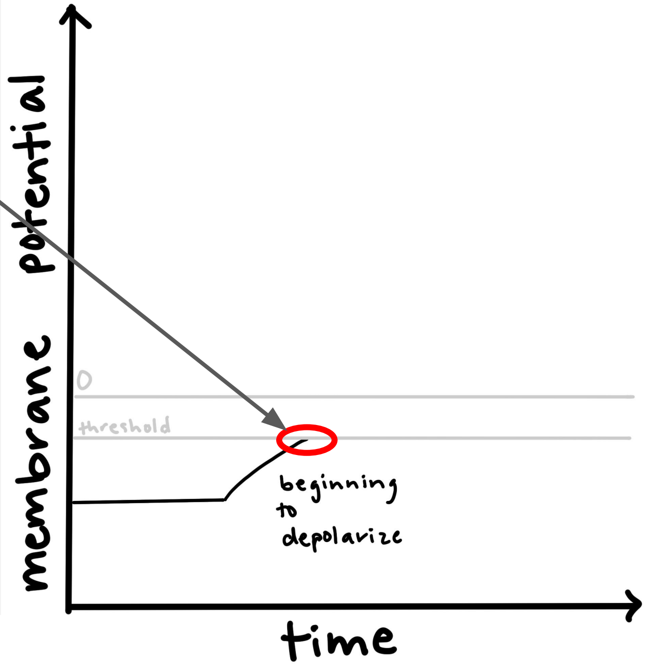
We reach the threshold potential.



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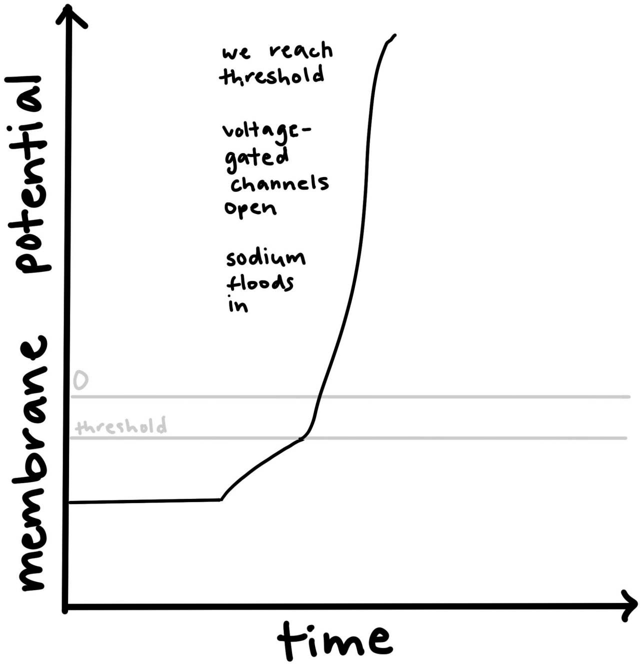
We reach the threshold potential.

The voltage-gated channels open.



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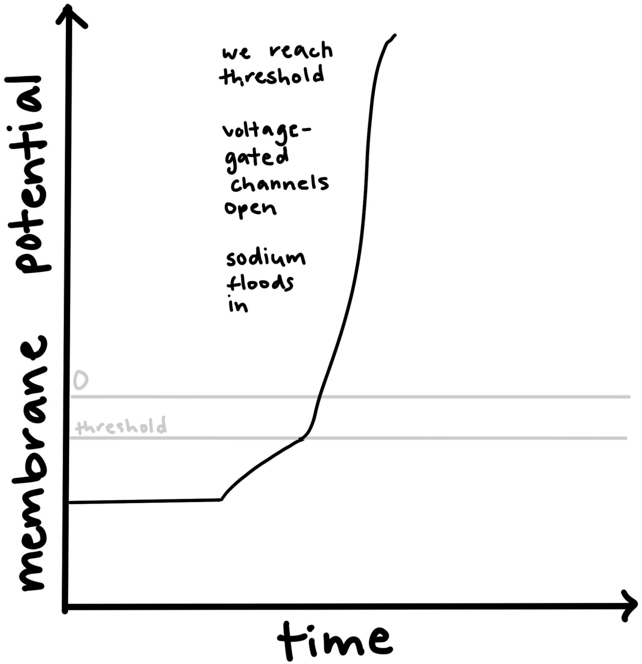
The voltage-gated channels open.

Sodium channels open fastest



How do action potentials happen?

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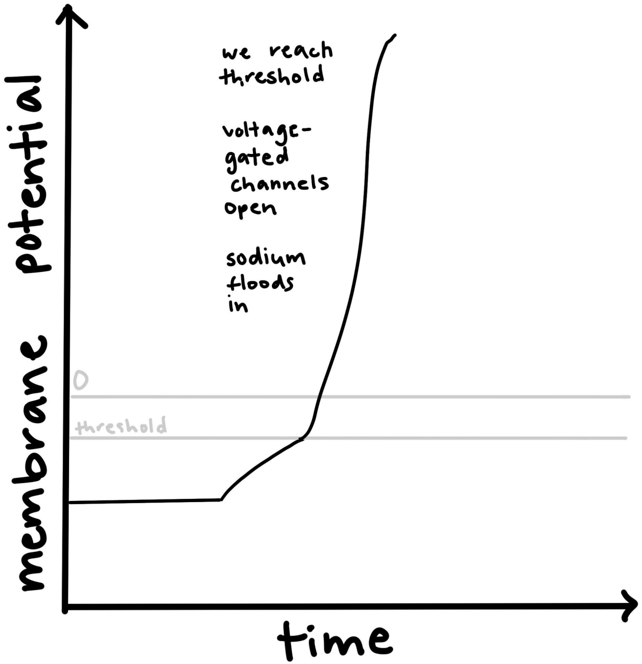
We reach the threshold potential.
The voltage-gated channels open.
Sodium channels open fastest
Sodium floods this patch of the neuron and we have the rising phase of the action potential



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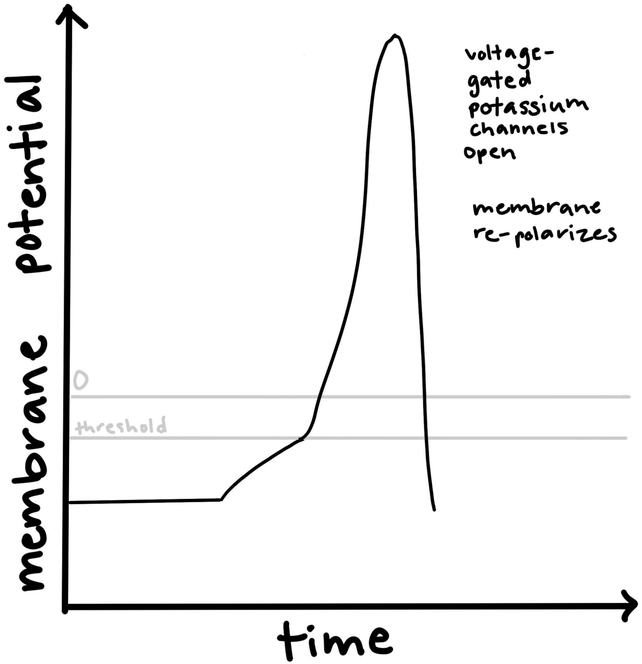
Voltage-gated potassium channels open more slowly, but now they open too.



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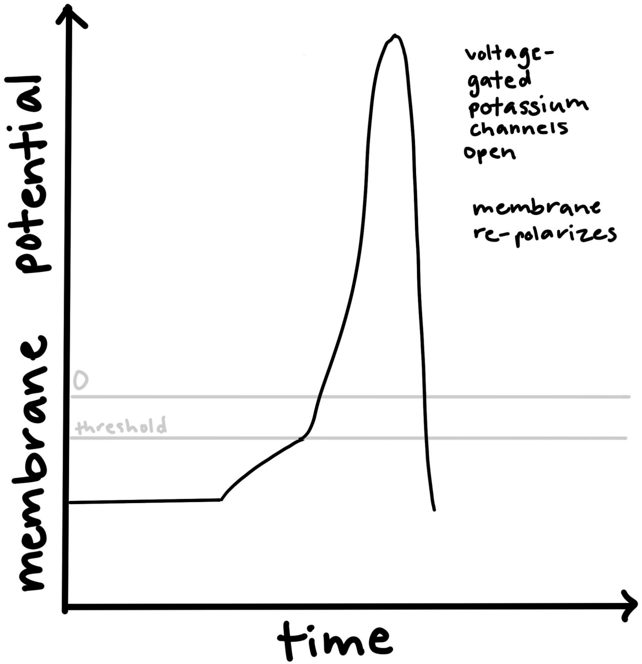
Voltage-gated potassium channels open more slowly, but now they open too.
Potassium rushes out of the neuron



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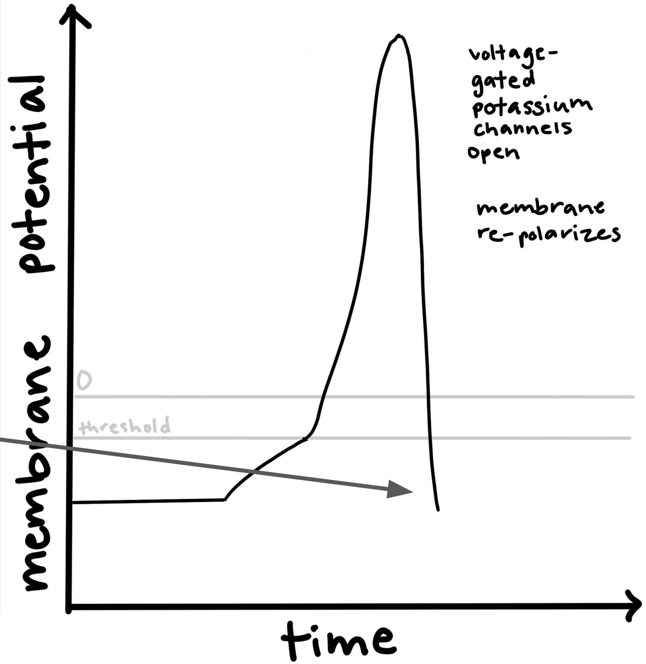
Voltage-gated potassium channels open more slowly, but now they open too.

Potassium rushes out of the neuron

This causes the membrane potential in this part of the neuron to become negative again



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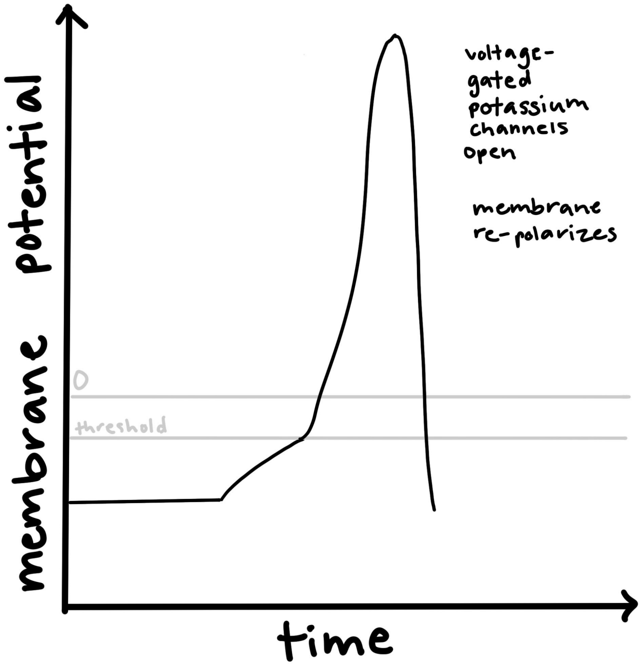
The voltage-gated potassium channels are slow to close, too.



How do action potentials happen?

- There are five steps in creating an action potential:

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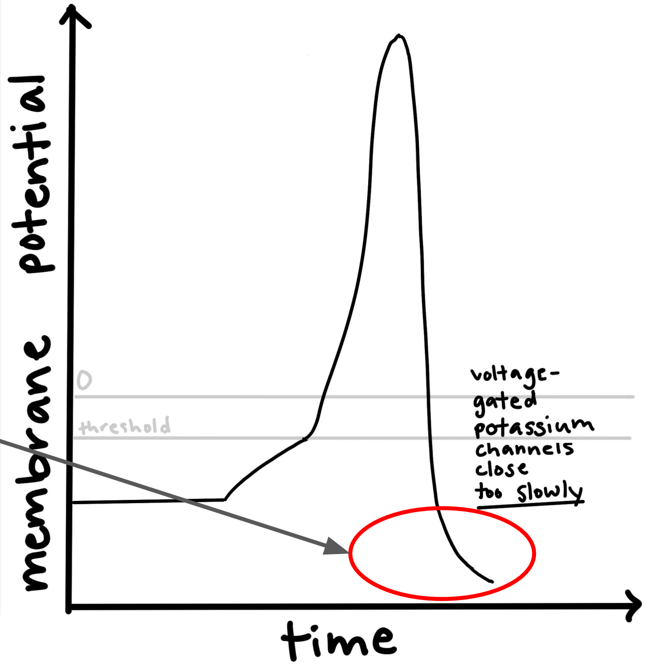

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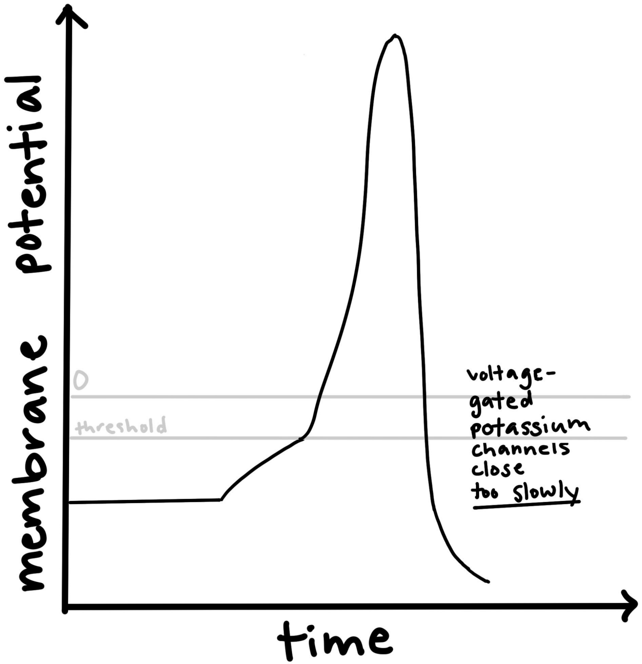

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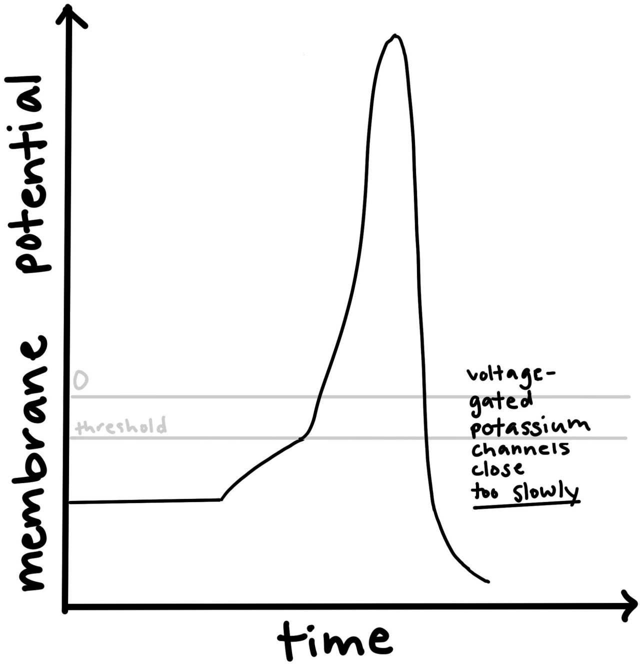
As we will see, this is crucial to ensure that the action potential travels in one direction only.



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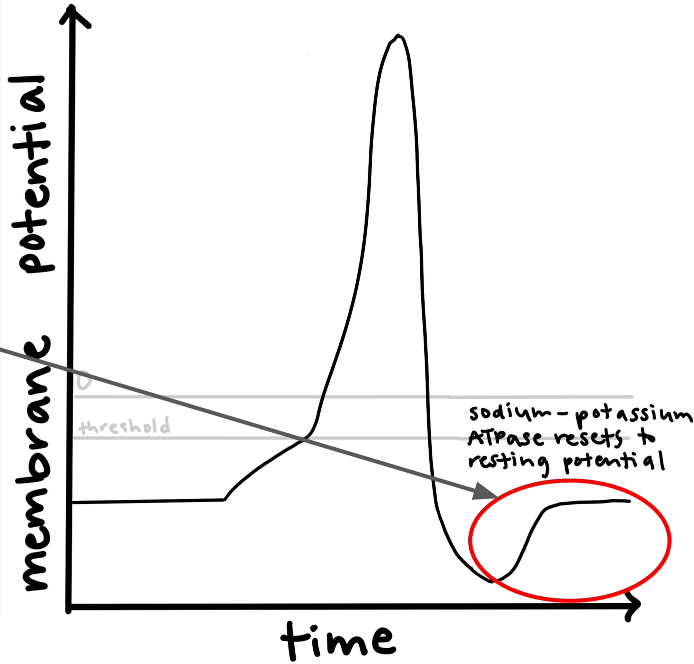
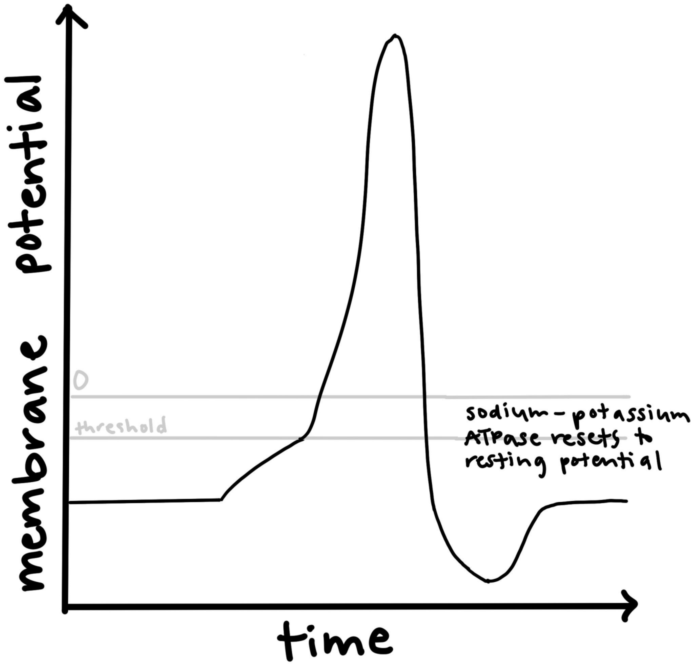
Return to normal

After a brief time, the sodium-potassium ATPase returns the patch of membrane to the normal resting potential.



How do action potentials happen?

- You should really know all five steps in this process
- Make sure to learn:
    - Which channels are open when
    - Which ions move in what direction at each time
    - How the membrane potential changes in each step



Why do action potentials move <u>uni</u>directionally?

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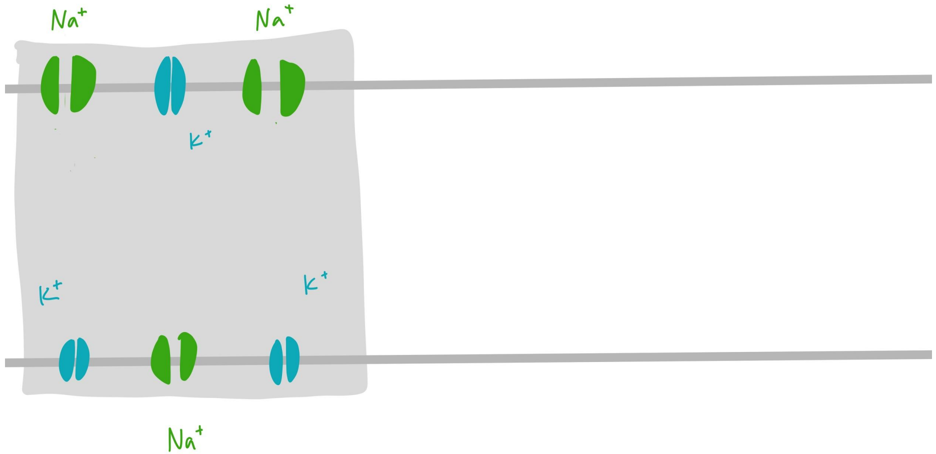

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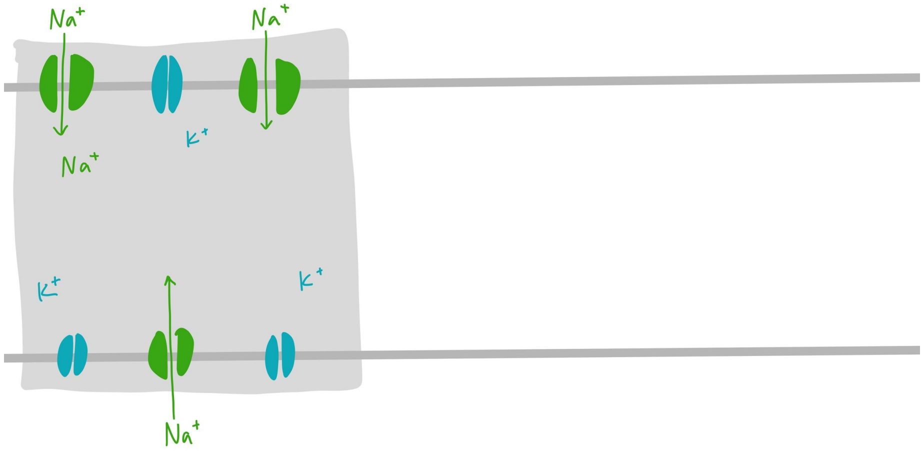
It goes through an action potential and sodium rushes in as it depolarizes.



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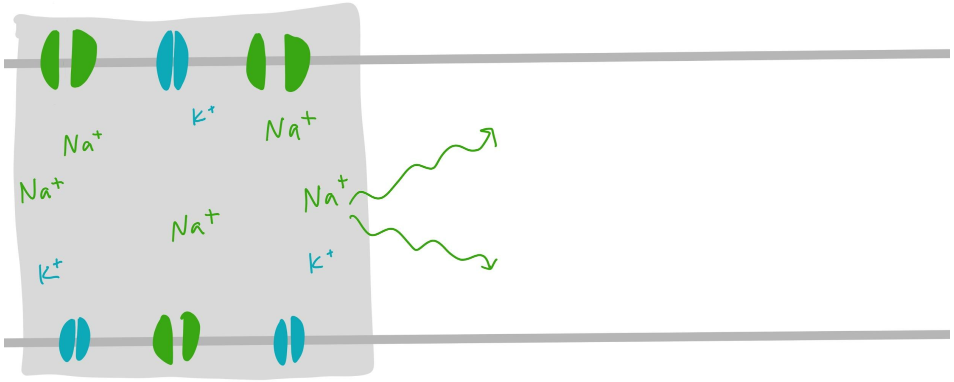

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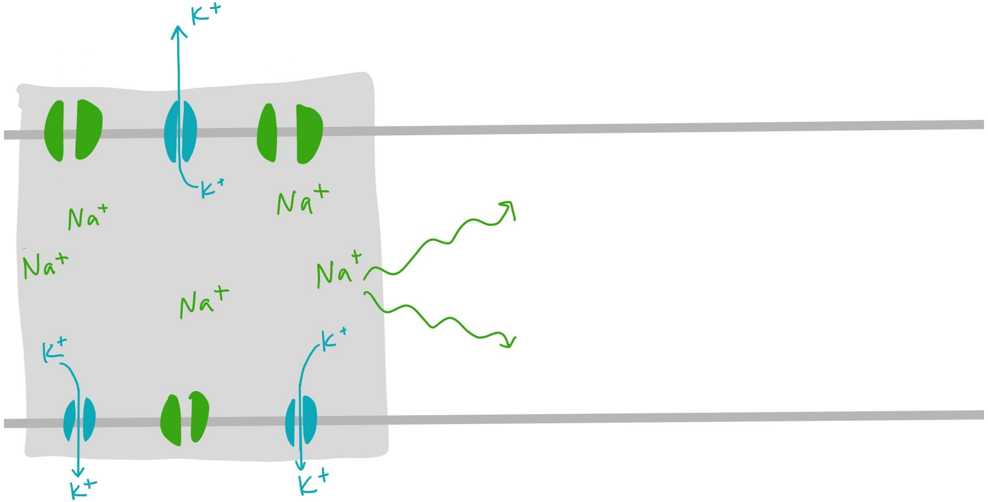

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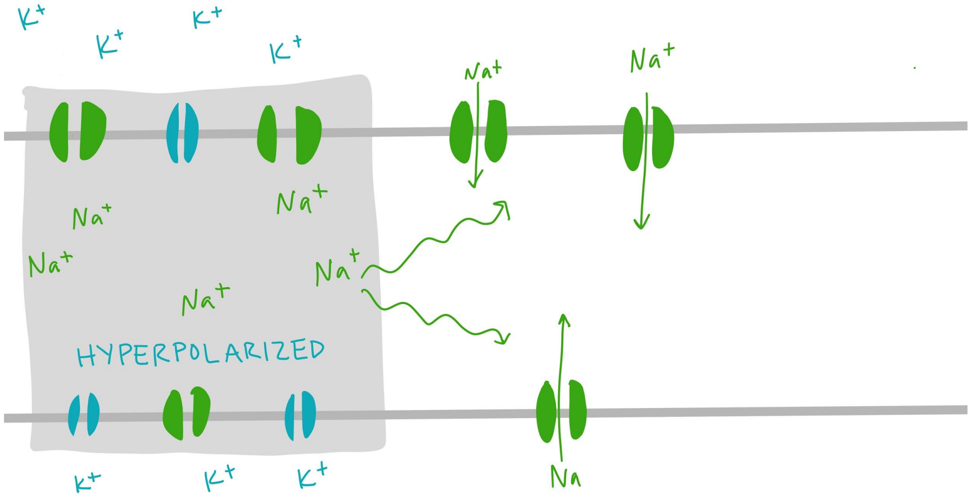

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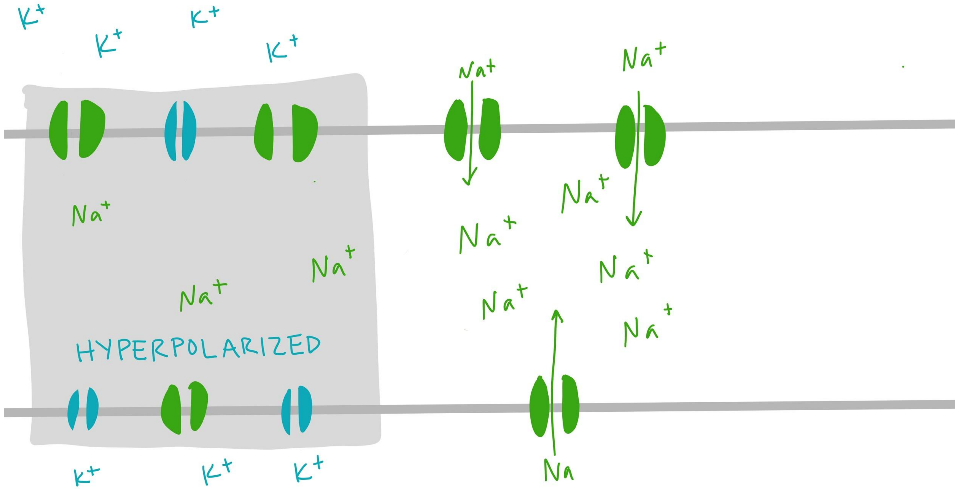

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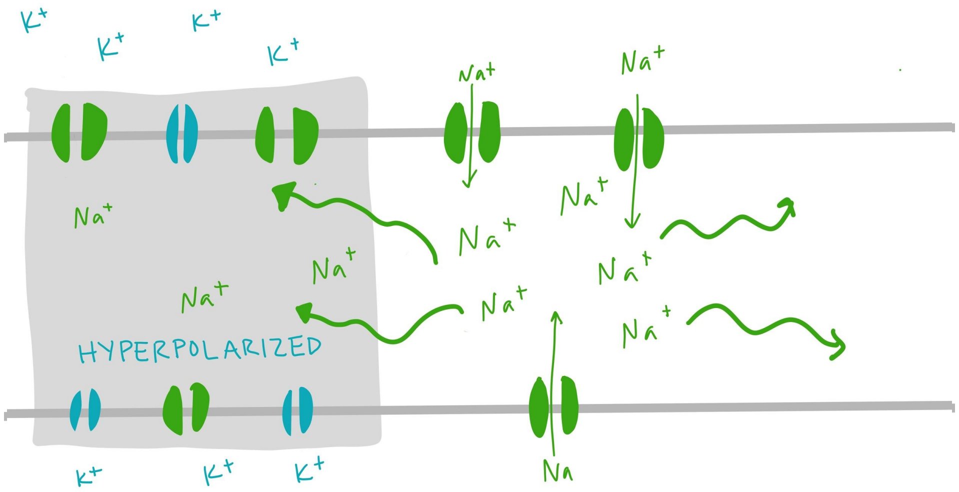

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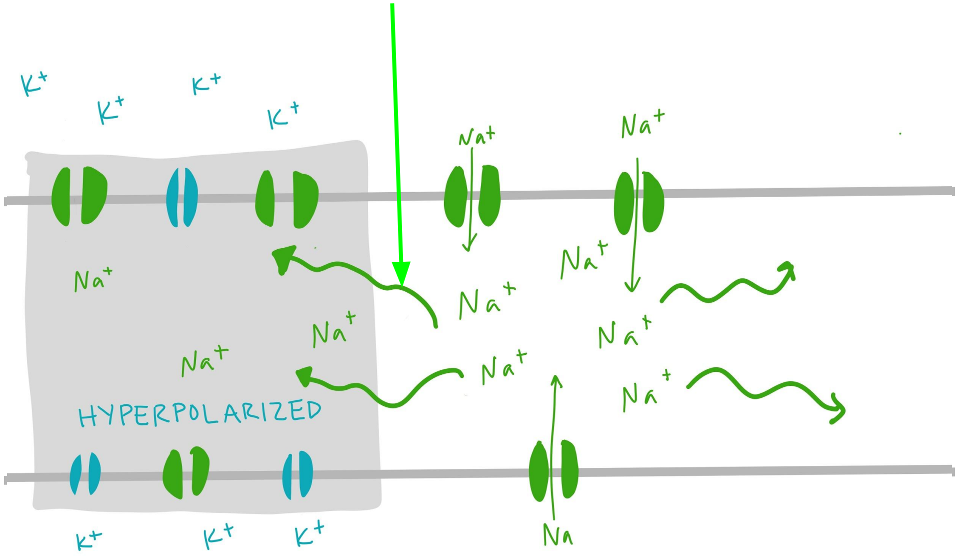

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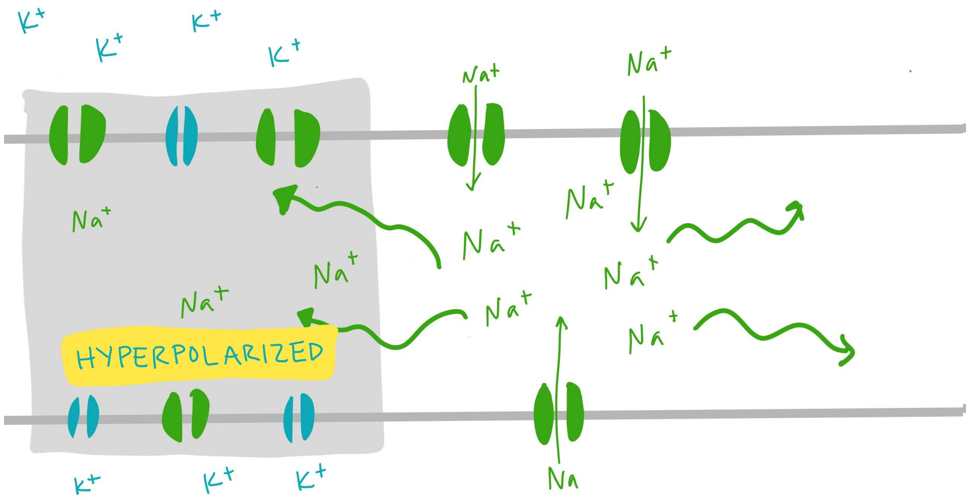

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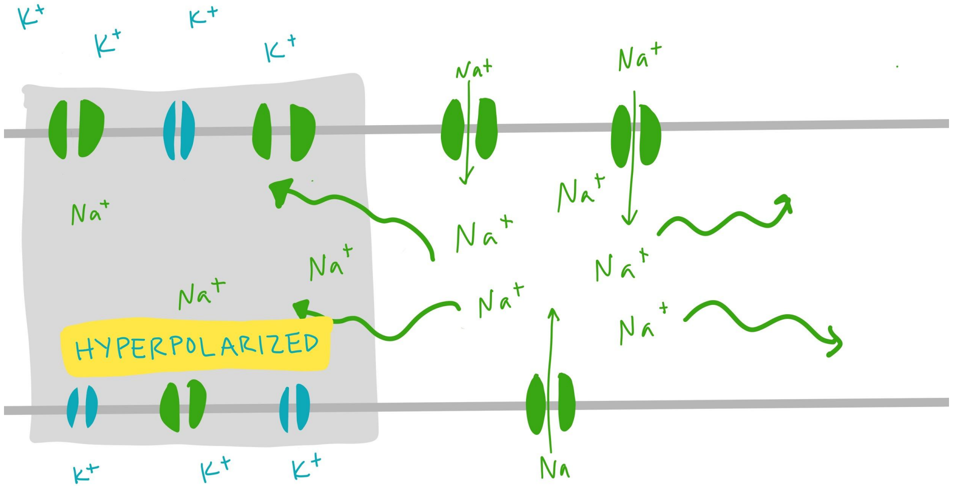
Even if sodium diffuses in, it can't balance out all the potassium that rushed out and hyperpolarized the old patch of neuron



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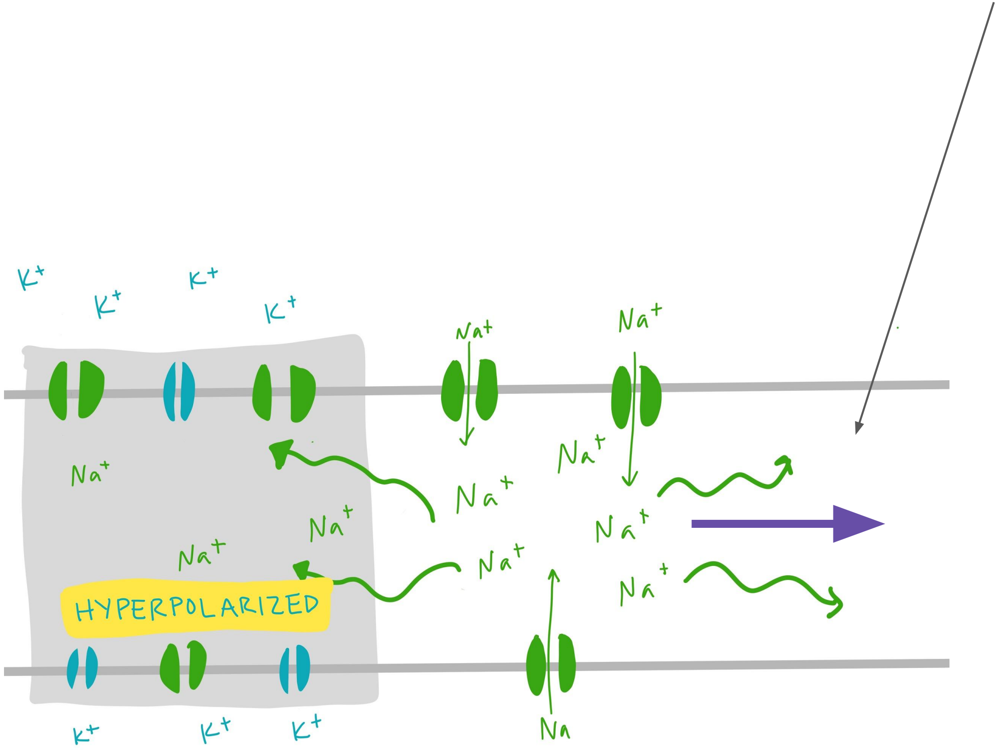
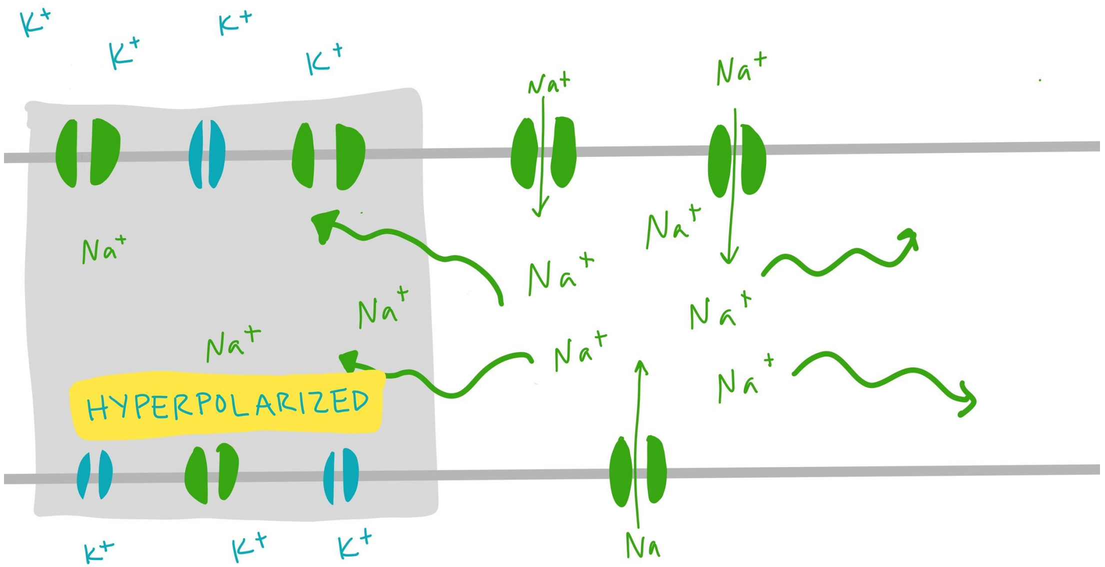
So the action potential only travels forward, into another new patch of neuron.



Why does hyperpolarization = unidirectional action potentials?

The take-home message is:

Hyperpolarization prevents the backwards diffusion of sodium from causing backwards propagation of the action potential.



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- As we just saw, passive diffusion of sodium could propagate an action potential along a neuron for a small distance
- But as we know, diffusion is not effective over large distances
- So if diffusion was all a neuron used to propagate the action potential, the action potential would never make it to the next neuron.

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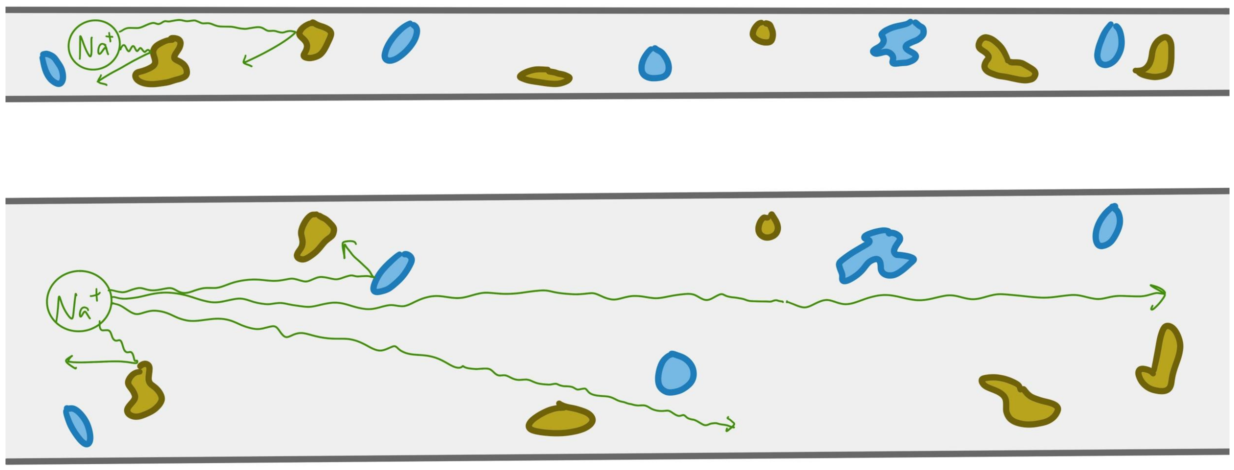
    - Smaller neurons will have more tightly packed proteins and organelles that the ions run into and get slowed down by (green lines)



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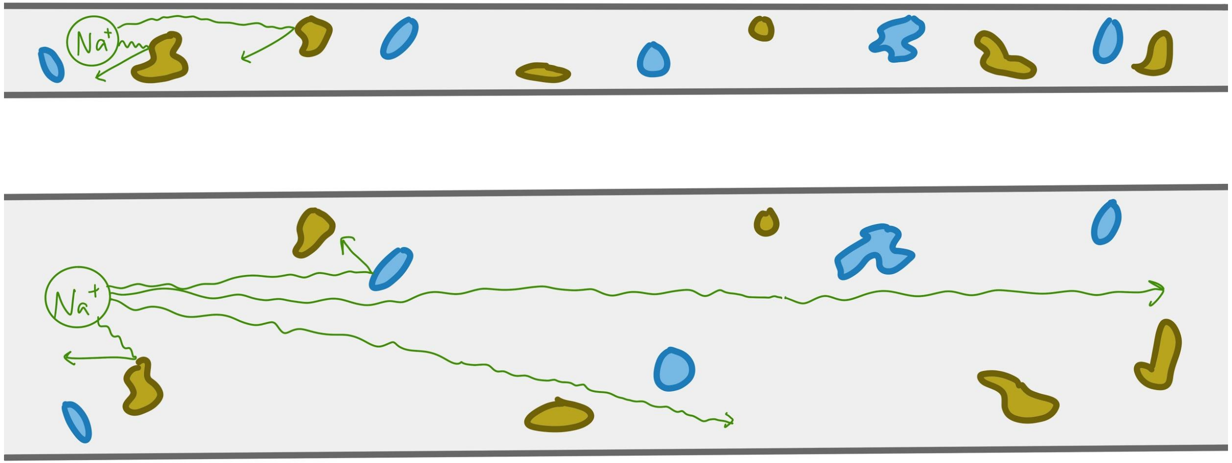
- So, action potentials decay more slowly in neurons with larger diameters



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  - Remember, the neuron always has some leak channels open, letting ions in and out
  - The leaking of those ions will eventually drown out the ion diffusion that propagates the action potential
- So, the more that ions leak across the membrane, the more rapidly the action potential will decay to zero.

Why don’t action potentials decay to zero?

- Neurons have adaptations to cope with both of these causes of decay.

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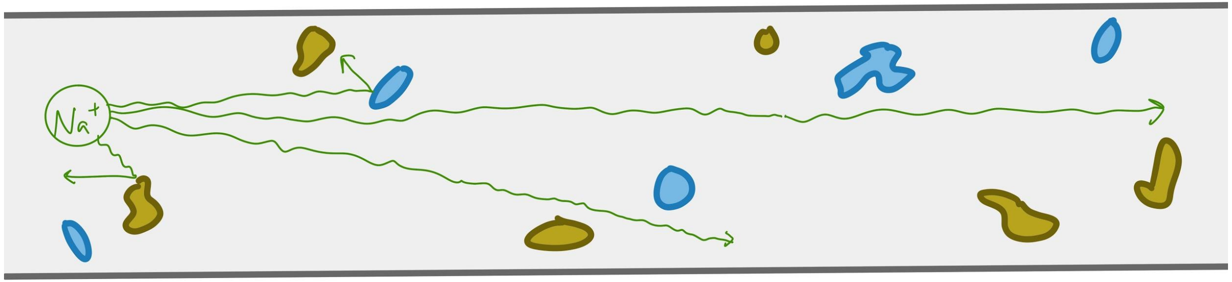

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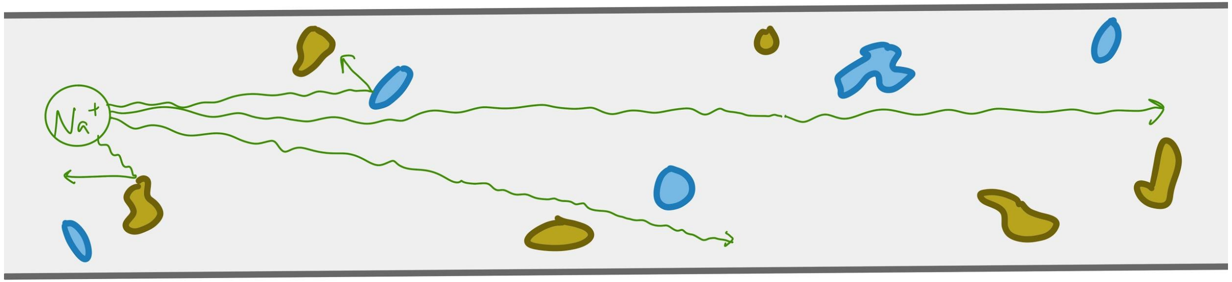
    - This is a strategy used by invertebrates like giant squid and cockroaches.



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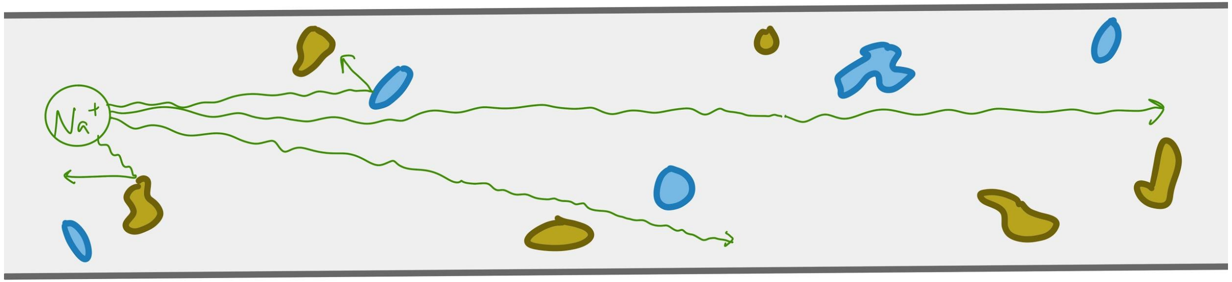

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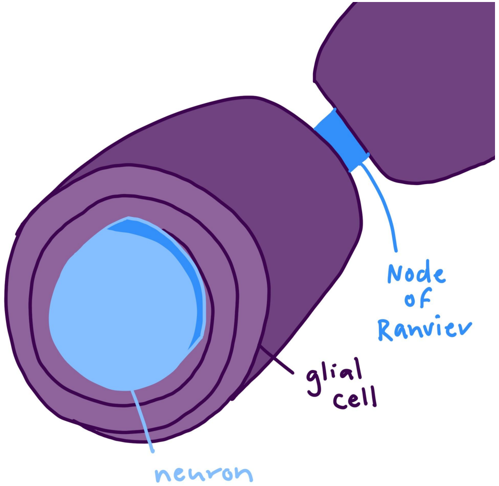

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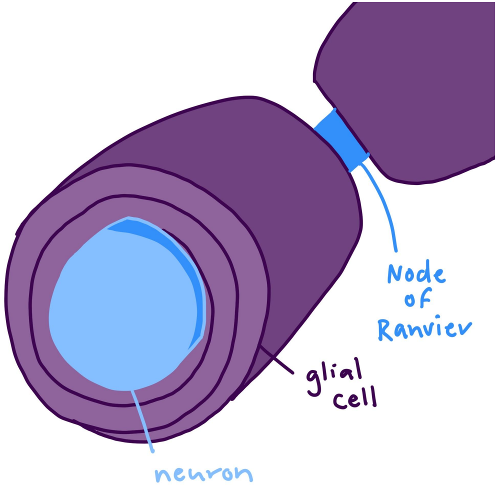
    - This is called **myelination**.



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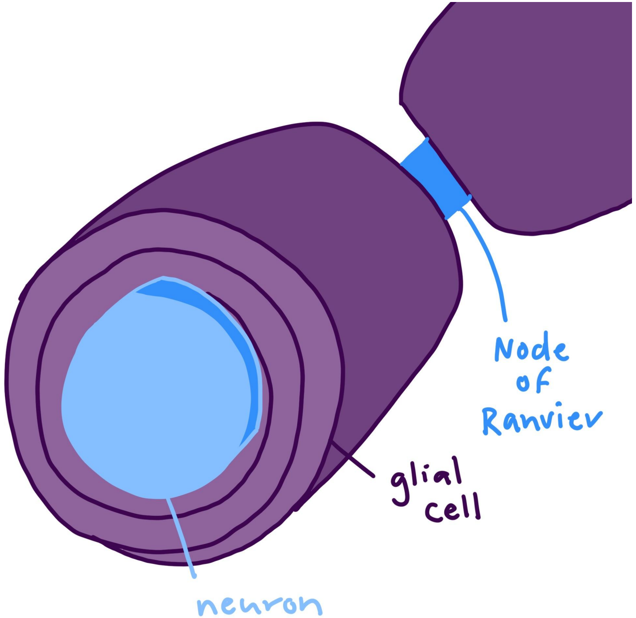
- Ion channels are only found in the gaps between myelinated patches- the **Nodes of Ranvier**.



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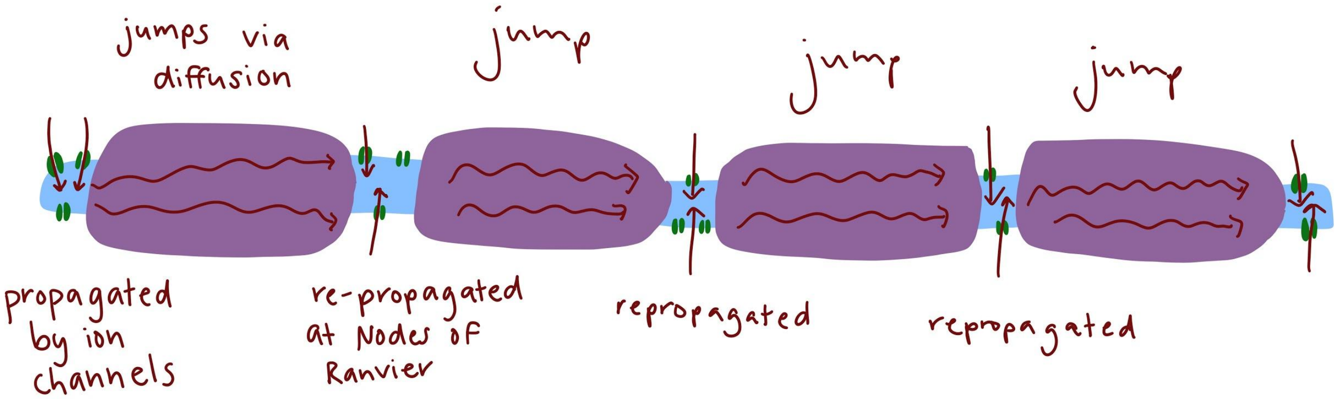
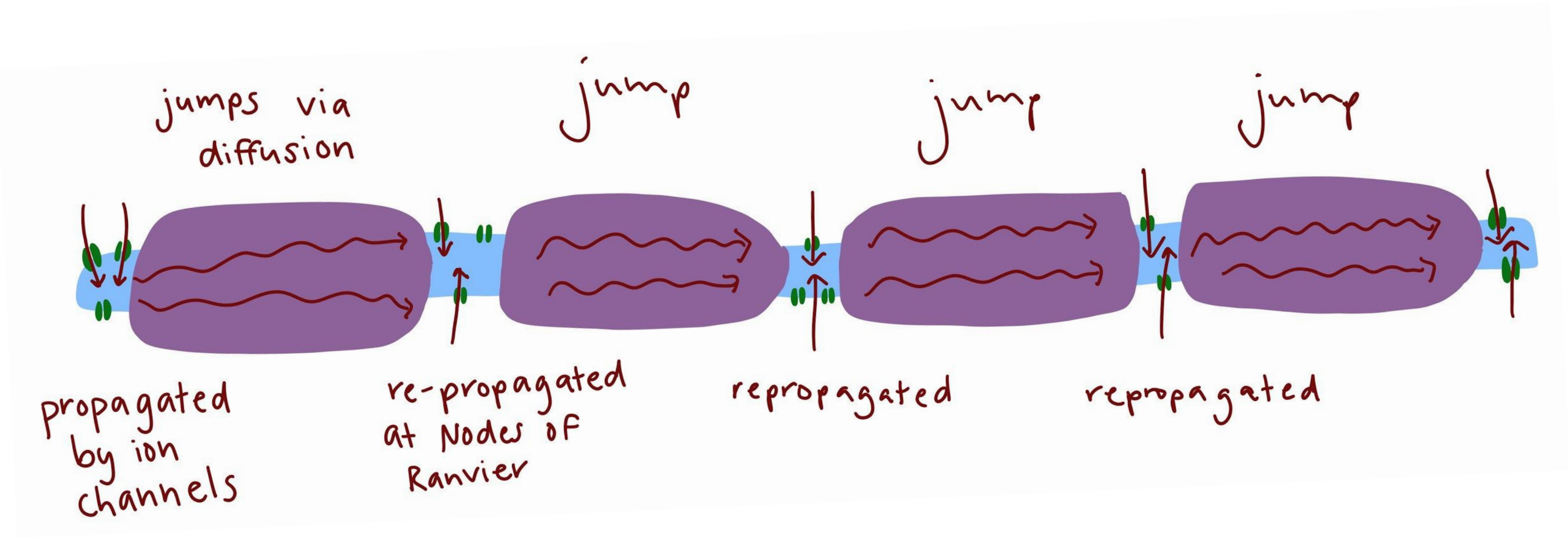
- This means that action potentials move in a jumping manner between the Nodes of Ranvier- this is **saltatory** (jumping) **conduction**



Saltatory conduction



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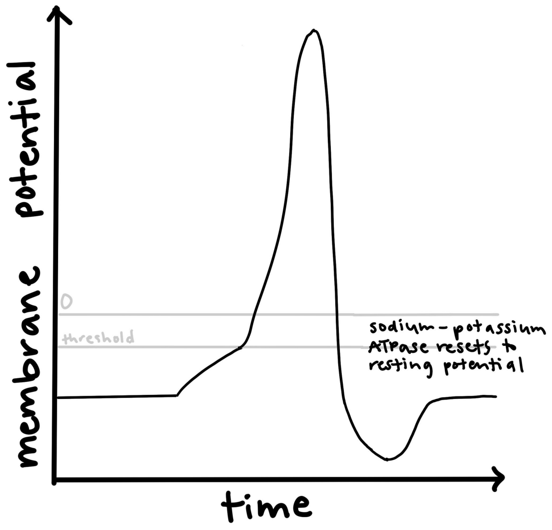
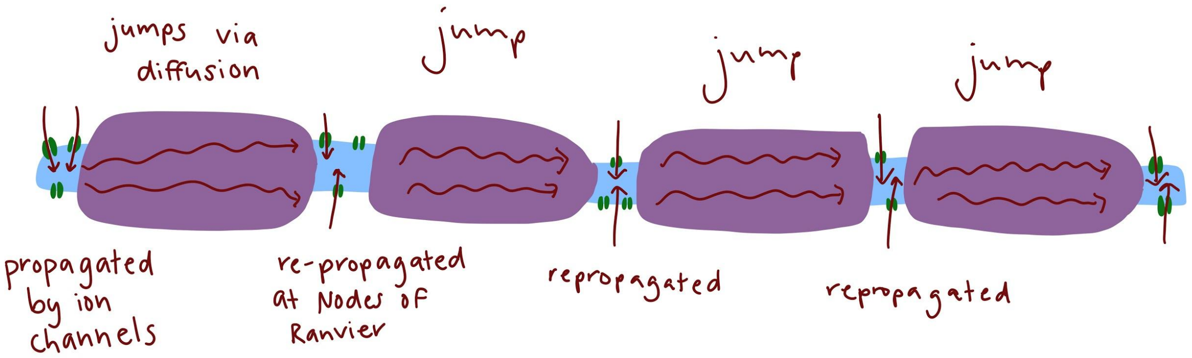
- This is actually the cause of multiple sclerosis
- It also creates the “shivering mice” that you saw in lecture, which can’t move properly

What happens if ion channels are blocked or overstimulated?

- As we have seen throughout this lecture, ion channels opening and closing at the correct time are **crucial** for normal neuron and nerve signalling





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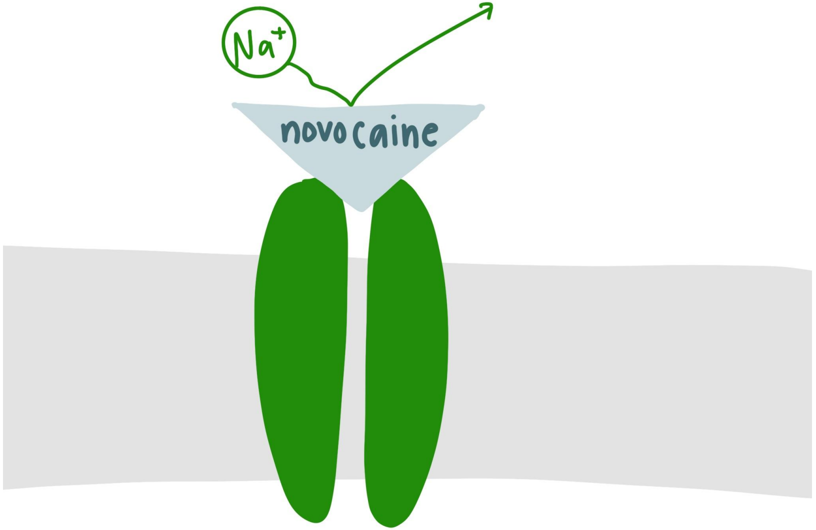

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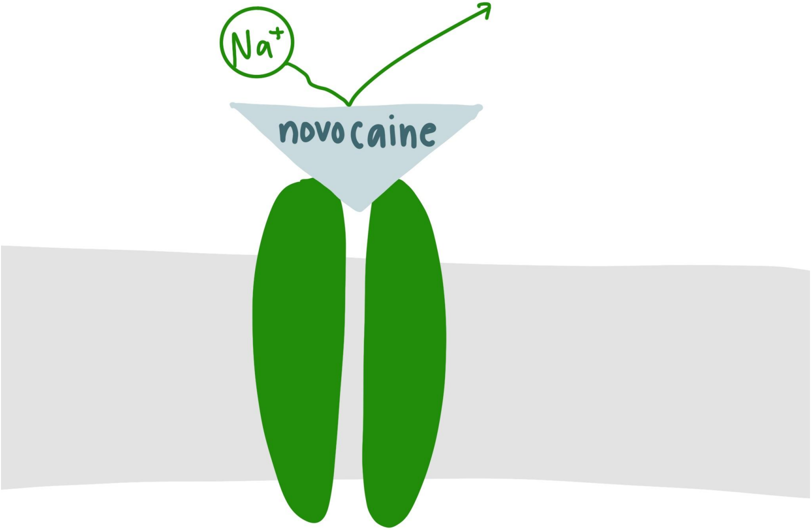

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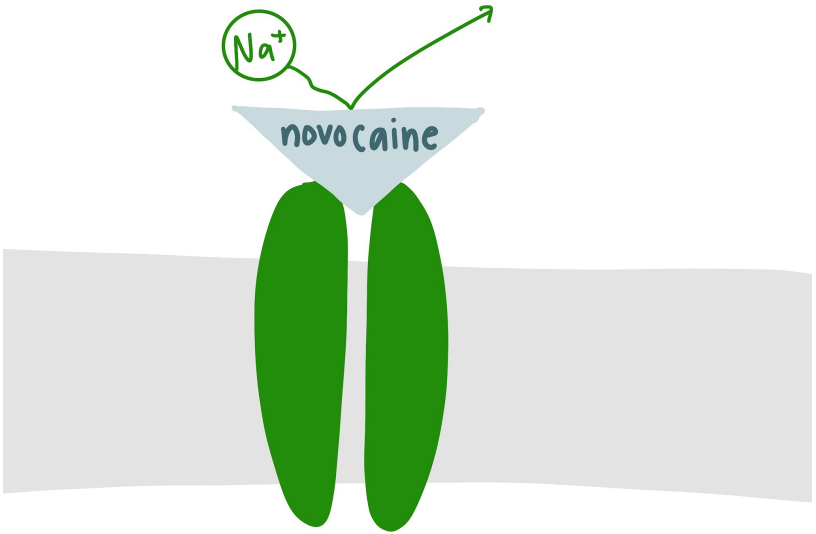
- And that's how local anesthetic at the dentist works!



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    - Basically the opposite effect of novocaine

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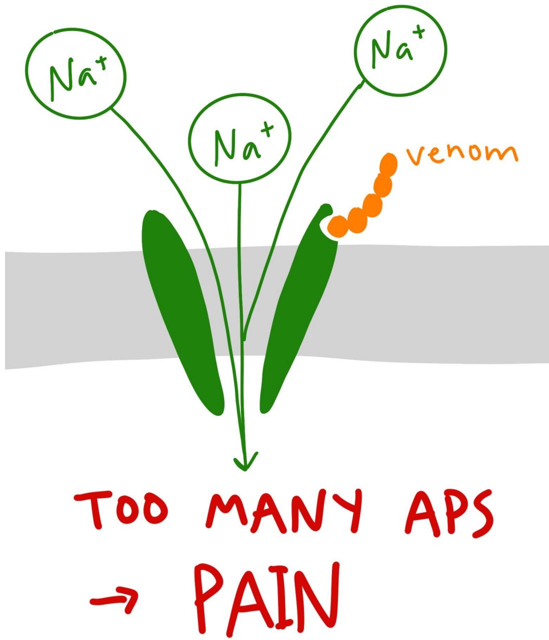

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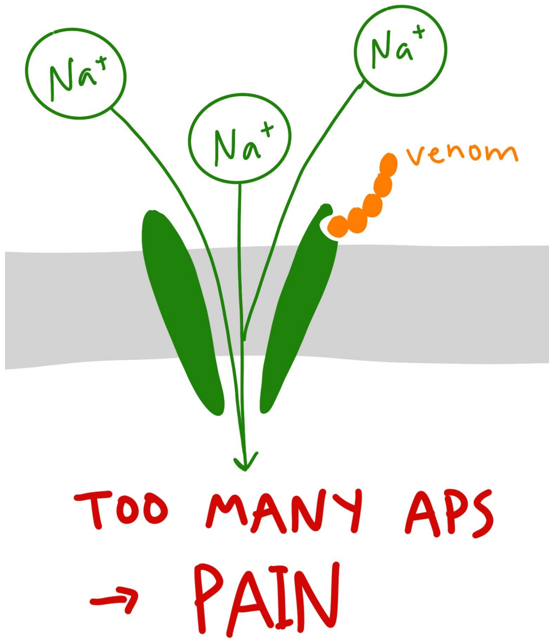

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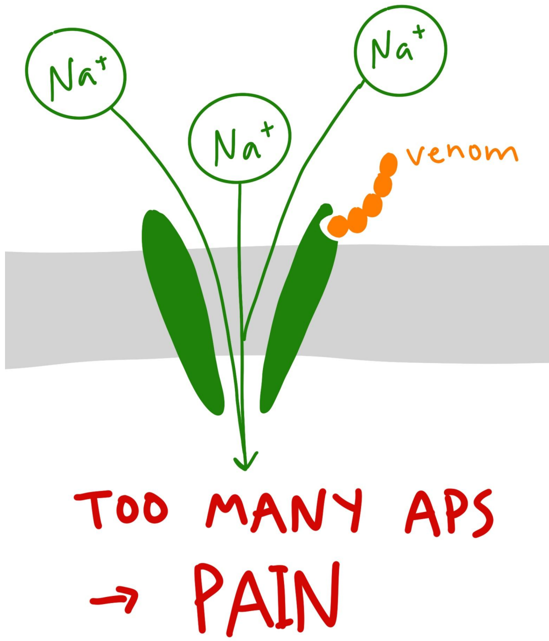

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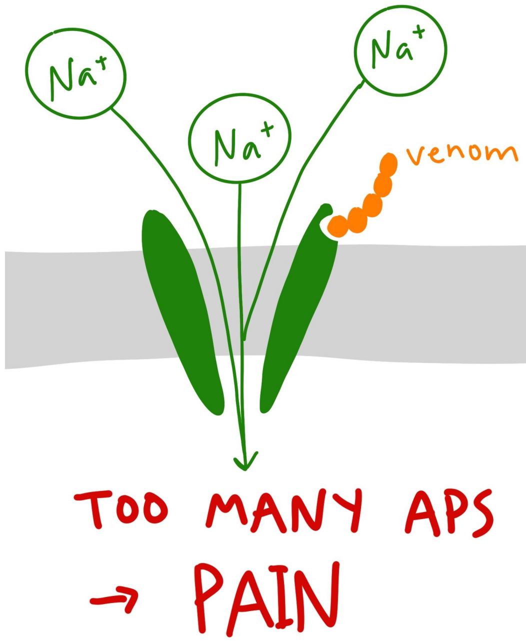

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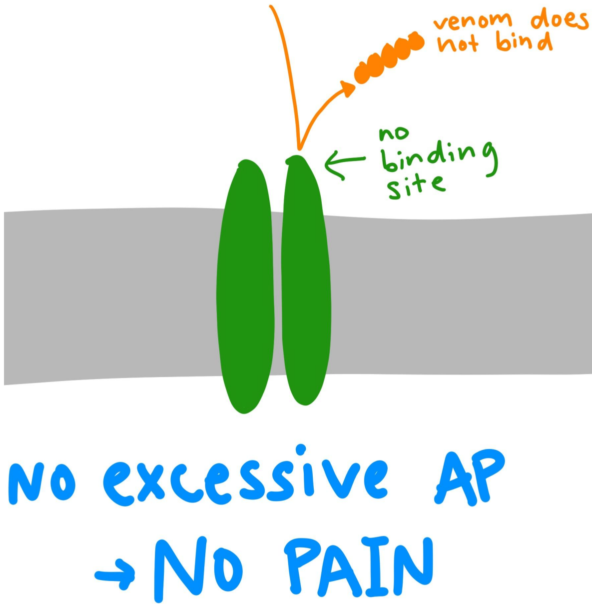

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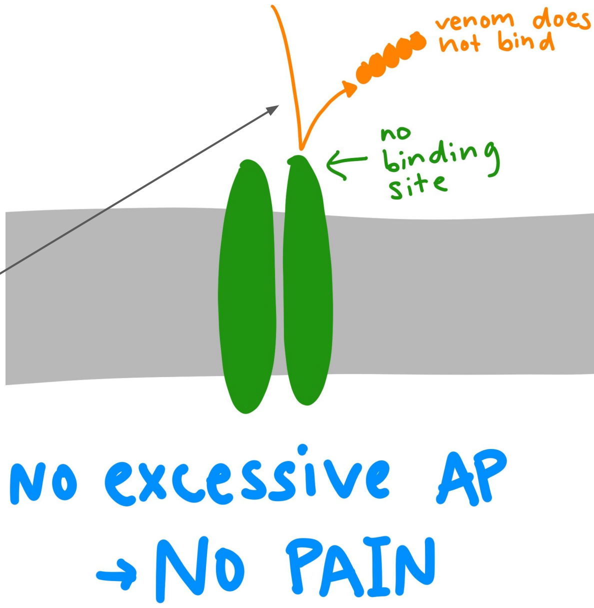
- The ion channels don't have the amino acid that the venom normally attaches to, so they can eat the scorpions!



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- But real membranes are permeable to more than one ion at a time!

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- **To find the real membrane potential, when the membrane is permeable to many kinds of ions, you just do a weighted average of this equation for all the ions.**
  - But you almost certainly will not need to do that on the prelim.

Graded potentials

What is a graded potential?

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- It should make more sense once you know about:
  - Action potential propagation along the axon
  - Inter-neuron communication by neurotransmitters.

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- So they don't trigger voltage-gated channels to open
- And therefore they do not cause an action potential.

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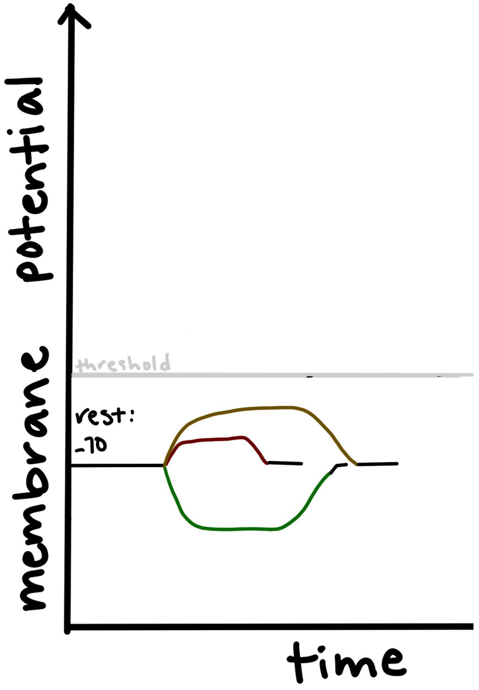
- Graded potentials can be:



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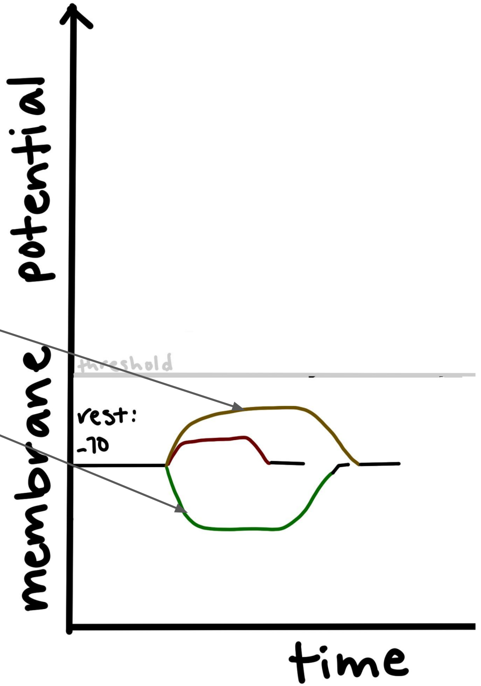

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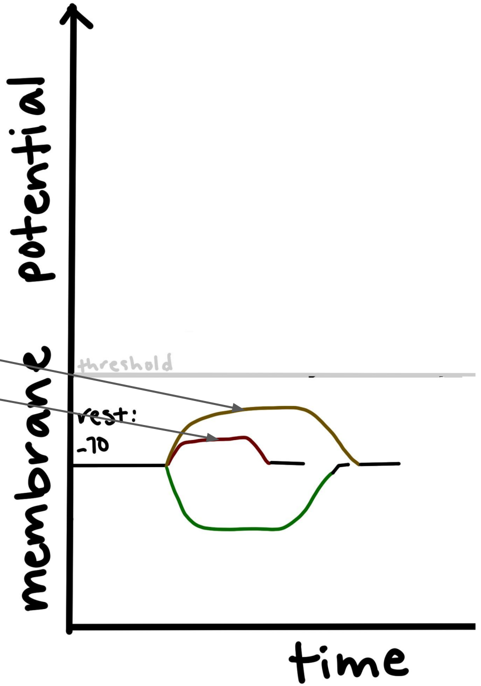

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  - Of long duration
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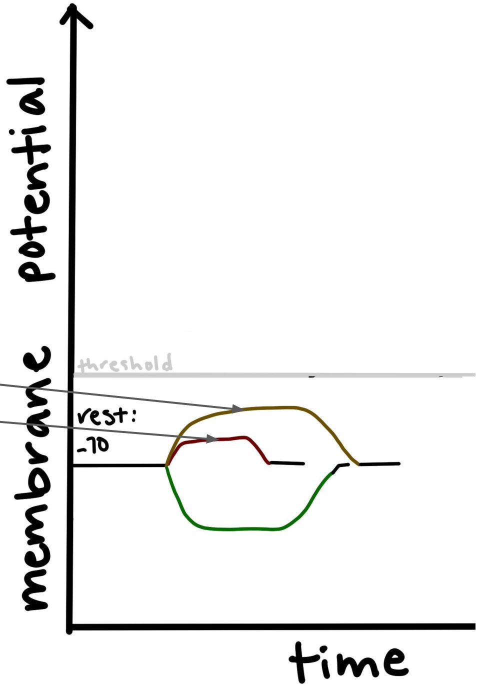
  - Large magnitude
  - Smaller magnitude



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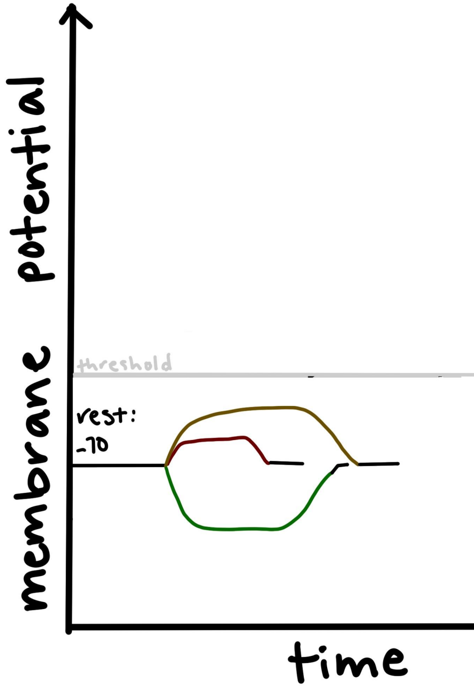

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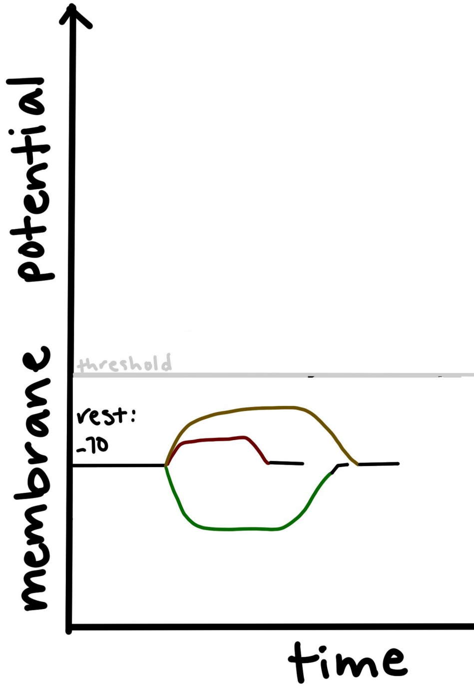

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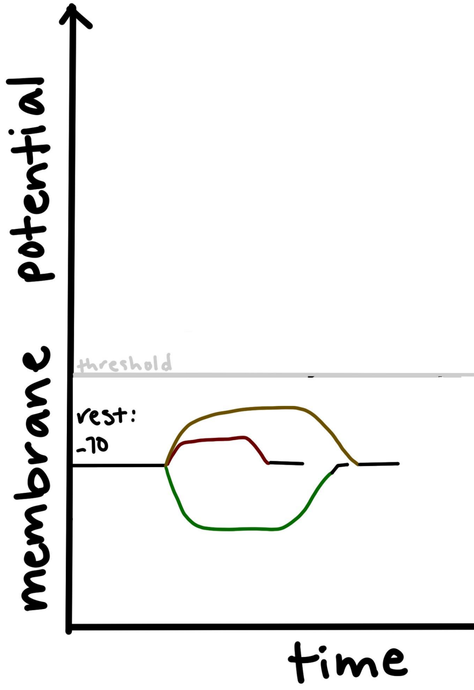

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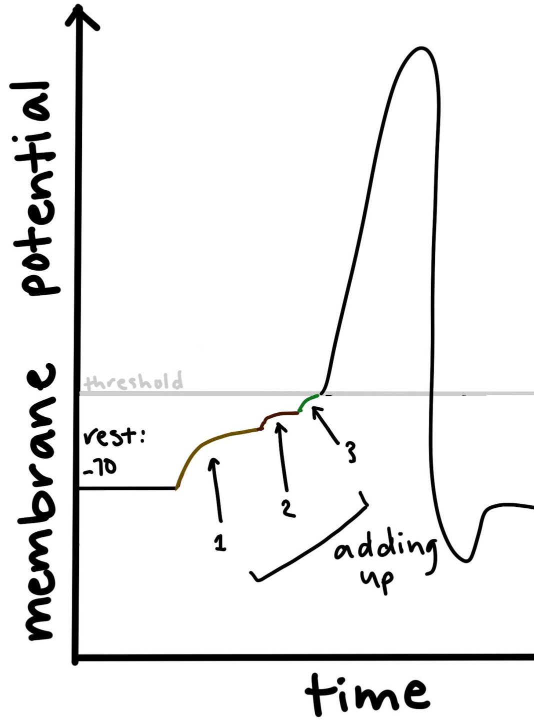

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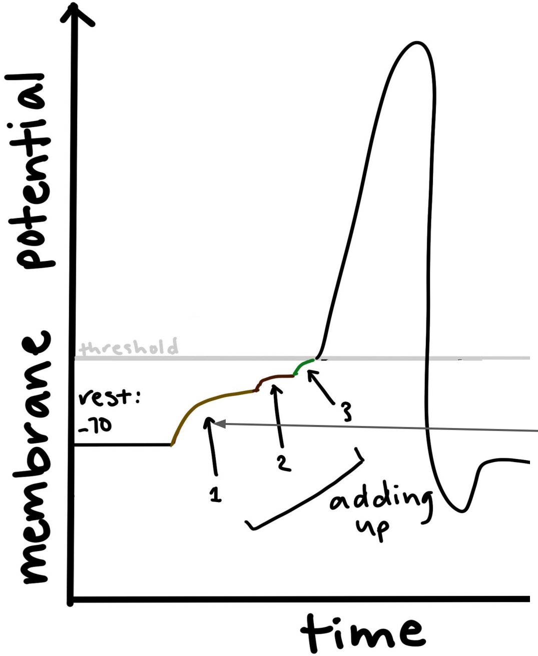

One neighbor releases some dopamine

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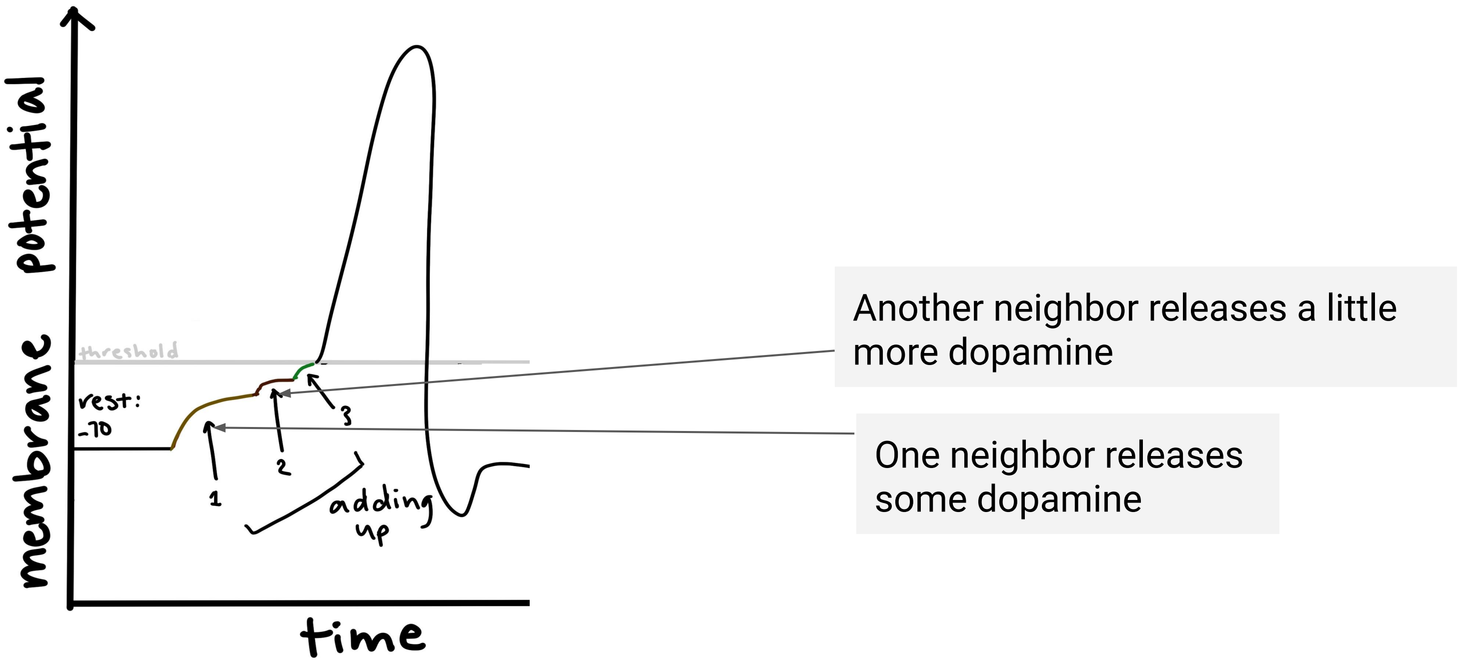

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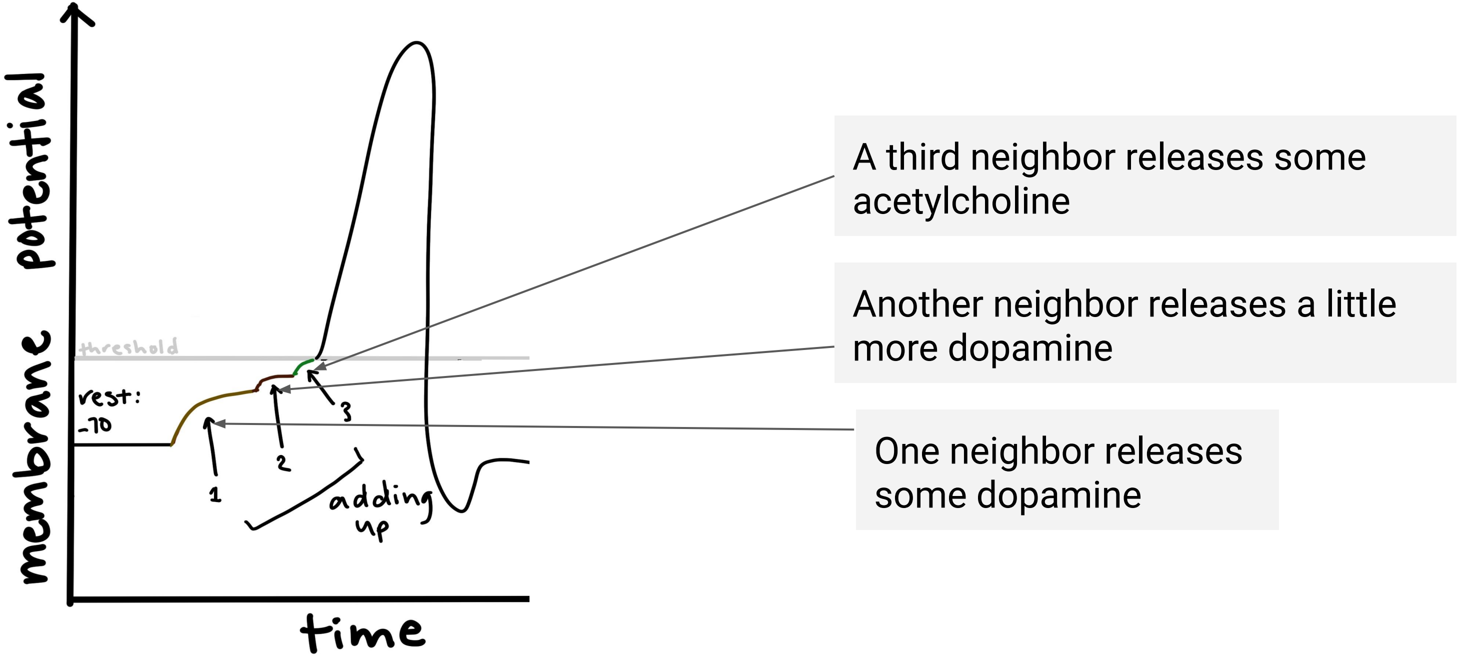

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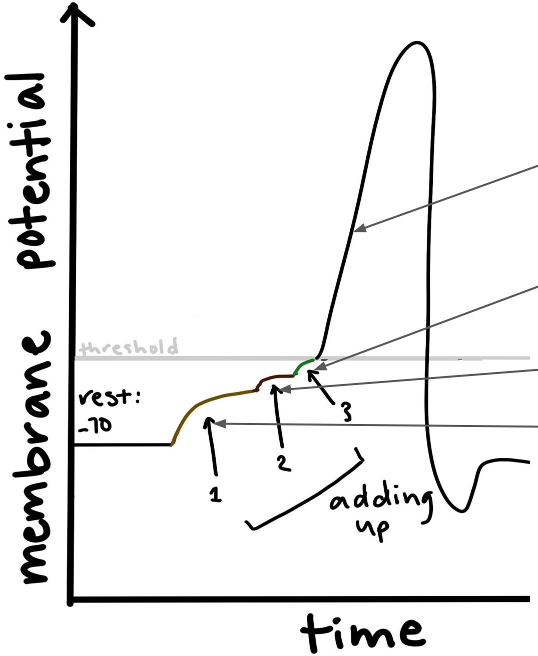

An action potential is produced!

A third neighbor releases some acetylcholine

Another neighbor releases a little more dopamine

One neighbor releases some dopamine

Keep this in mind for the next lecture

- This will be useful when learning about generation of postsynaptic potentials in Lecture 19.