PSYC304: Neural communication 1 (within cells)

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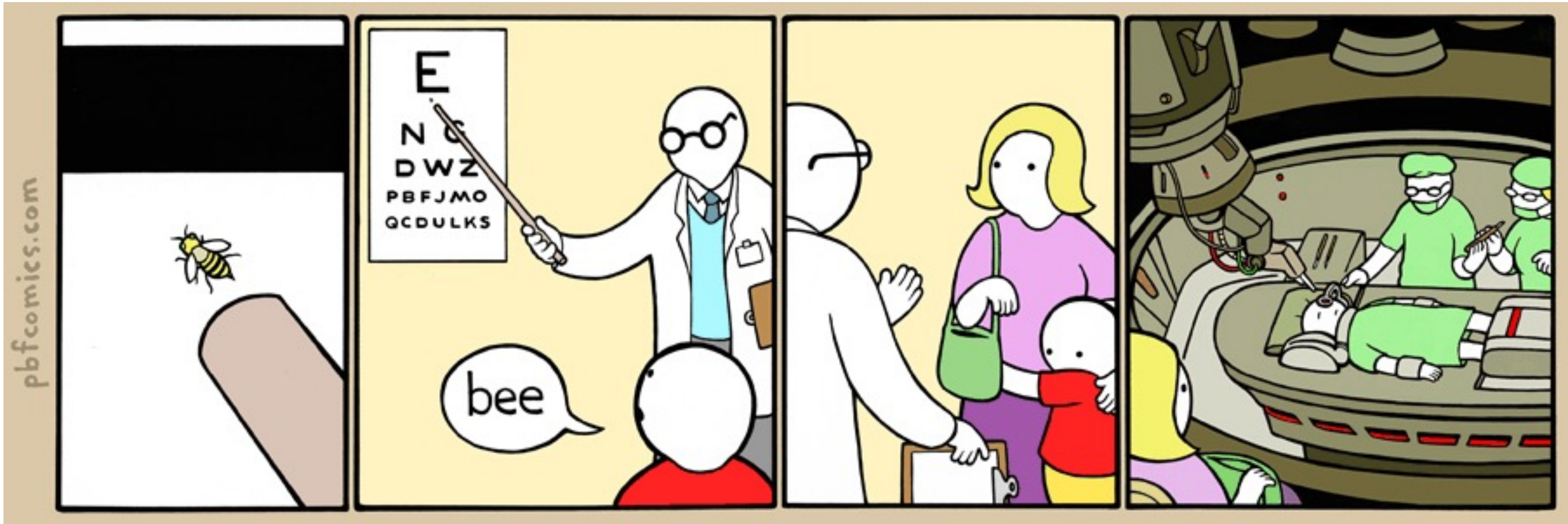
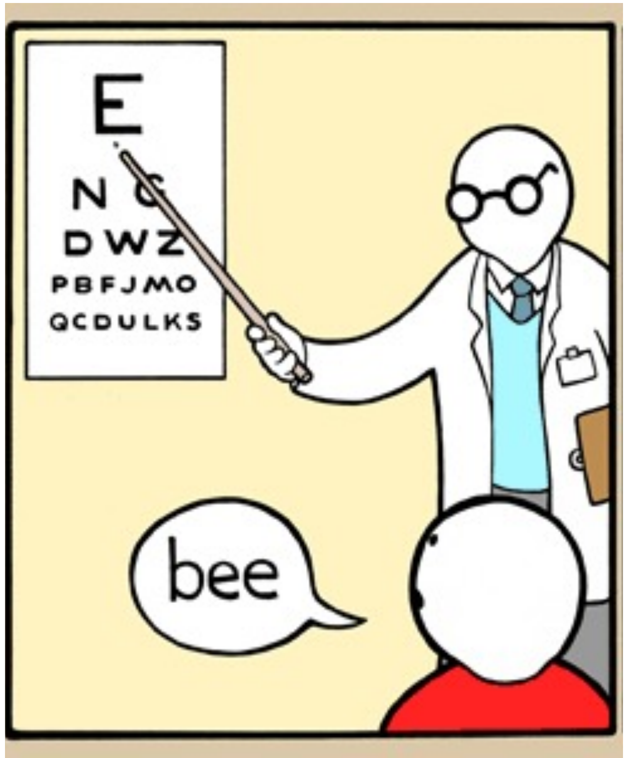


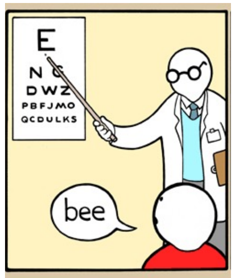
Overview

A. Introduction to neural communication
B. The resting membrane potential
C. Postsynaptic potentials
D. The action potential
E. Conduction of the action potential



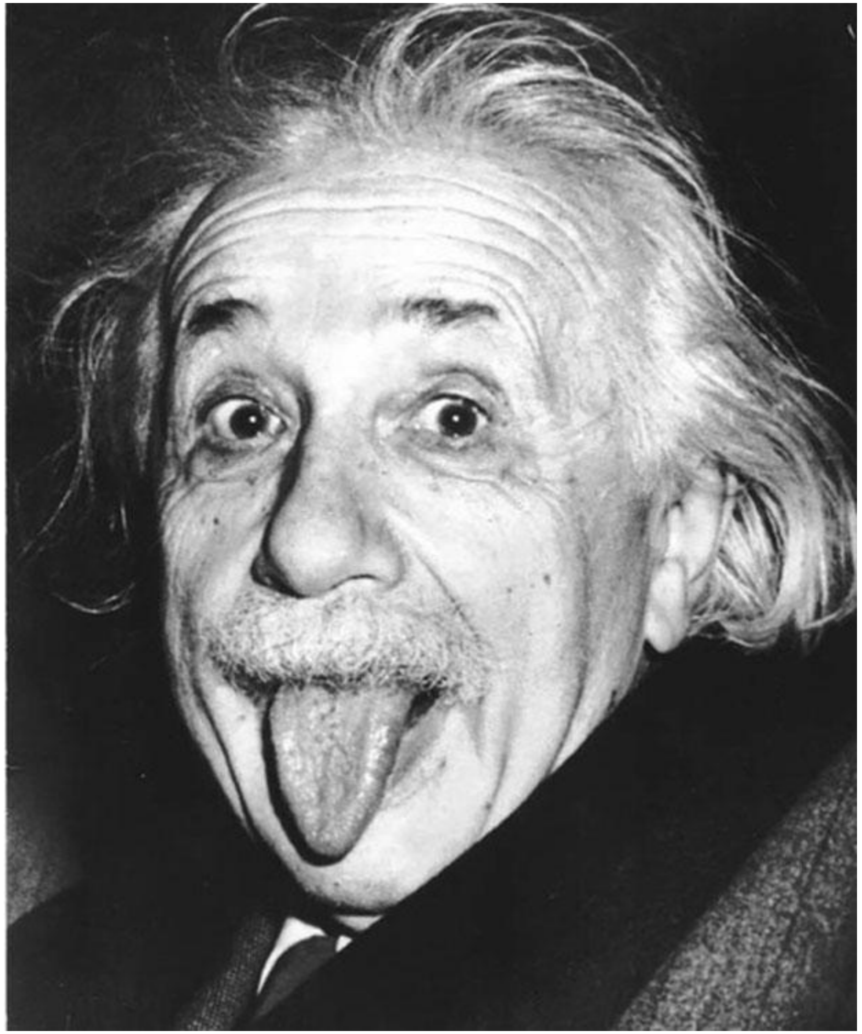
Learning objectives

1. What does it mean to say that neuronal communication is an electrochemical process?
2. Describe the chemical and electrical gradients for a neuron at rest.
3. What two proteins are responsible for the resting membrane potential? How so?
4. Describe how the resting membrane potential is established.
5. What two proteins are responsible for the action potential? How so?
6. Describe how an action potential occurs, including its threshold, stages, and refractory periods.
7. Why does conduction only happen in one direction along the axon? Can you imagine a possibility in which conduction could travel in the opposite direction? (This likely happens in nature.)
8. Describe the differences between conduction in unmyelinated versus myelinated axons.
9. Identify and define four key differences between postsynaptic potentials and action potentials. Additionally, describe where each occurs, and why.

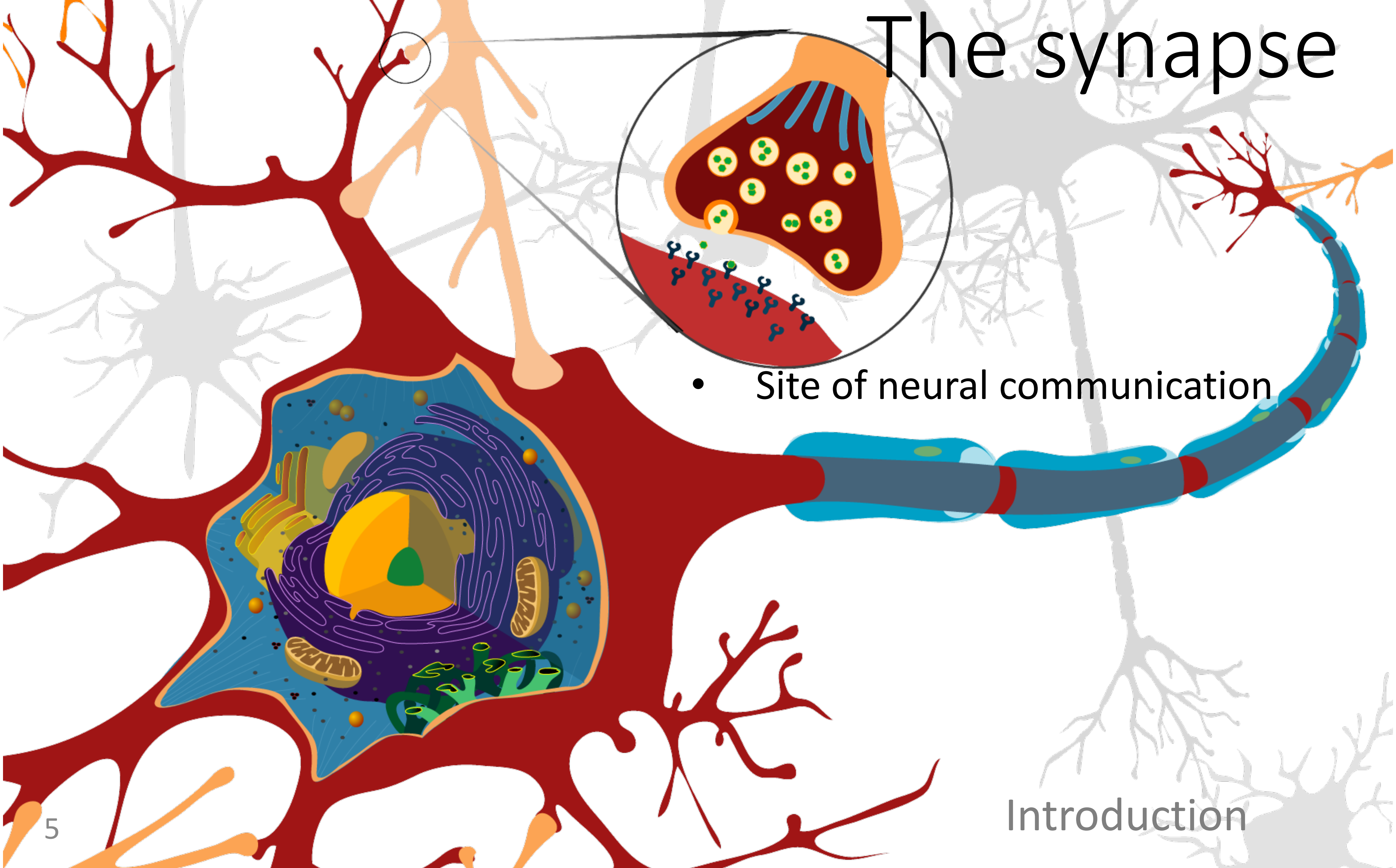


Listen to Einstein(-ish)

"Make things as simple as possible, but no simpler."

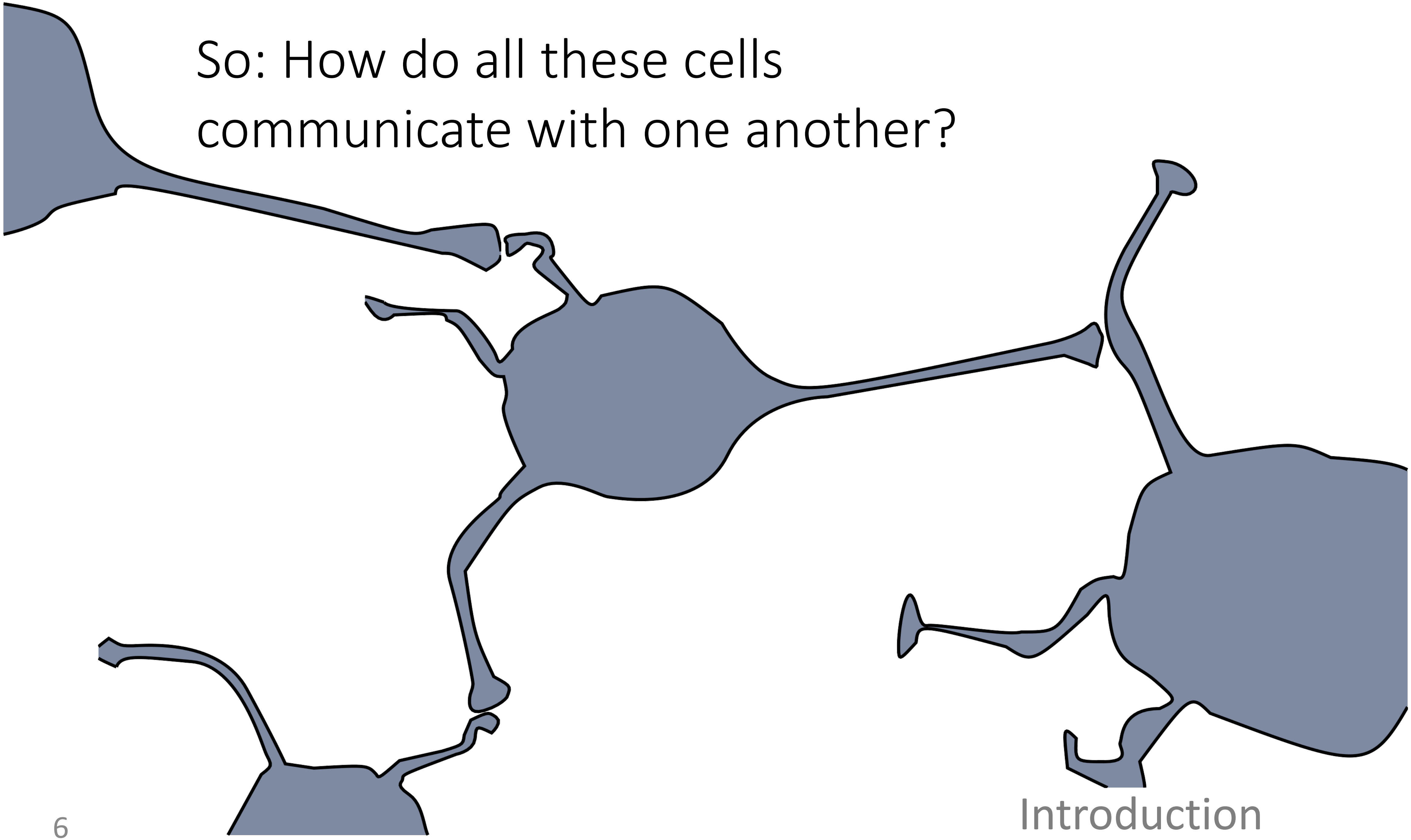


The synapse



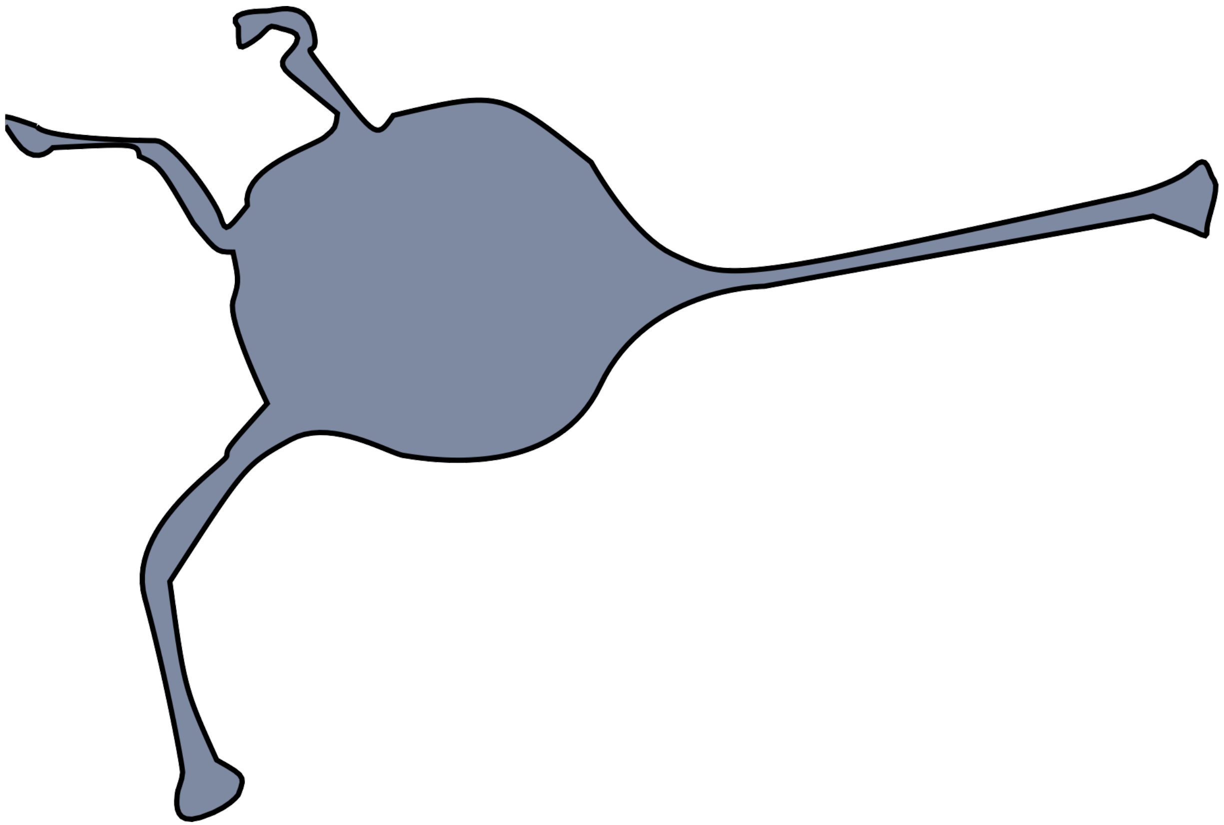
- Site of neural communication

So: How do all these cells communicate with one another?

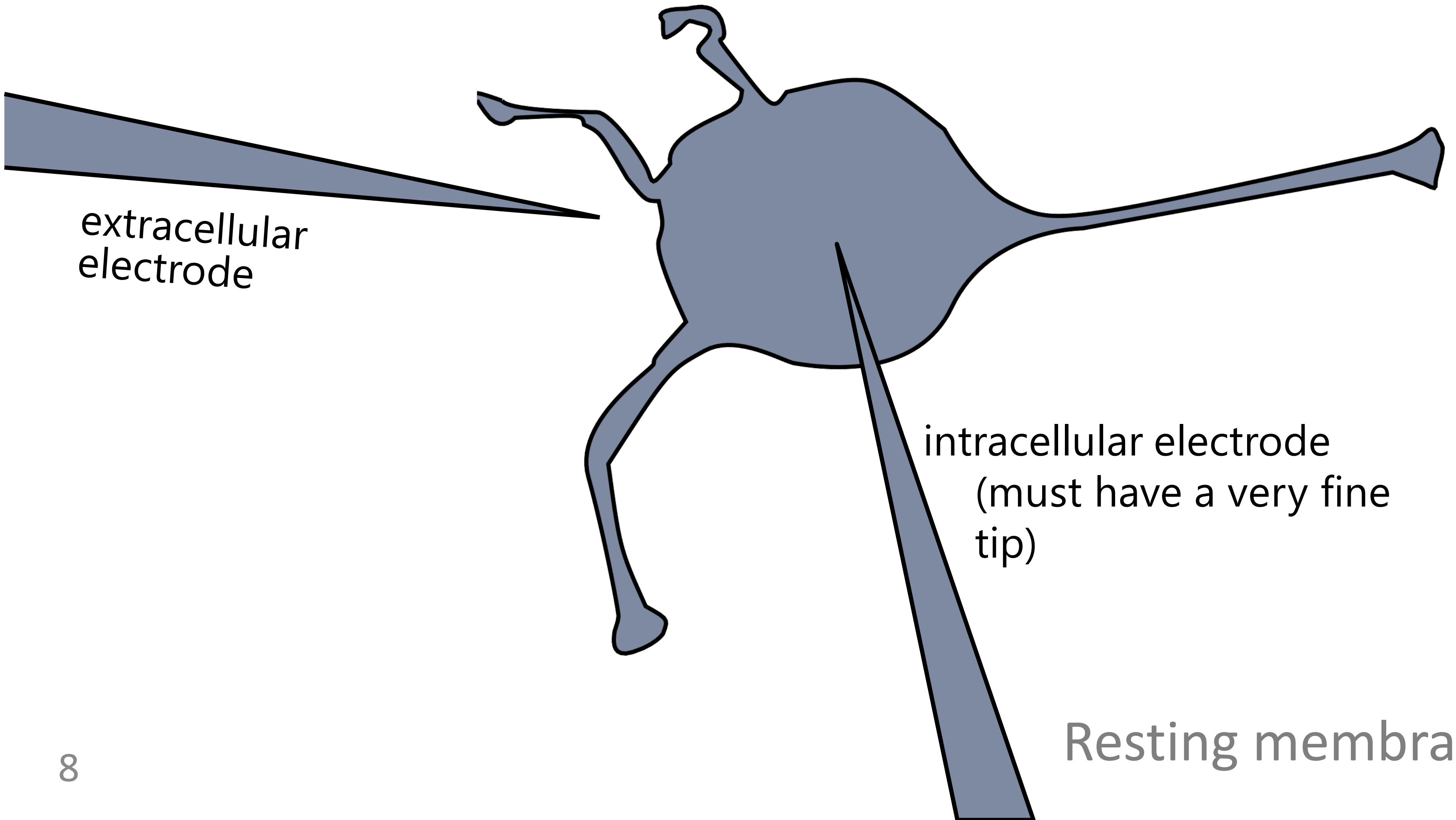


Introduction

As a first step: How does communication occur within a single neuron?



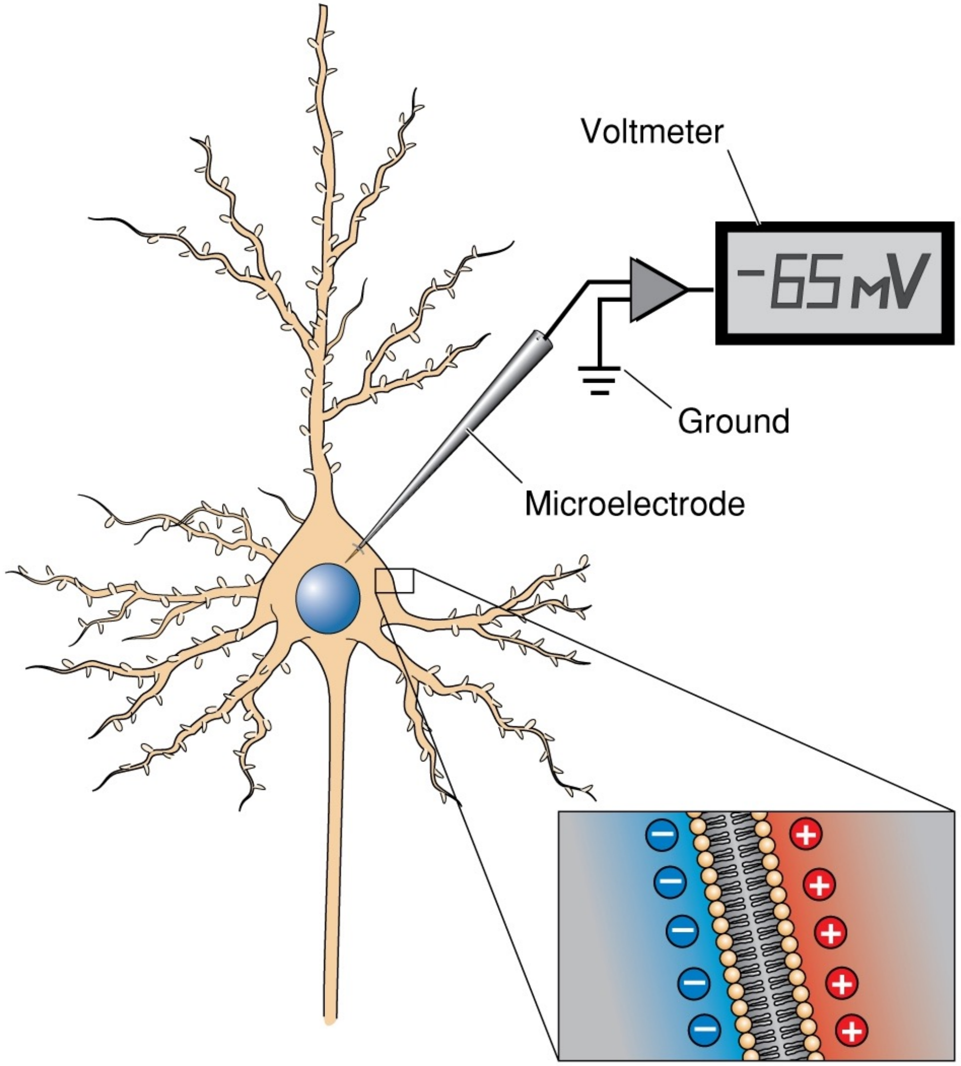
A healthy neuron has a resting membrane potential (or membrane voltage) of between -60 and -80 mV (the voltage inside the neuron is 60-80 mV less than outside the neuron).



Resting membrane potential

The membrane potential

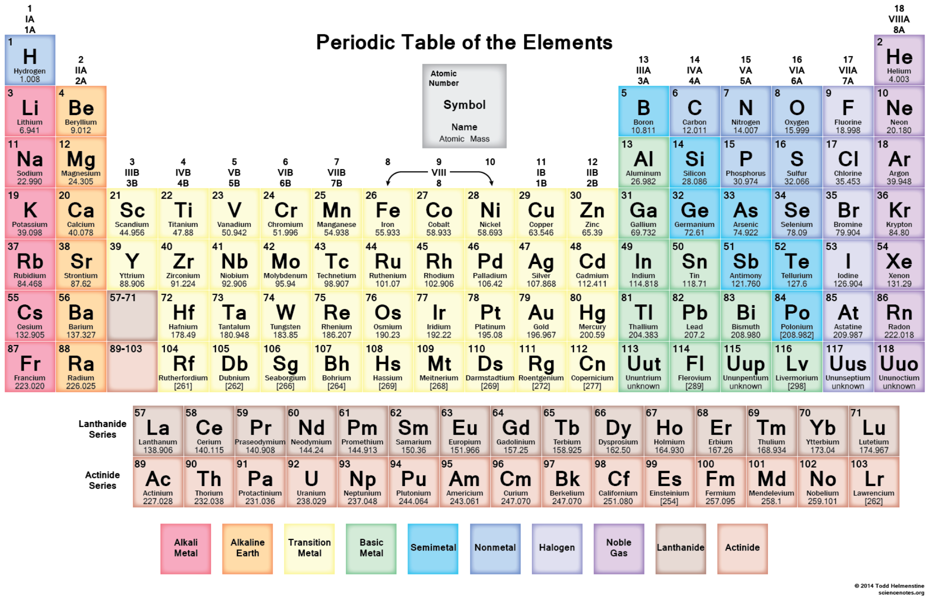
- Originally performed with invertebrates (why?)
- Varies a little from cell to cell / region to region (why?)
- https://www.youtube.com/watch?v=k48jXzFGMc8

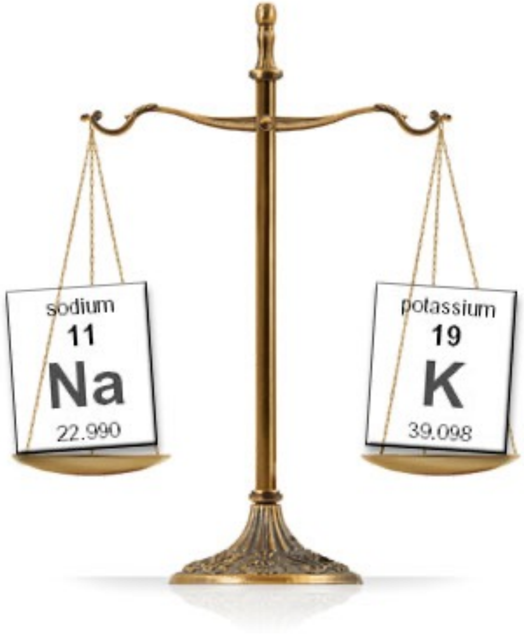


Resting membrane potential

Neuronal communication is chemical

1. Primarily the result of two ions, sodium (Na+) and potassium (K+)
2. Ions move into or out of the cell, but not freely





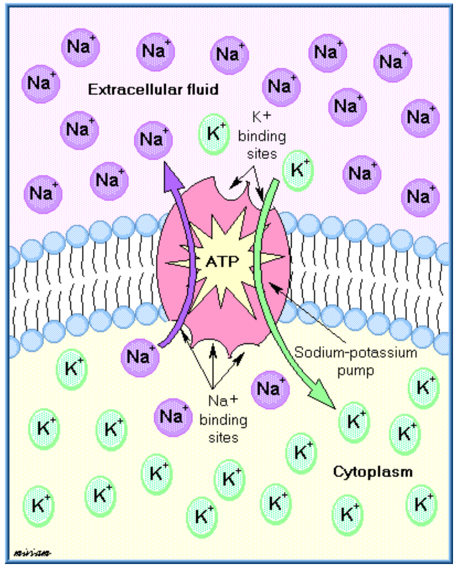
Resting membrane potential

Neuronal communication is electrical

1. Ions are positively and negatively charged (Na+ and K+ are both positive, as per “+”)
2. As they move into or out of cell, they change the *potential* (voltage) at the membrane

   Note: absence of pos. is neg.!

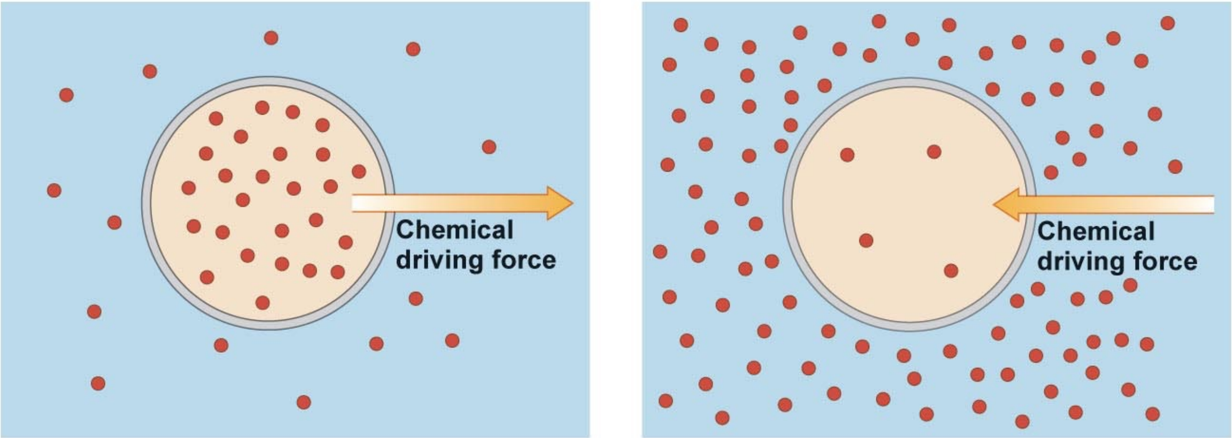
   i.e. remove a pos., leave a neg.



Resting membrane potential

Chemical gradients

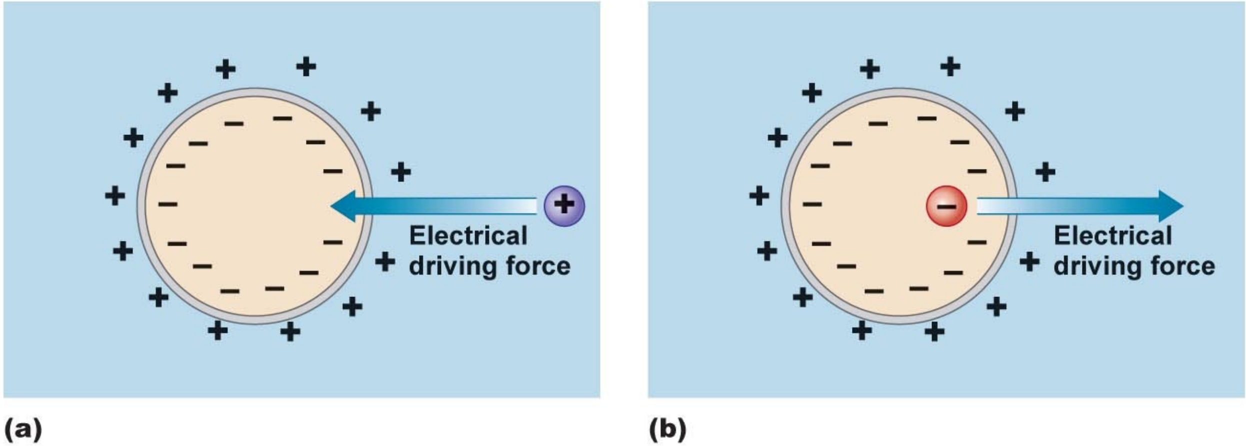
- Ions want to flow from high concentration to low concentration



(a) (b)

Electrical gradients

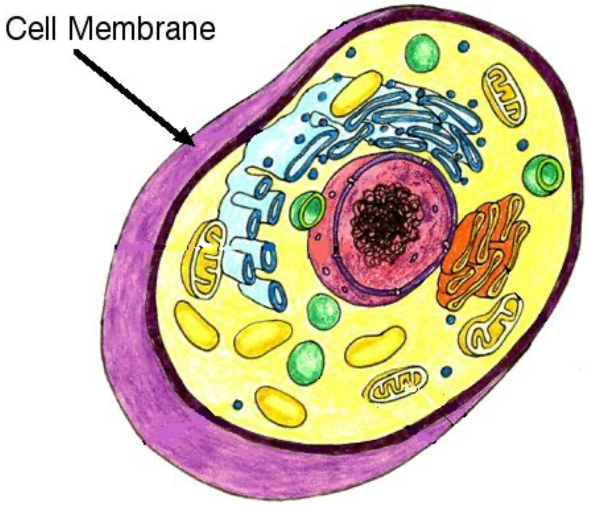
- Charge/potential wants to flow from high concentration to low concentration, too

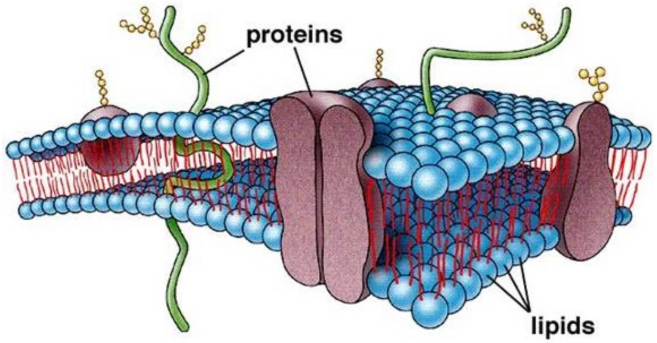


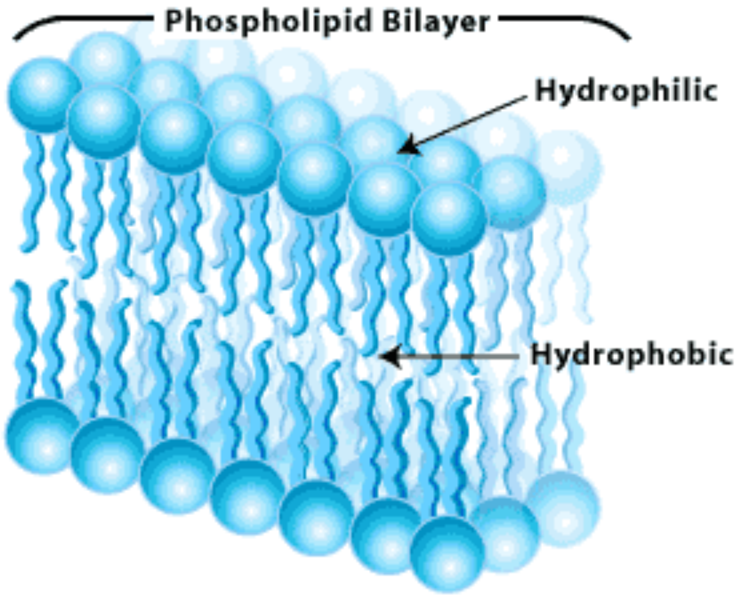
- Sometimes electrical and chemical gradients are at odds, causing an *equilibrium* that =/= 0mV

The cell membrane - guardian

- Lipid bilayer is tightly packed, both hydrophobic and hydrophilic, keeping out all dangerous entities
  - e.g.?



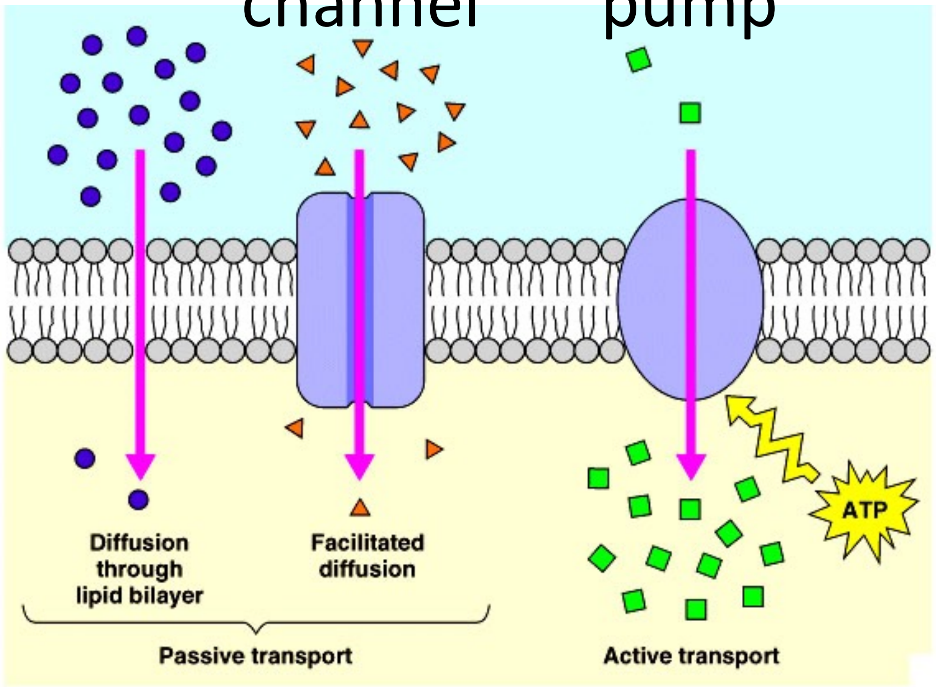




Channels and pumps

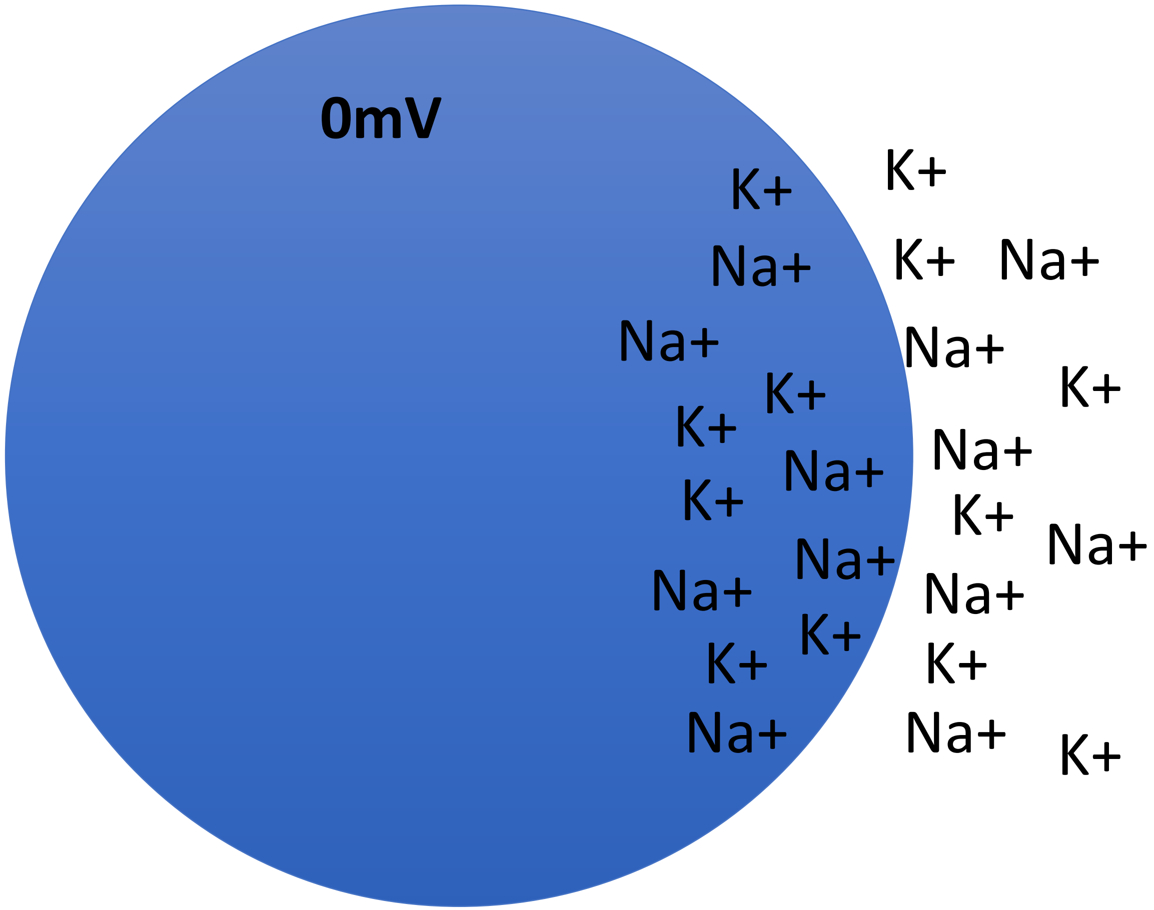
- Only certain molecules and ions permitted via *channels* and *pumps*
  - Channels: allow *passive* diffusion (i.e. along chemical gradient)
  - Pumps: actively push ions against their chemical gradient
    - Requires energy (ATP)

channel pump



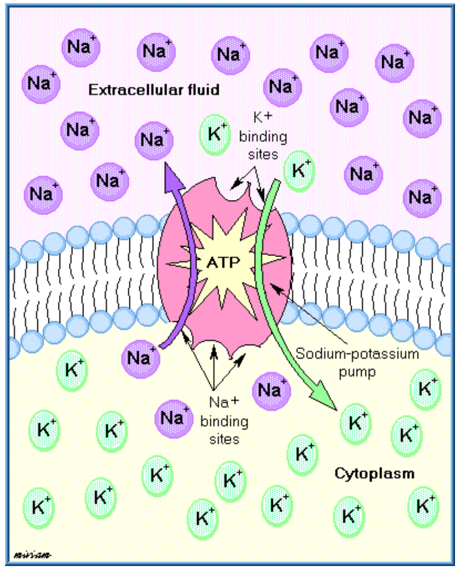
A cell with no channels or pumps

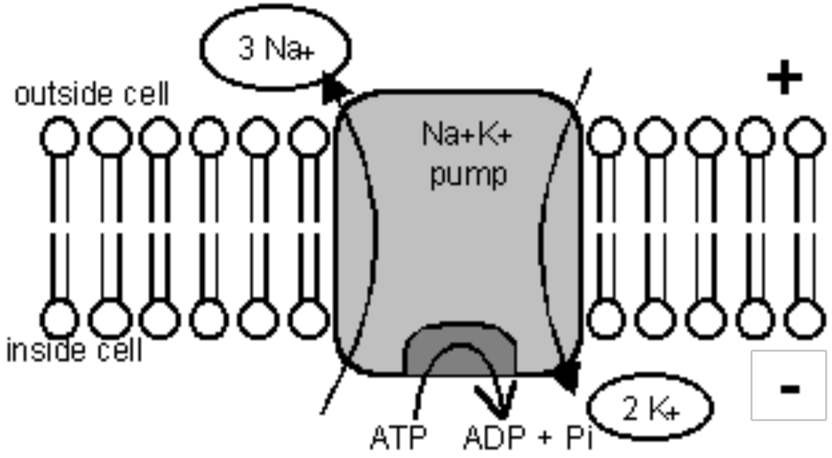
- Nothing moves into or out of the cell

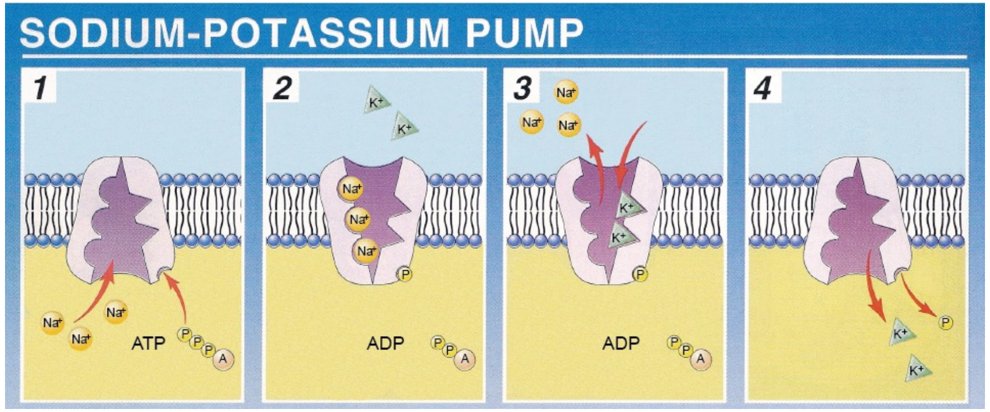


The Sodium-Potassium Pump

- Embedded in cell membrane
- **Extremely** important
  - Consumes 2/3rds of all neuronal energy!
- Pushes 3 Na+ out and 2 K+ in
  - i.e. Active process that requires energy
- How does this affect the chemical gradients?
- How does this affect the electrical gradient?

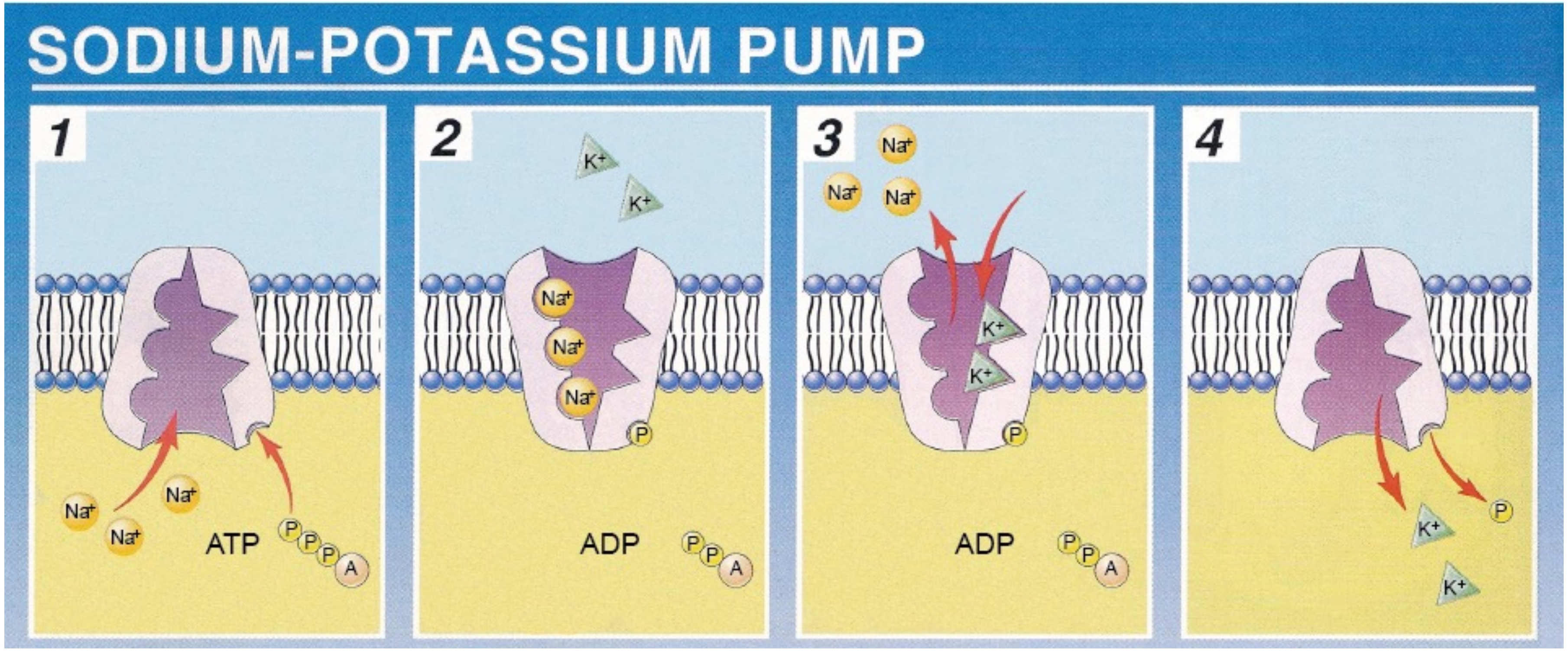






Resting membrane potential

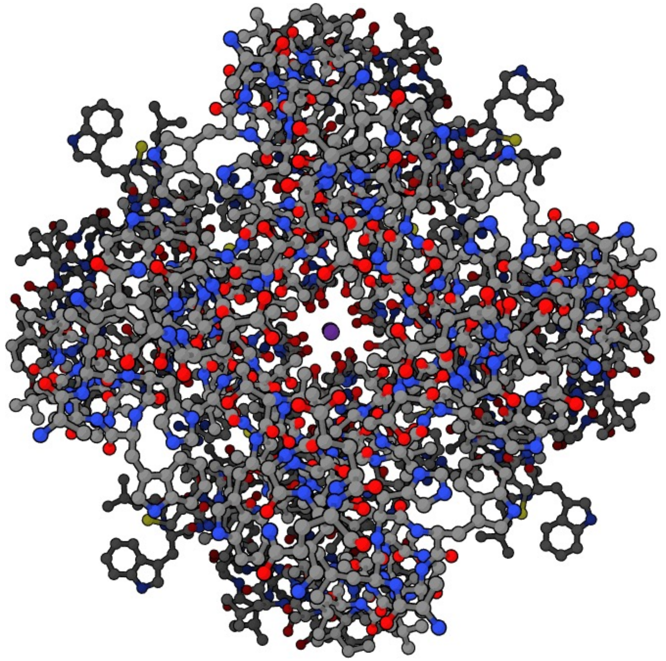
The Sodium-Potassium Pump

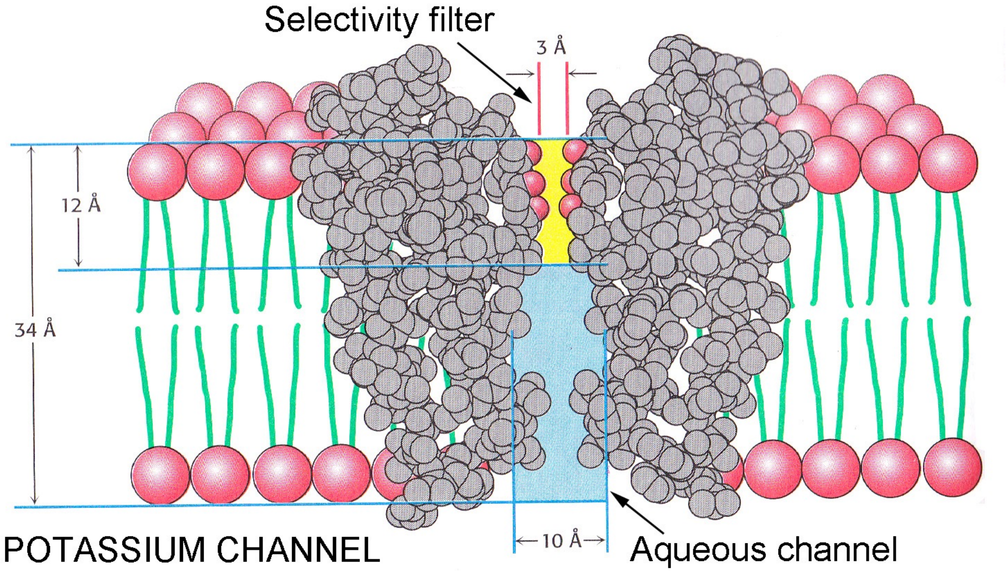


Resting membrane potential

Potassium "leak" channels

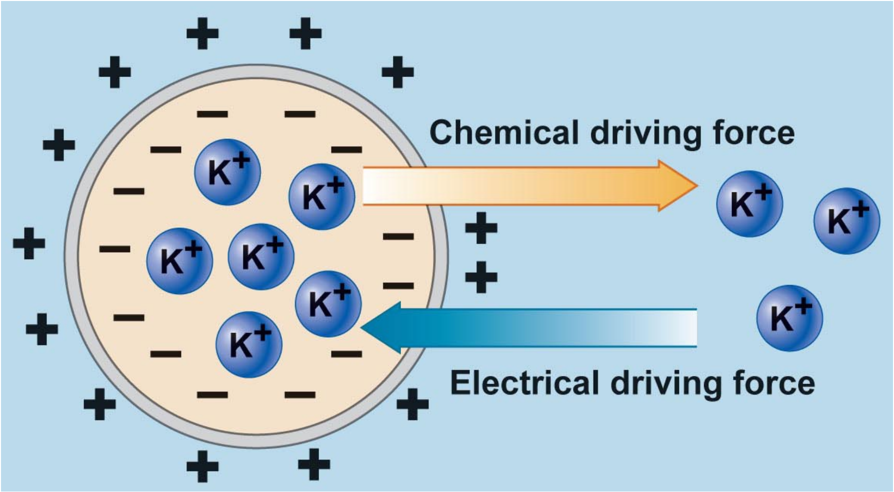
- K+ can move freely via K+ "leak" channels that are always open
- Na+ **cannot** move freely across the membrane
  - It has channels, but they are usually closed





Cells are *polarized*

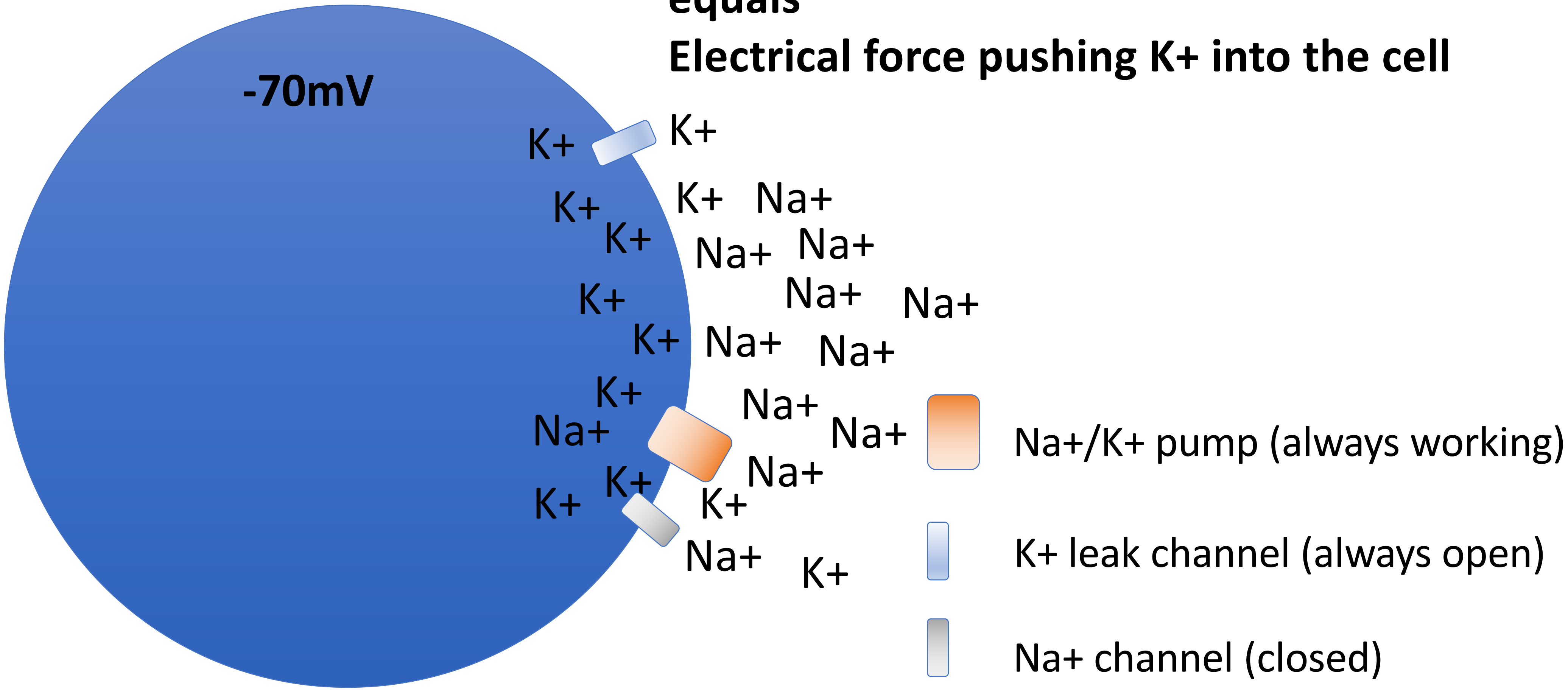
- Na+/K+ pump pushing more Na+ out of cell than K+ into cell
  - Result: inside of cell slightly more negative than outside
- **But** K+ can move freely through its leak channels
  - Result: K+ wants to move with chemical gradient, out of the cell
- **But** this moving K+ is making the cell even more negative
  - Result: flow of K+ stops when force of electrical gradient equals force of chemical gradient
- End result: cell has resting membrane potential of ~-70mV



Resting membrane potential

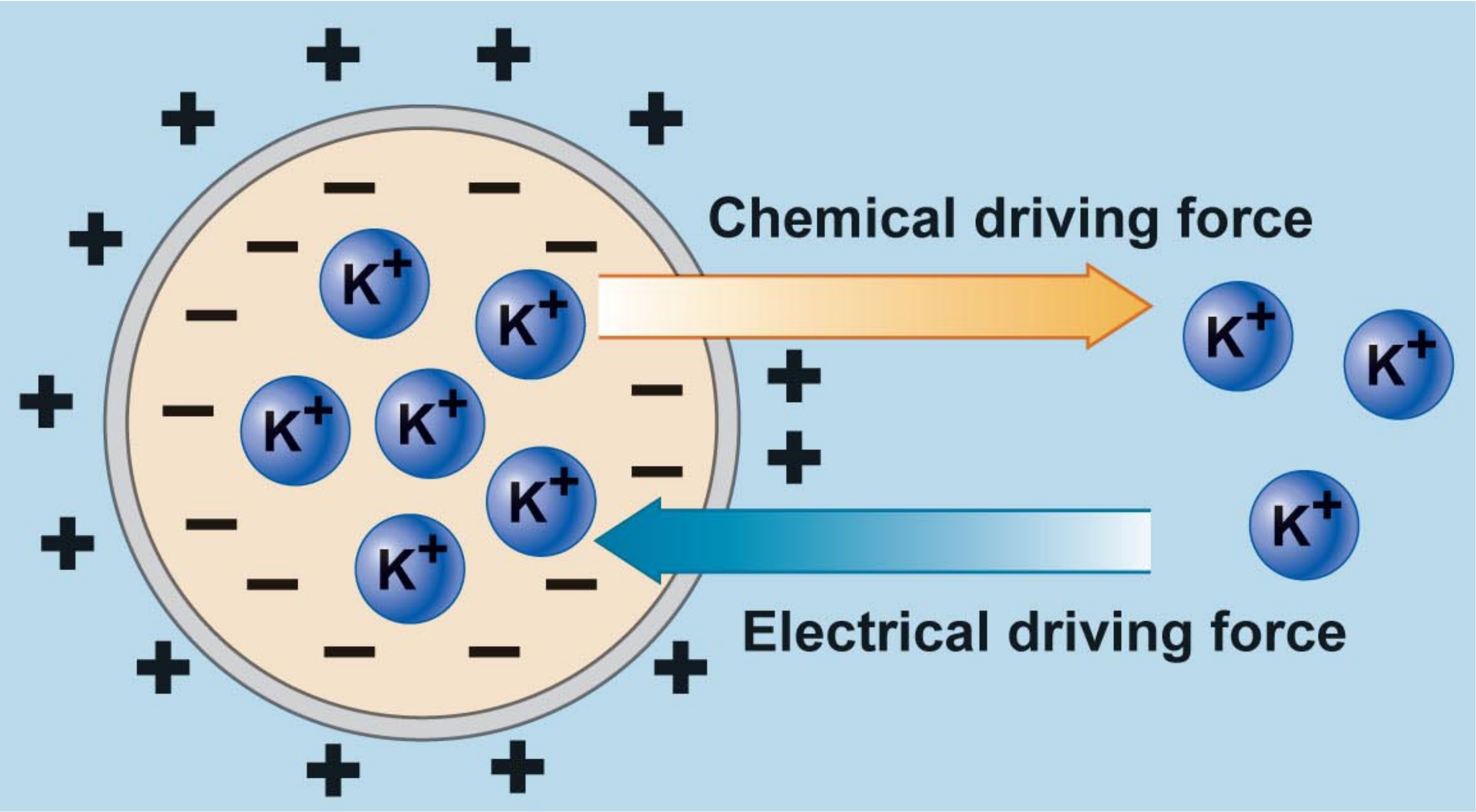
Cells are *polarized*

Chemical force pushing K+ out of the cell
equals
Electrical force pushing K+ into the cell



Resting membrane potential

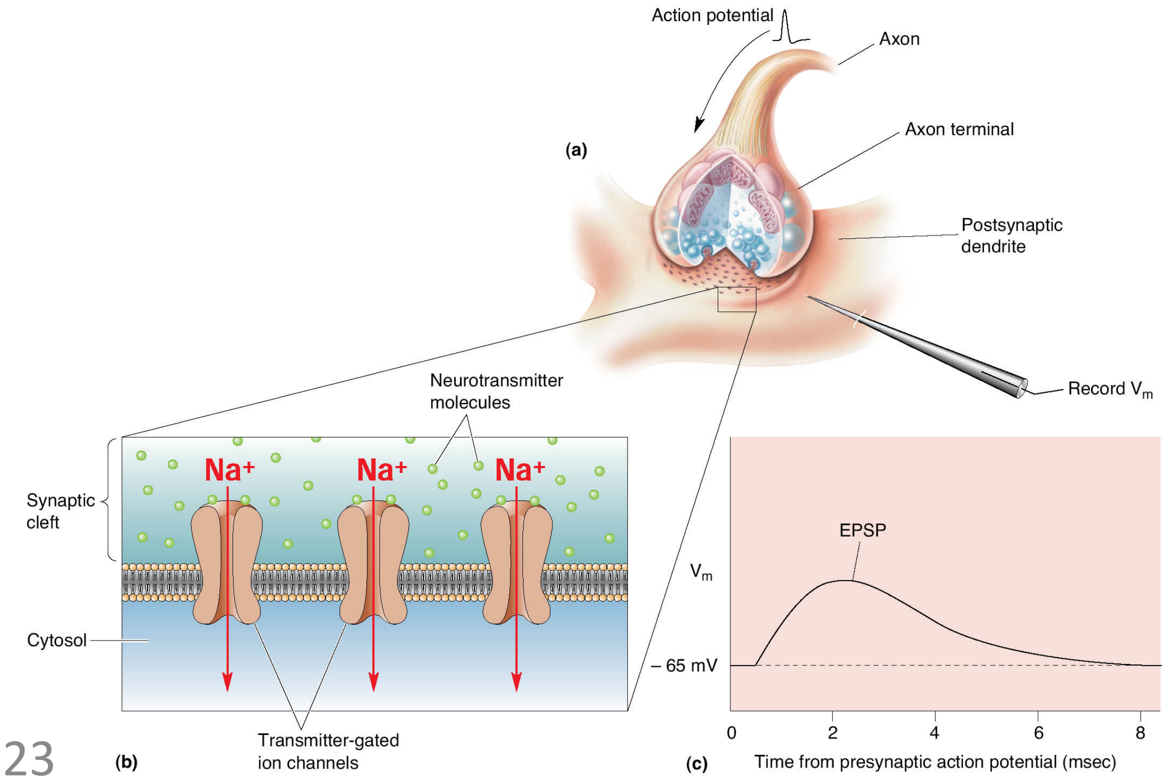
Cells are *polarized*



Resting membrane potential

When a neurotransmitter molecule binds to a postsynaptic receptor, it can have one of two localized effects:

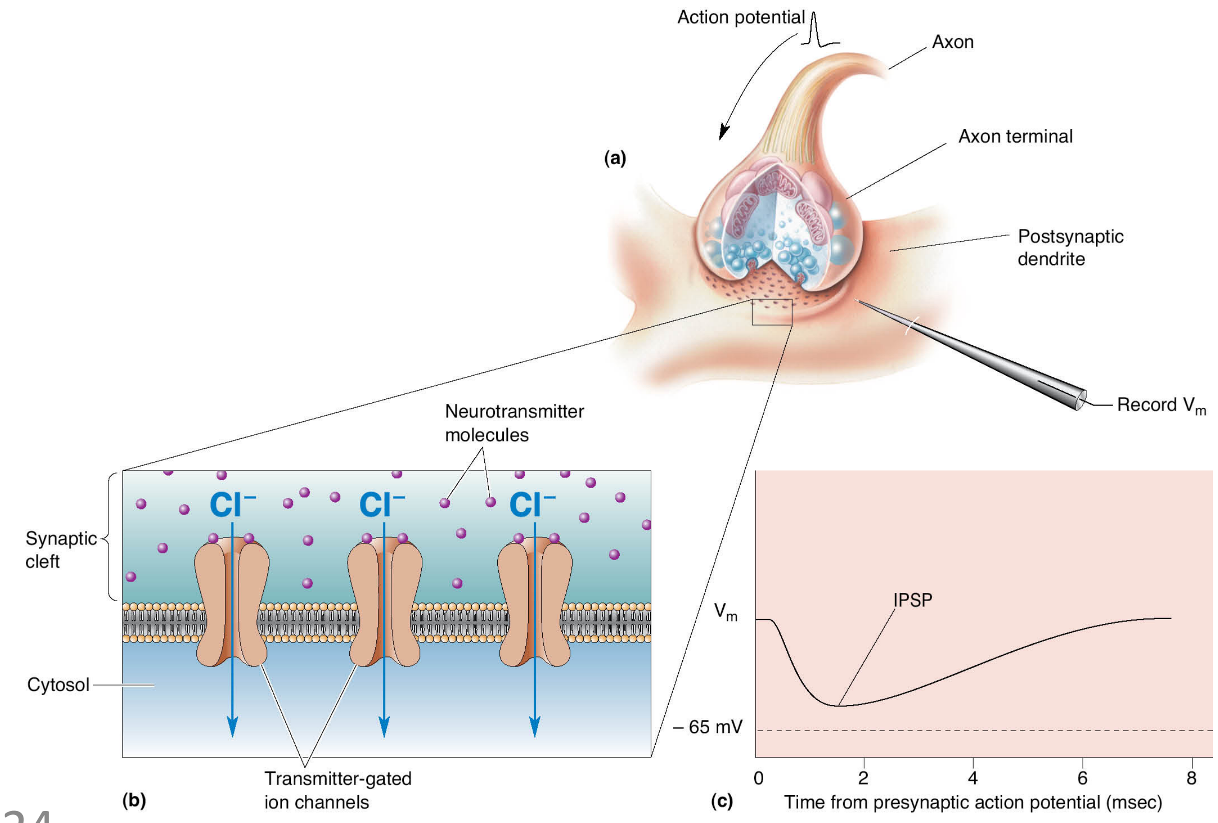
1. Depolarize the membrane (e.g., decrease membrane potential from -70 to -67mV)
2. Hyperpolarize the membrane (e.g., increase the membrane potential from -70 to -72mV)



Postsynaptic potentials

When a neurotransmitter molecule binds to a postsynaptic receptor, it can have one of two localized effects:

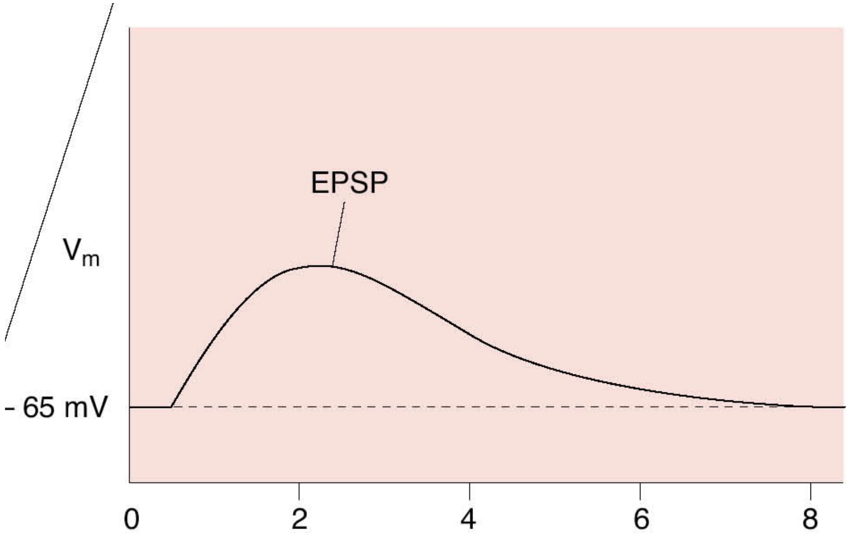
1. Depolarize the membrane = **Excitatory postsynaptic potential (EPSP)**
2. Hyperpolarize the membrane = **Inhibitory postsynaptic potential (IPSP)**



Postsynaptic potentials

When a neurotransmitter molecule binds to a postsynaptic receptor, it can have one of two localized effects:

1. Depolarize the membrane = EPSP = **Increase likelihood that the postsynaptic neuron will fire an action potential (AP)**
2. Hyperpolarize the membrane = IPSP = **Decrease the likelihood that the postsynaptic neuron will fire an AP**



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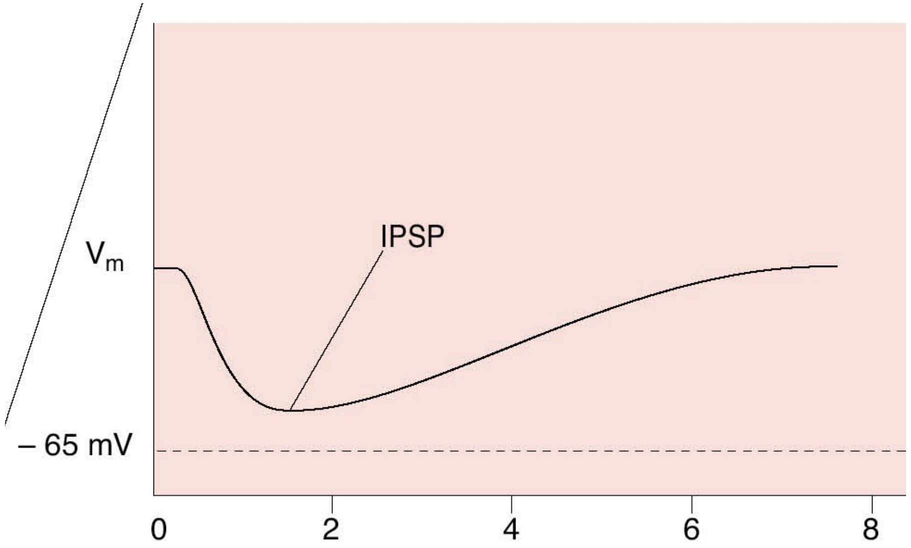

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Postsynaptic potentials

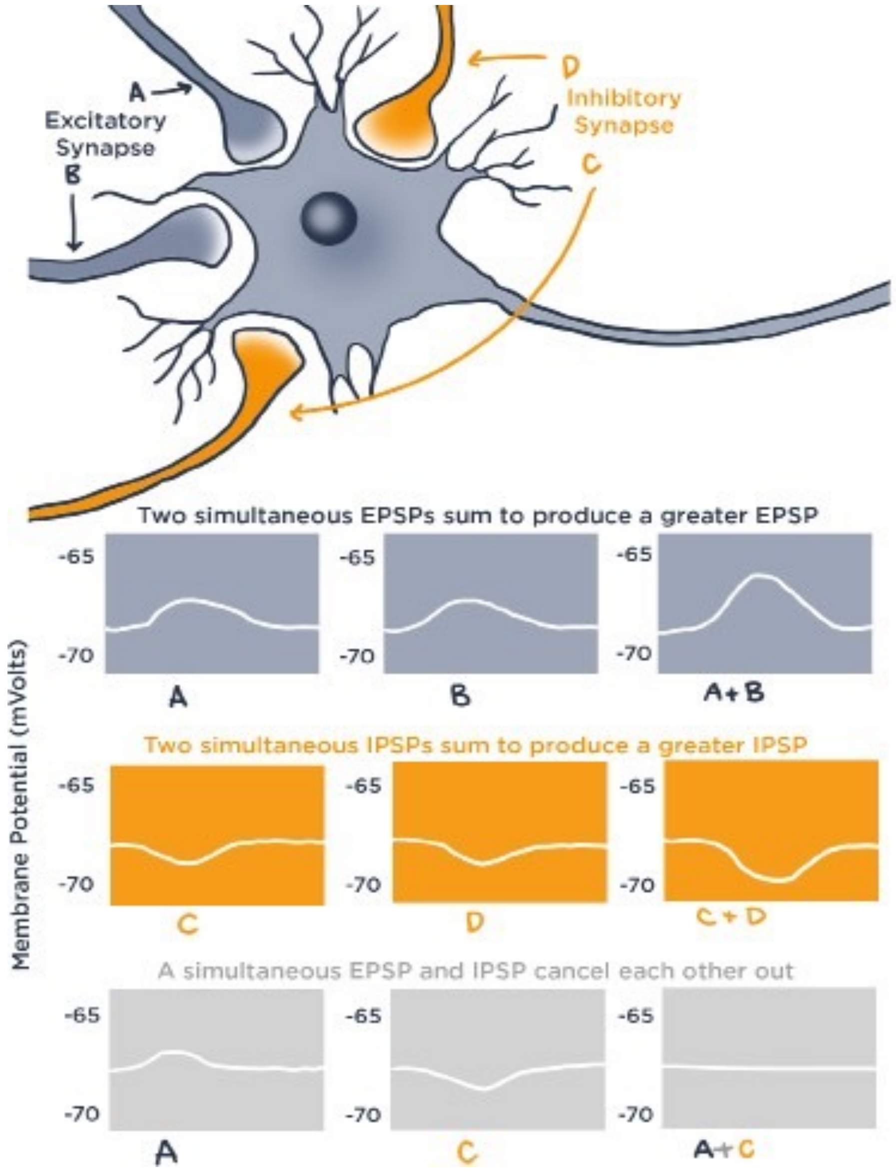
When a neurotransmitter molecule binds to a postsynaptic receptor, it can have one of two localized effects:

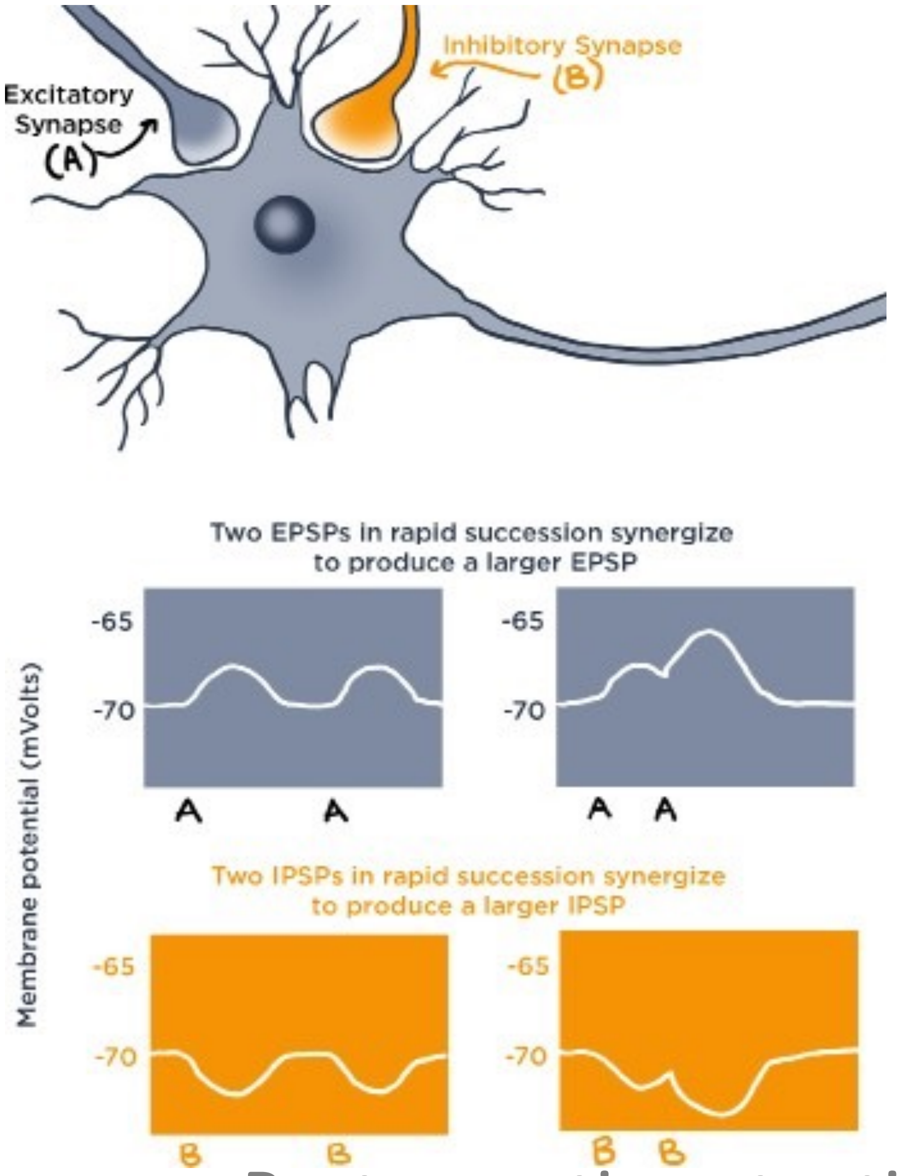
1. Depolarize the membrane = EPSP = Increase likelihood that the postsynaptic neuron will fire an action potential (AP)
2. Hyperpolarize the membrane = IPSP = Decrease the likelihood that the postsynaptic neuron will fire an AP

The transmission of postsynaptic potentials (PSPs) is **graded, rapid, and decremental**: PSPs travel like an electrical signal along an uninsulated wire.

Postsynaptic potentials

EPSPs and IPSPs sum both **spatially** and **temporally**



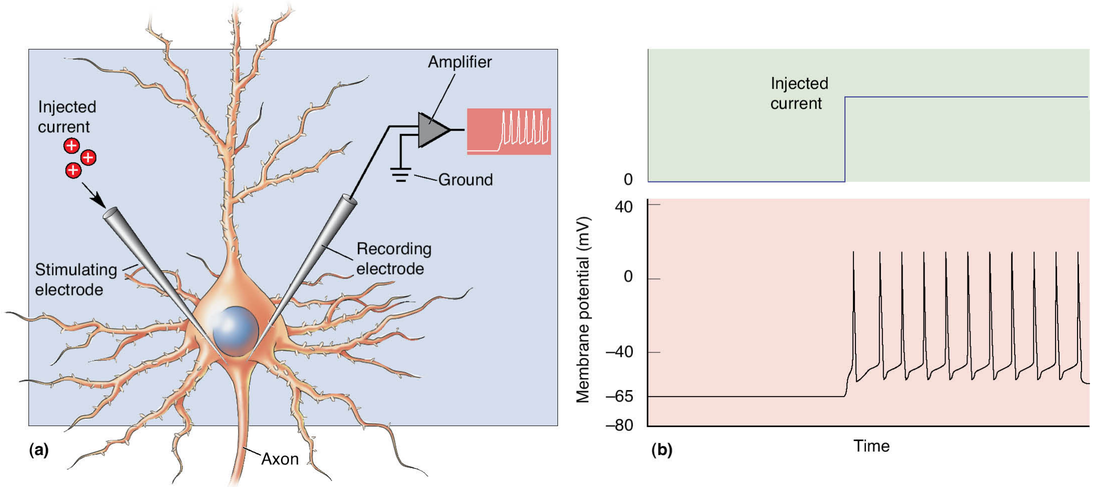


Postsynaptic potentials

AP Generation

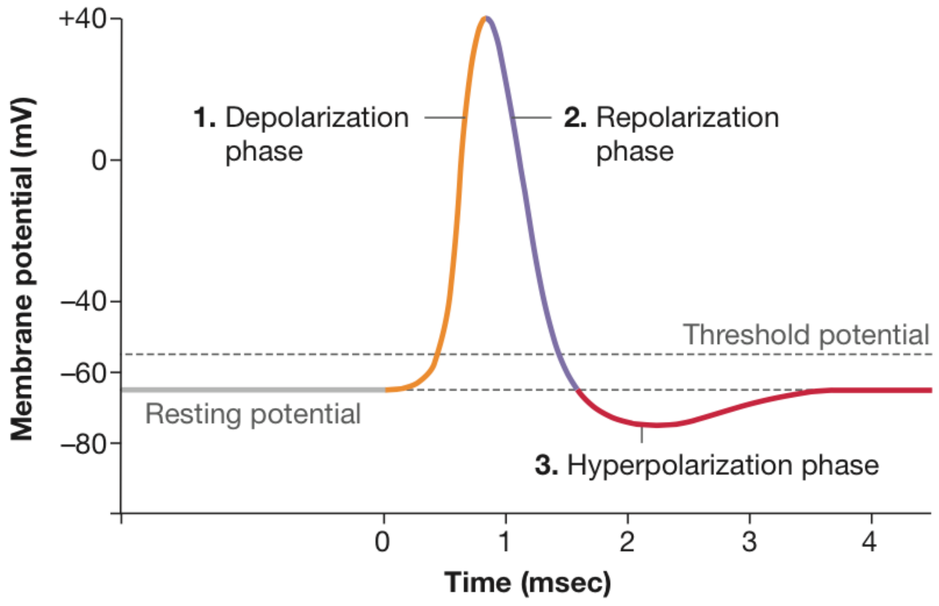
If the sum of the EPSPs and IPSPs that reaches the **axon initial segment** is sufficient to depolarize the membrane there above its **threshold of excitation** (e.g., -55mV) then an **action potential** (AP) is generated

The AP is a massive momentary reversal of the membrane potential (e.g., from -70 to +55 mV)



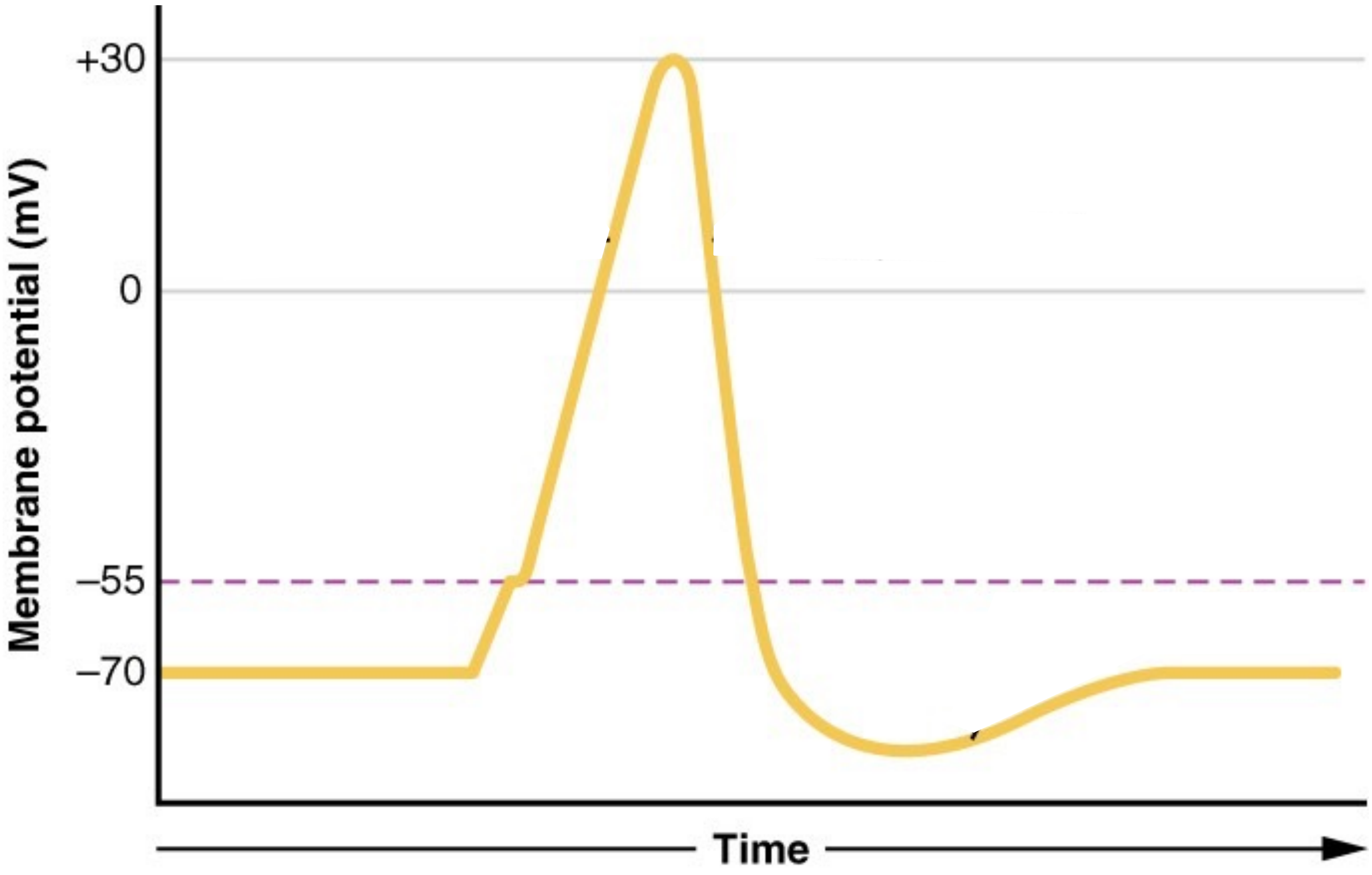
Reverse the polarity!

- *Action potential*: a rapid, brief reversal of the polarity at the membrane, from negative to positive
- **It’s the main method of brain communication**
- It’s all-or-none (off or on), **not** graded (e.g. 0-100%)
  - i.e. always the same size/shape in a cell
  - How do neurons convey magnitude, then?
- Why does this reversal happen?



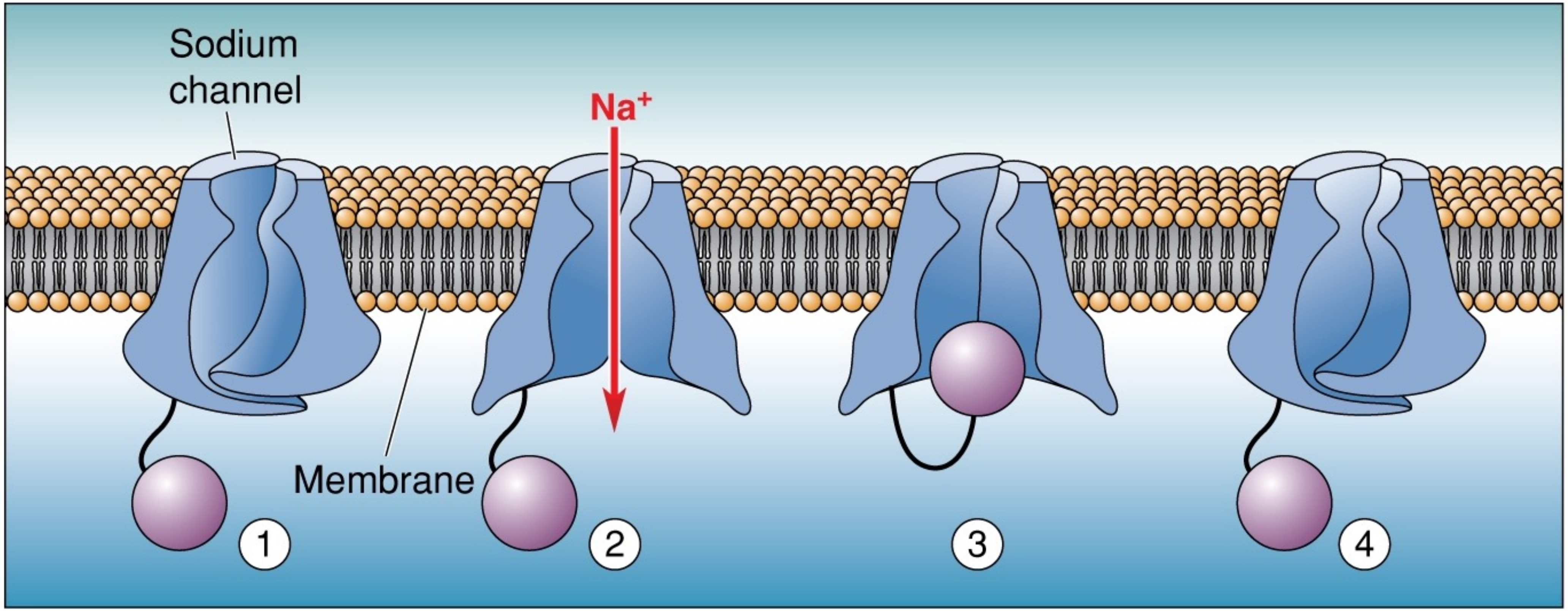
The action potential

Once the membrane potential reaches a certain threshold, an **action potential (AP)** can be generated



The action potential

AP generation and conduction are both the result of **voltage-activated ion channels (primarily Na_v)**



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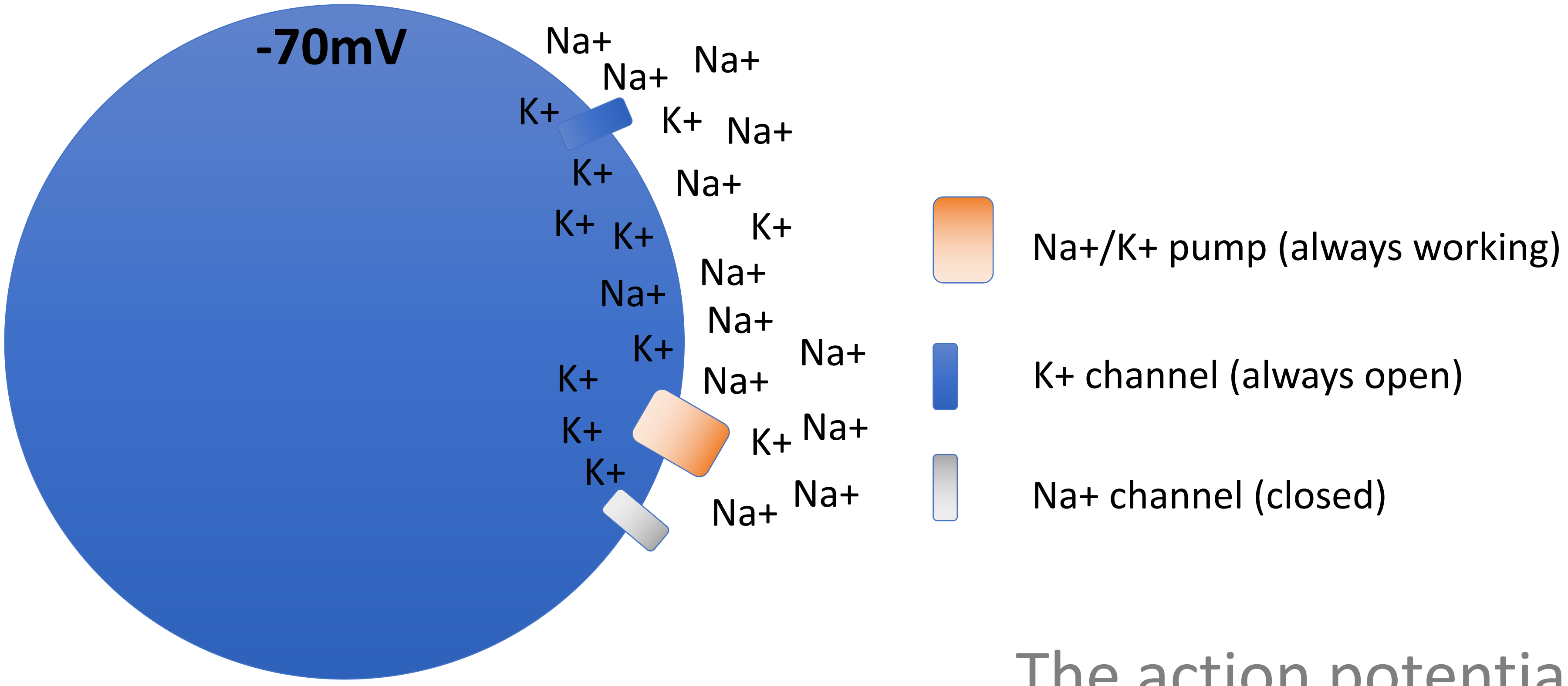
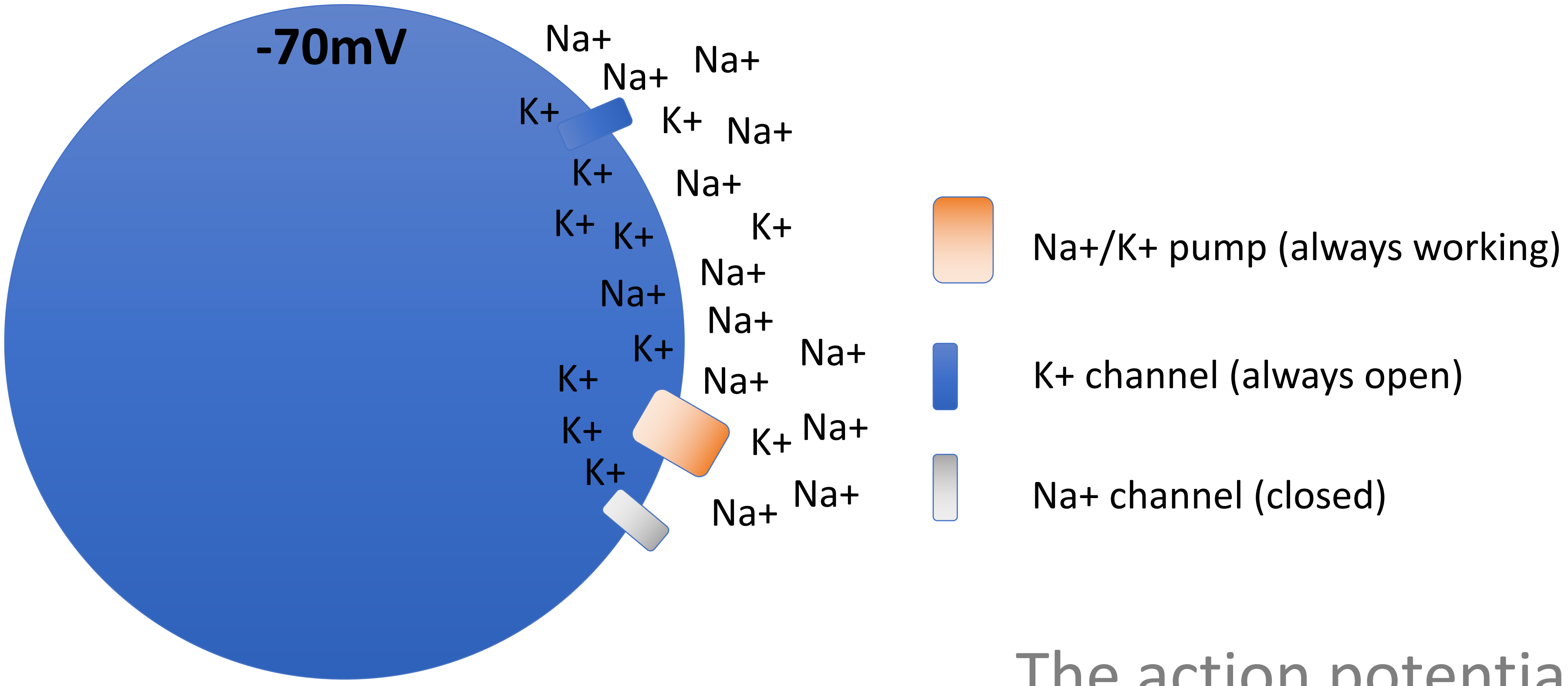
Small depolarizations

- Remember: Na+ channels usually closed
  - **But** these Na+ channels are *voltage-gated*, i.e. they open at a certain voltage (~-55mV)

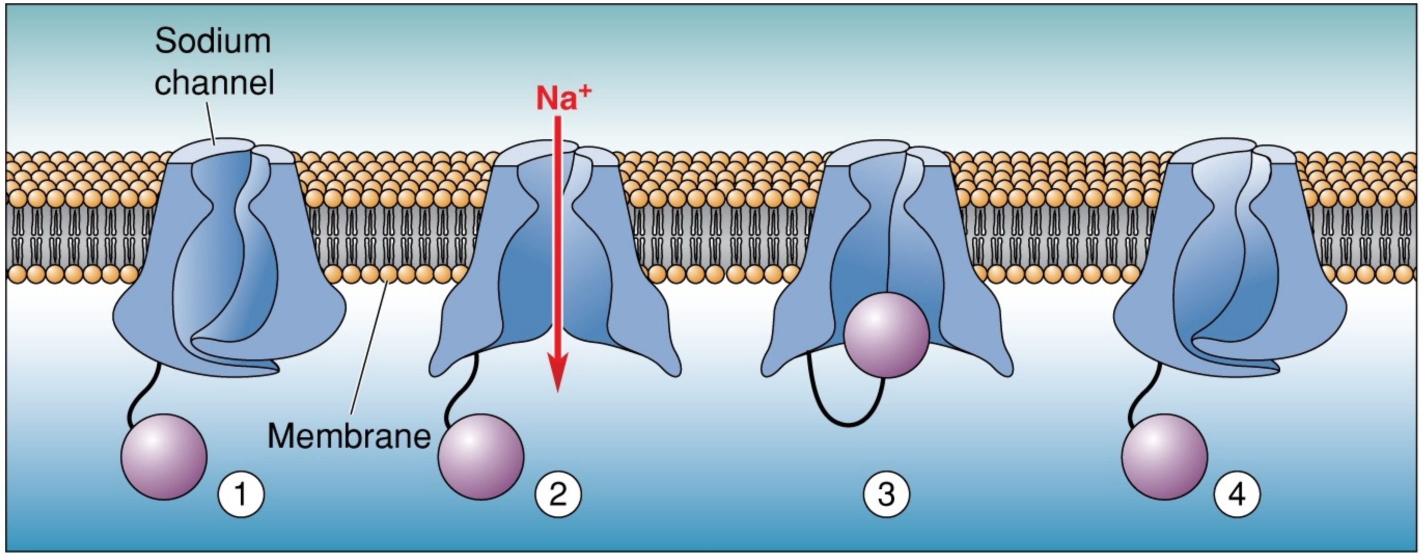


Small depolarizations

- When enough EPSPs arrive at the same time (~5-10mV), the membrane is depolarized enough to reach the Na+ channels' voltage threshold (*threshold potential*), and the channels open!
- Which direction does Na+ want to flow? Why?

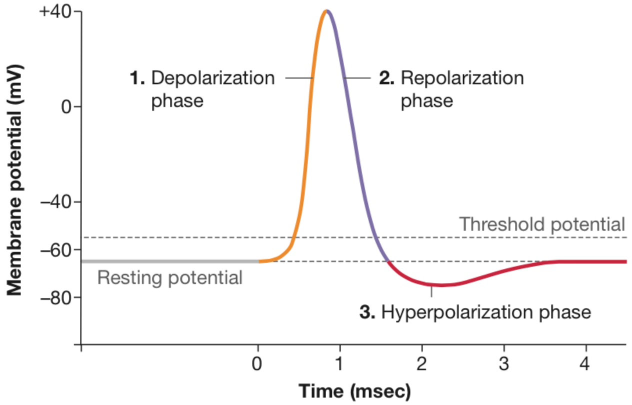


Rapid huge depolarization



(c)

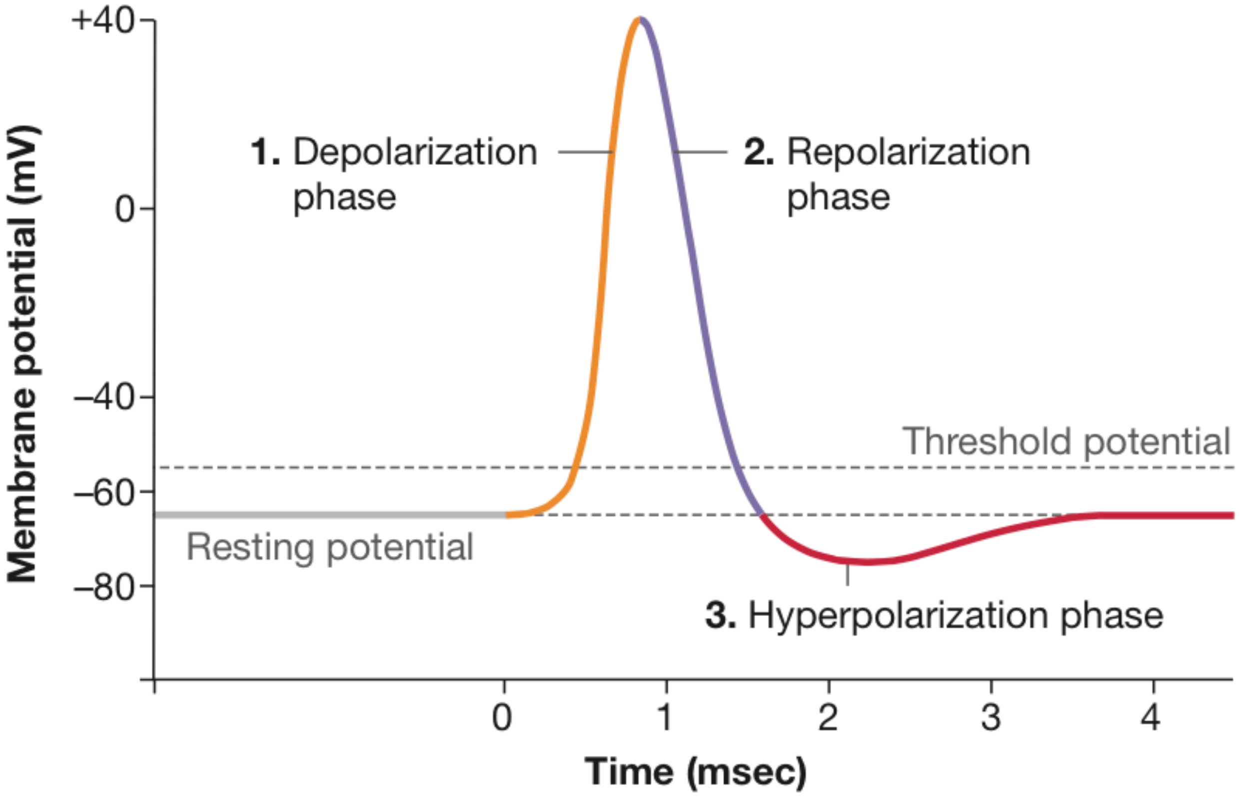
- Na+ channels open → Na+ into cell
  - Effect?
- Cell *membrane* flips from neg. to pos.
- BUT Na+ channels have built-in inactivation
  - Shut-off automatically, after ~1ms
- Na+ channels stay inactivated until membrane goes back to resting poter
  - i.e. No more action potentials until reset!
  - This leads to the **absolute refractory period**



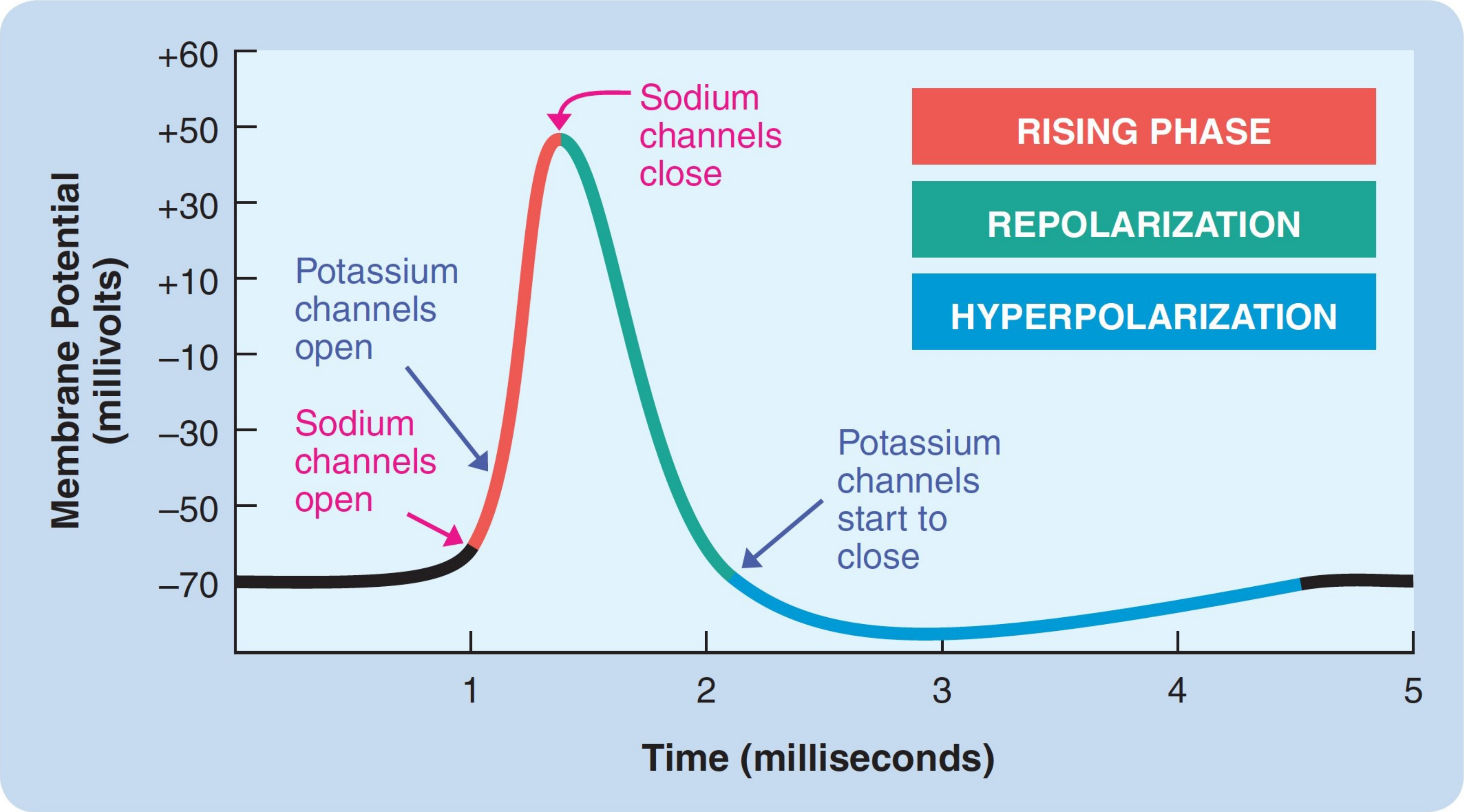
The action potential

Repolarization

- K+ channels, as always, are open
- But even more K+ channels open during AP (some others are voltage-gated)
- Membrane is now pos., so which way does K+ flow?
    - Effect: return cell to neg. resting membrane potential
- Slow closing of voltage-gated K+ channels leads to hyperpolarization phase and the **relative refractory period**
- Na+/K+ pump restores ion balance over time (slow)

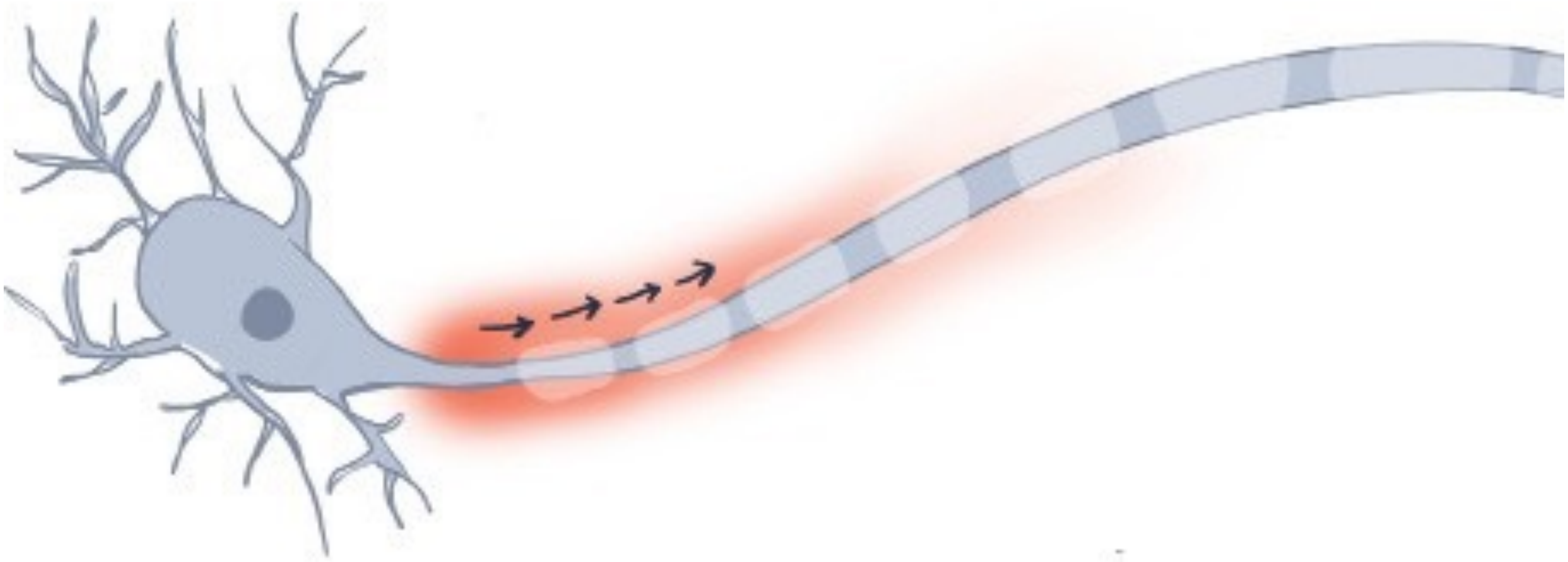


The action potential



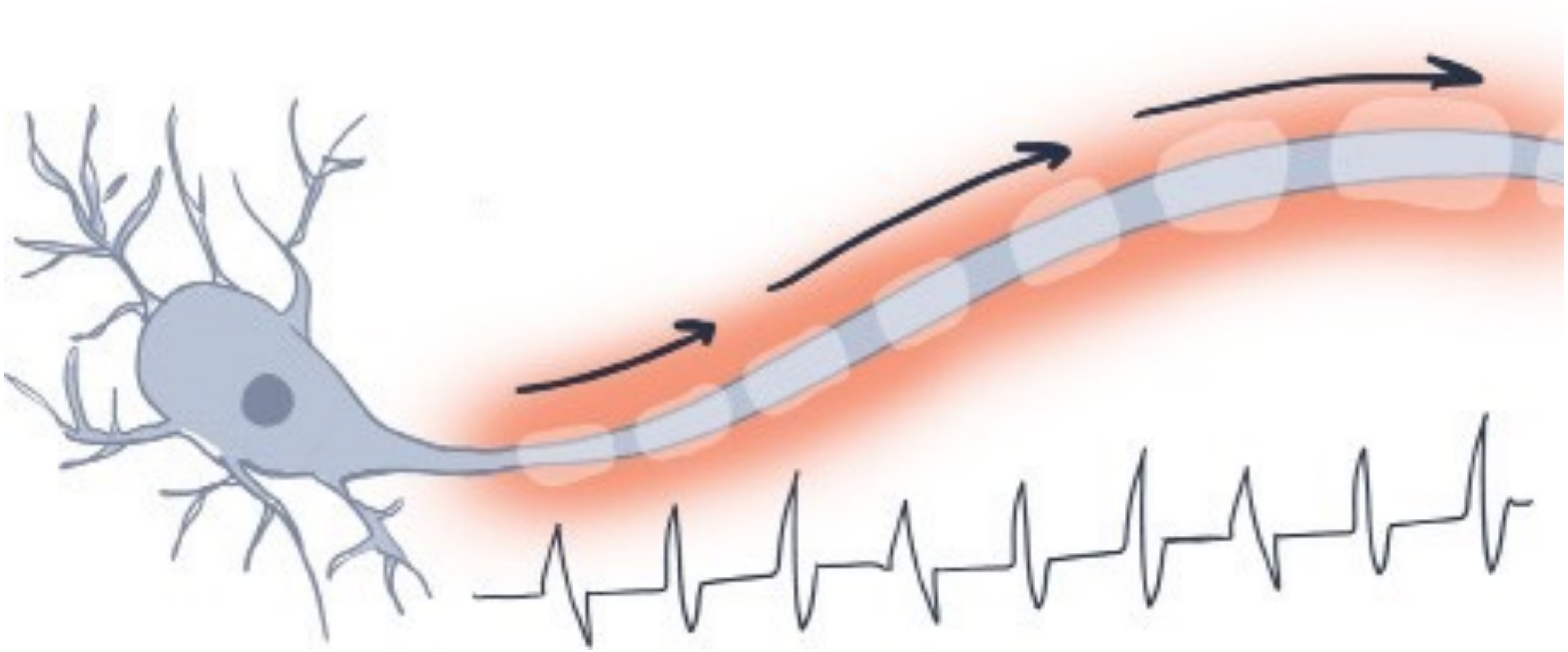
The action potential

Effect of subthreshold stimulation of an axon:



An excitatory potential is produced, but it is not sufficient to elicit an AP

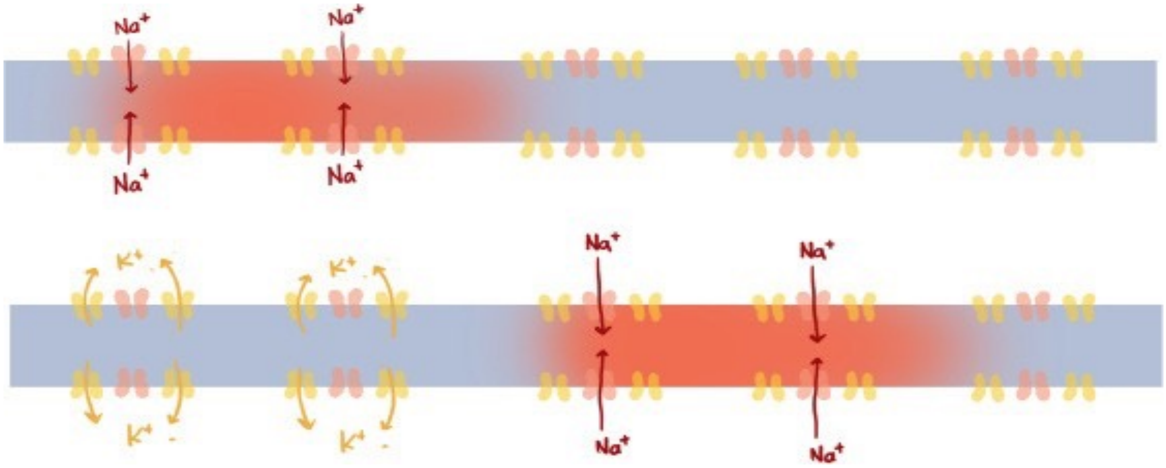
Effect of suprathreshold stimulation of an axon:

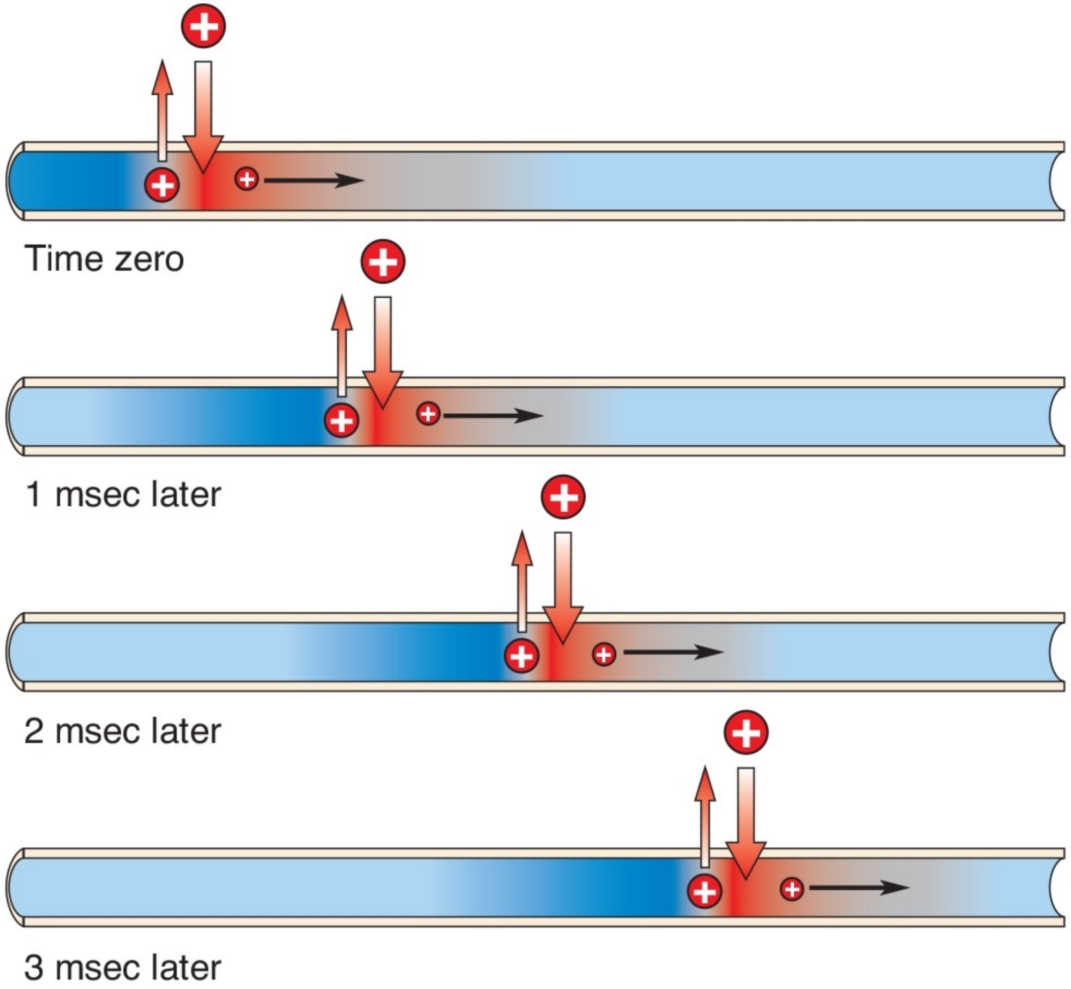


An excitatory potential is produced that exceeds the threshold of excitation and produces an AP that continues undiminished down the axon

Conduction

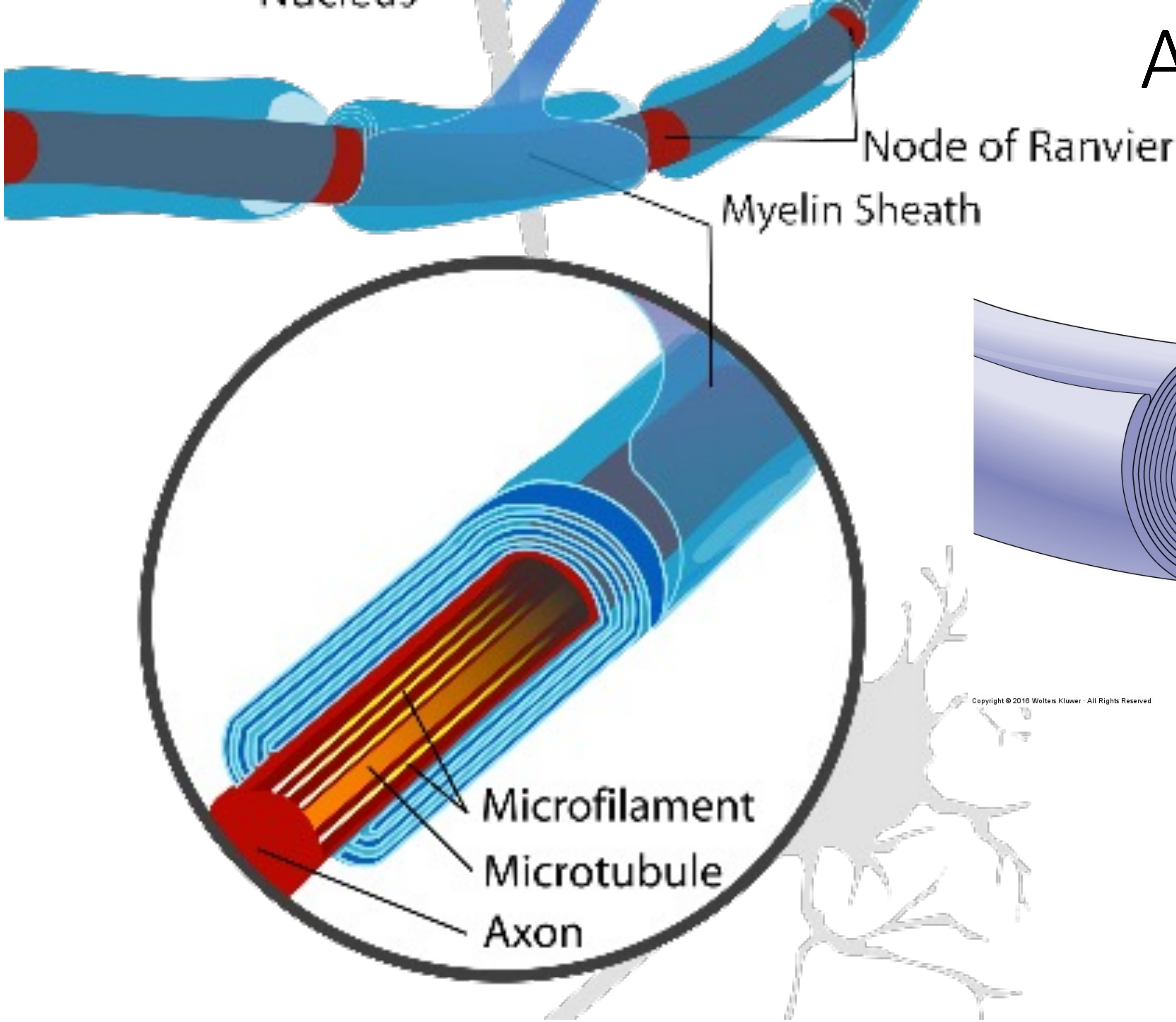
Conduction in an Unmyelinated Axon

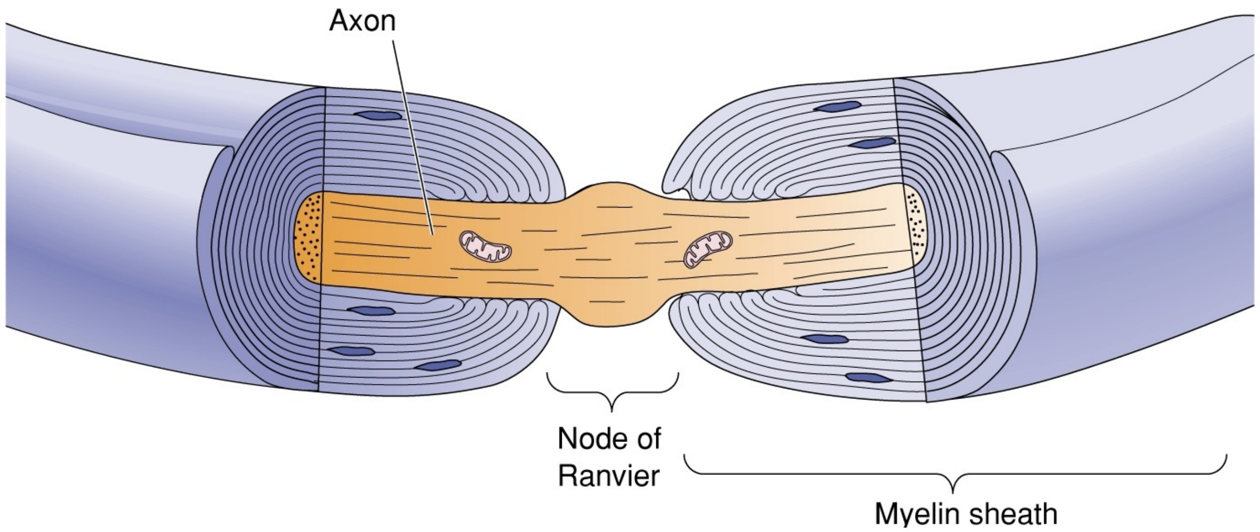




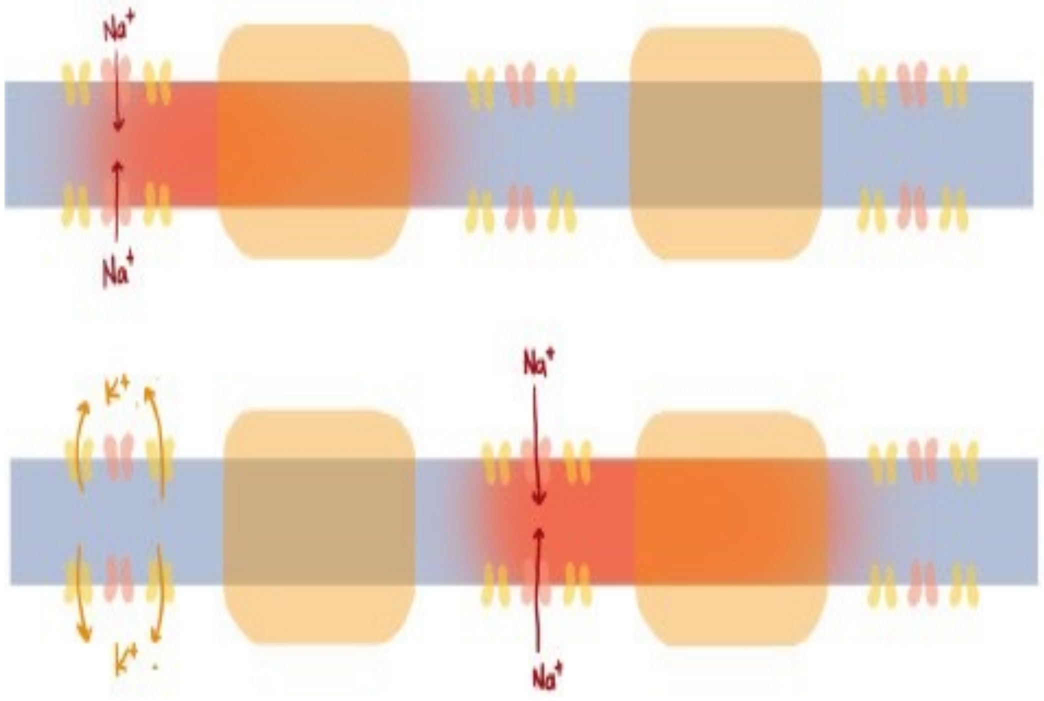
- Na+ channels are present all along the axon
- Unmyelinated axons: Na+ channels everywhere

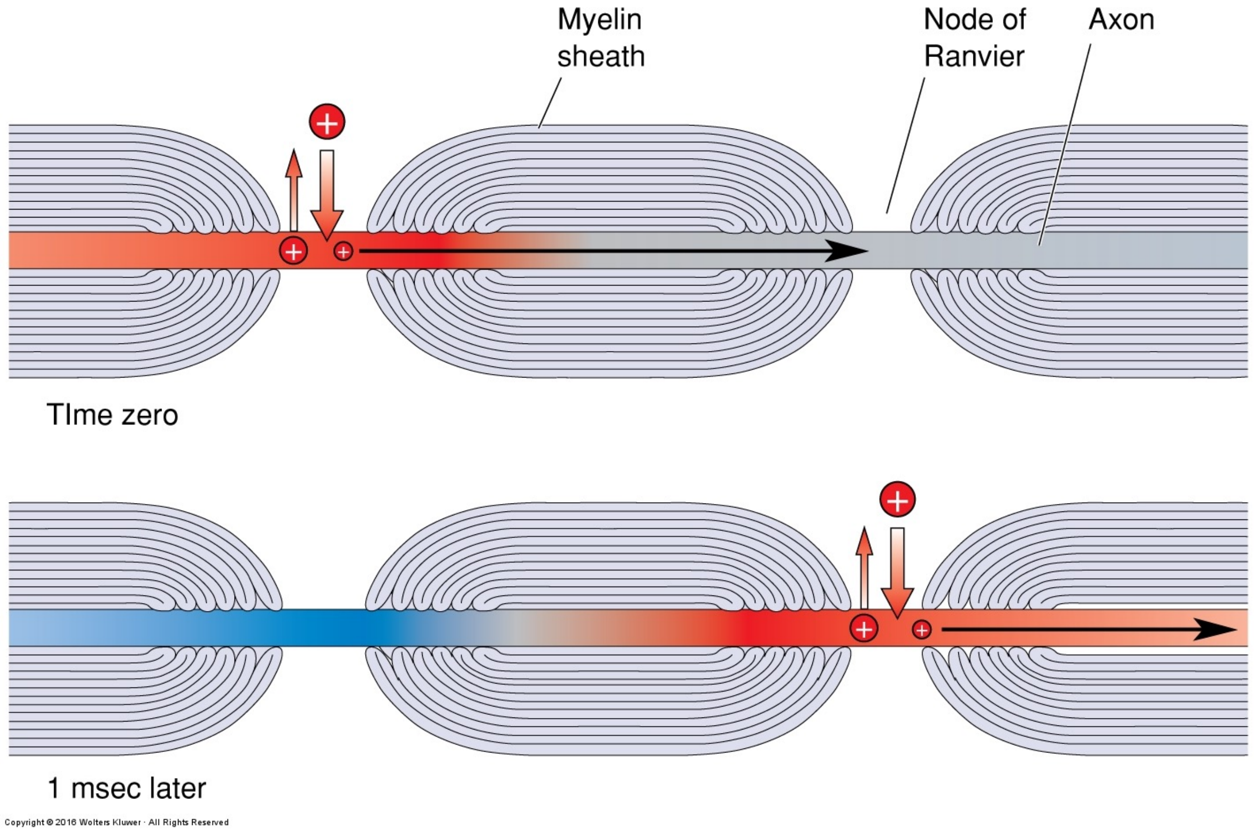
Axon Myelination





Conduction in a Myelinated Axon

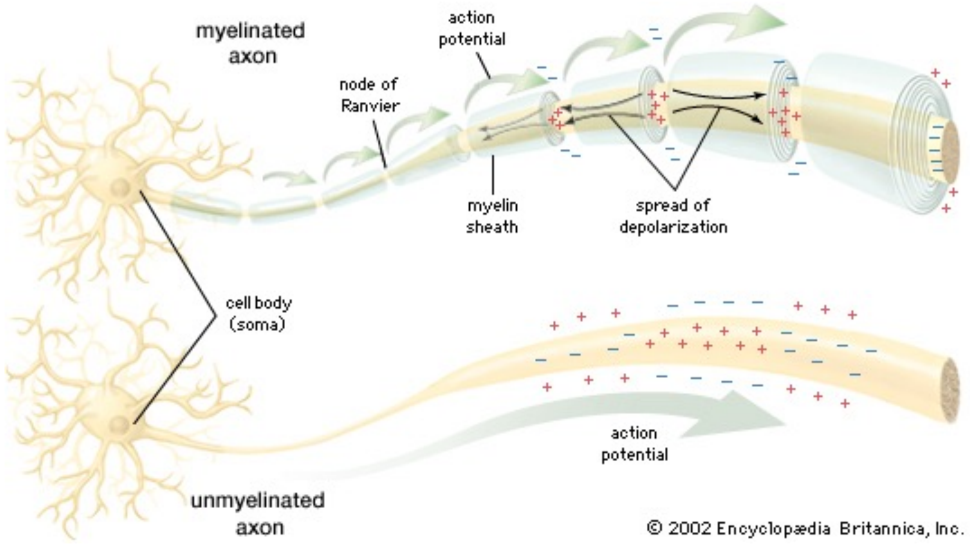




- Na+ channels are present all along the axon
- Unmyelinated axons: Na+ channels everywhere
- Myelinated axons: Na+ channels only at the Nodes of Ranvier

Speed and direction

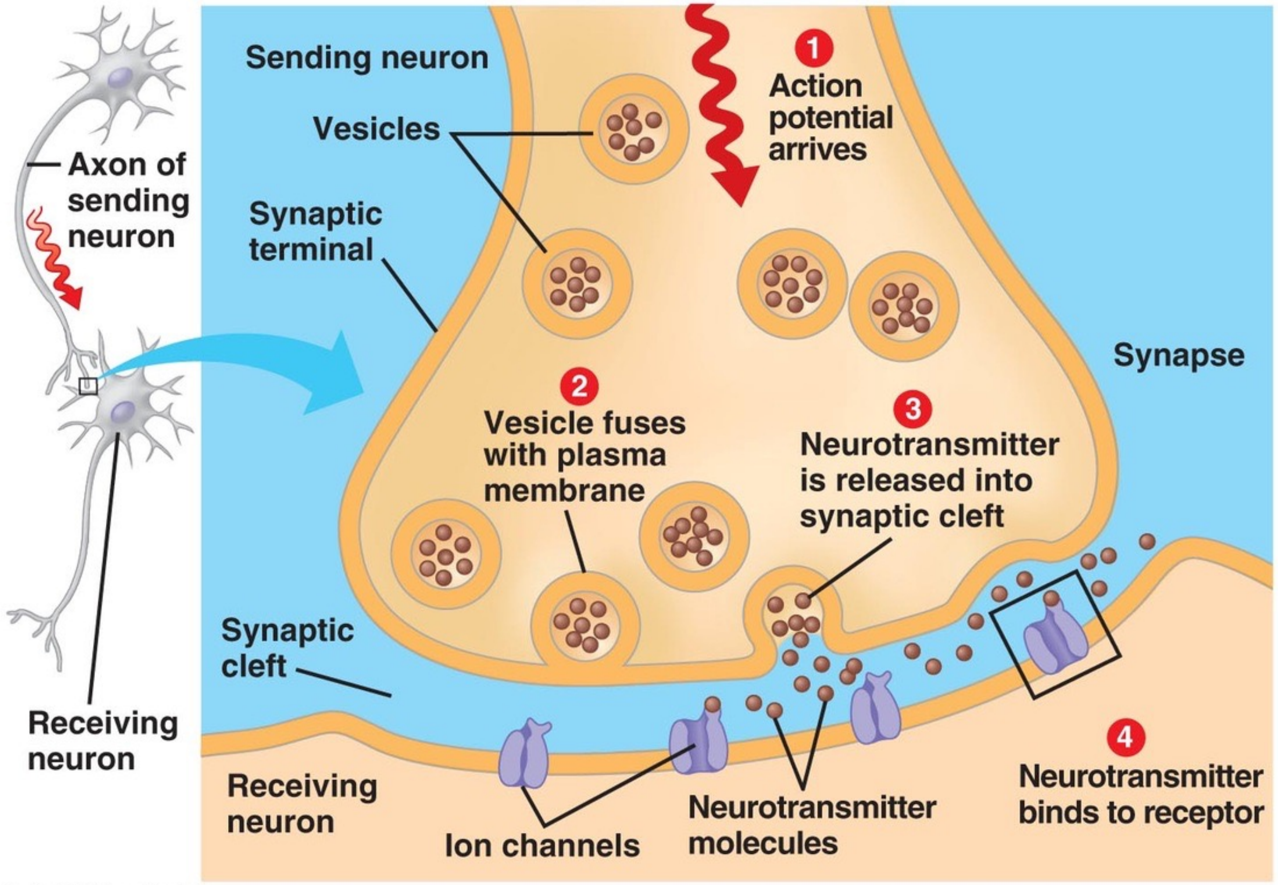
- Action potential is faster down myelinated axon than unmyelinated axon
  - Why? (Two reasons)



- Action potential only travels in one direction
  - Thanks to Na+ channel – why?

Conduction

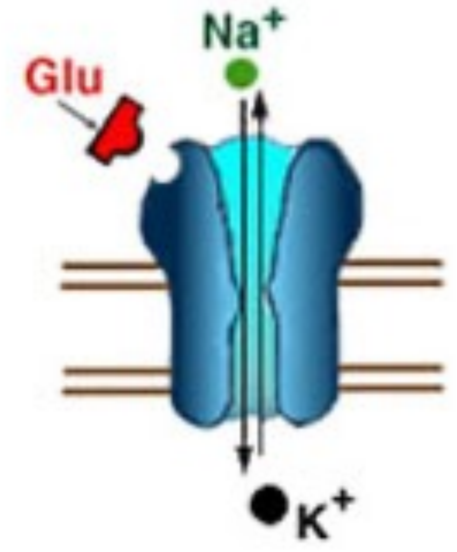
End of the line

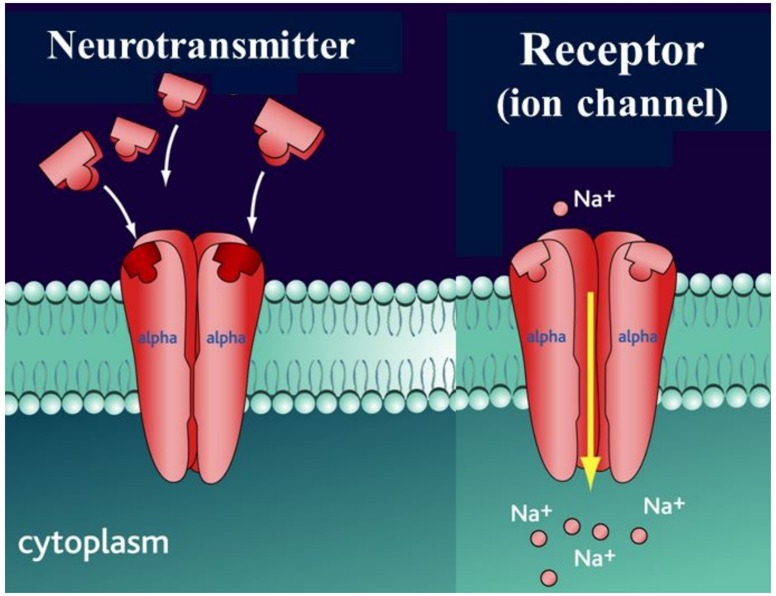


- Axon ends in terminal *boutons* ("buttons")
- Bouton has *vesicles* ("bubbles"?) filled with *neurotransmitters*
- Action potential depolarizes bouton
  - → Causes voltage-gated Ca++ channels to open
  - → Ca++ causes vesicles to fuse with membrane
  - → Neurotransmitters released into synapse

Welcome to the synapse

- Dendrite membrane has special *receptors* that fit, like lock and key, with the neurotransmitters
- Receptors are often just (closed) channels that open when they bind with neurotransmitter!
  - i.e. *ligand-gated ion channels*





Glu: glutamate, most common excitatory neurotransmitter

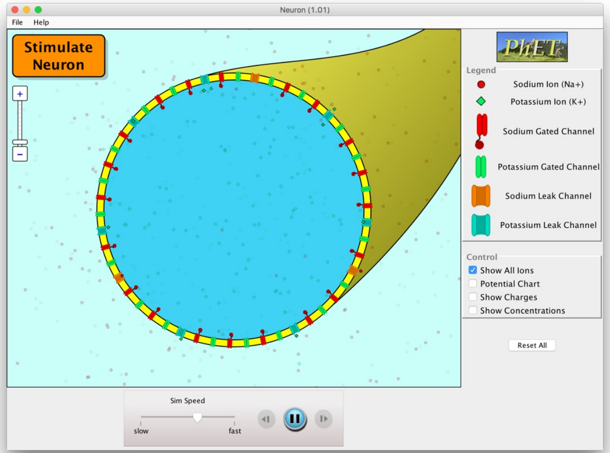
Neurotransmission

Types of Potentials

	PSPs	APs
Graded	Yes	No
Strength	AM	FM
Rapid	Yes	Less so
Decremental	Yes	No

A virtual neuron

1. Go to: https://phet.colorado.edu/en/simulation/neuron and run the simulation
2. Identify three proteins that we discussed
3. Identify one protein we did not discuss—it is real, but not particularly physiologically relevant for our story of RMPs and APs
4. Describe what's happening at rest (i.e. during resting membrane potential), as regards ionic flow (it helps to zoom in)
5. Describe the order of events when you stimulate the neuron (it helps to slow it down)
6. Turn on the potential chart (bottom right corner). What do you see when you stimulate the neuron? Be specific about voltage changes.
7. Turn on the "Show Concentrations" option (bottom right corner). What do the concentrations tell you at rest? How do those concentrations change when you stimulate the neuron? What do those changes tell you about the effects of an action potential?



Totally optional extra learning