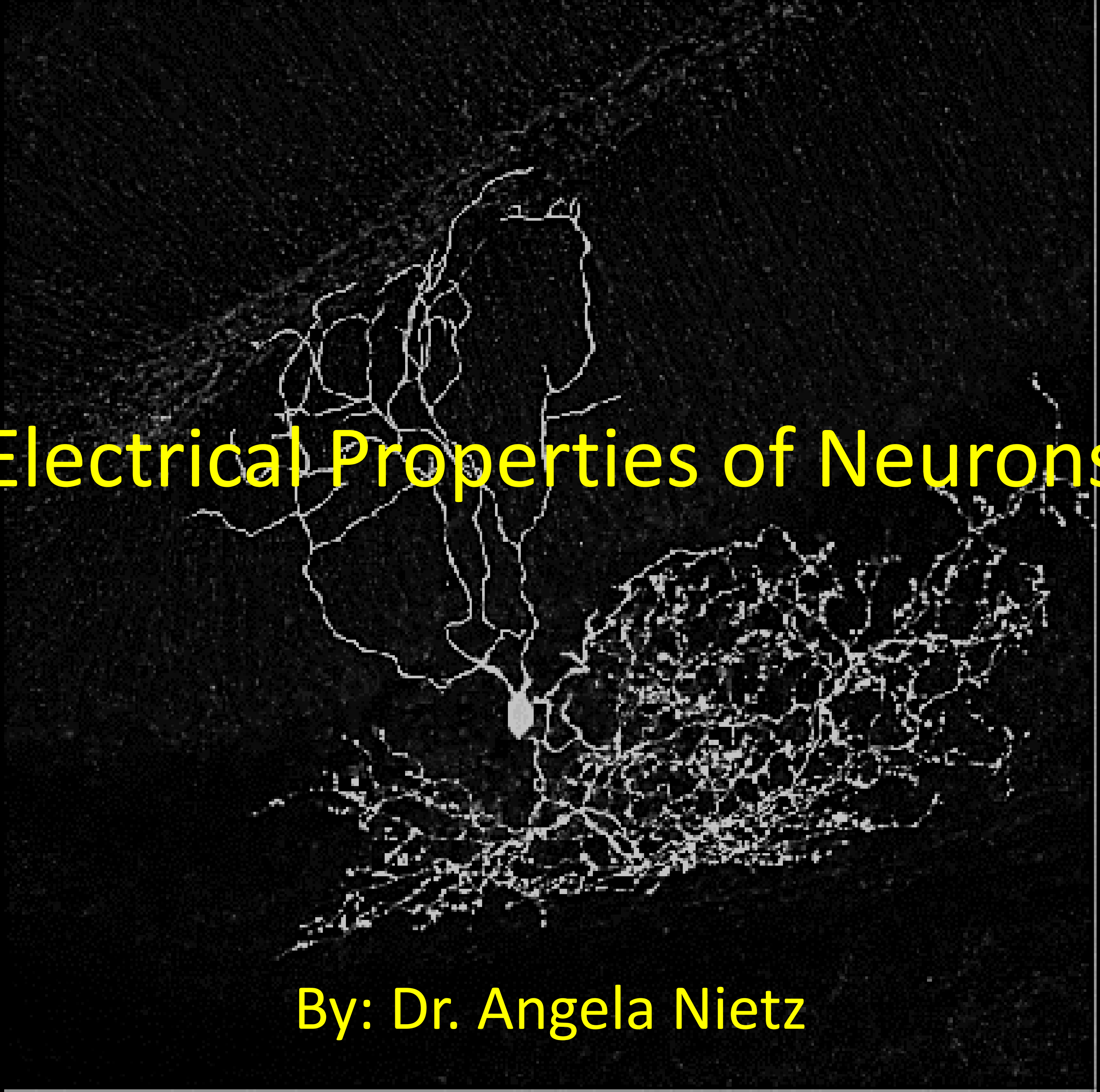
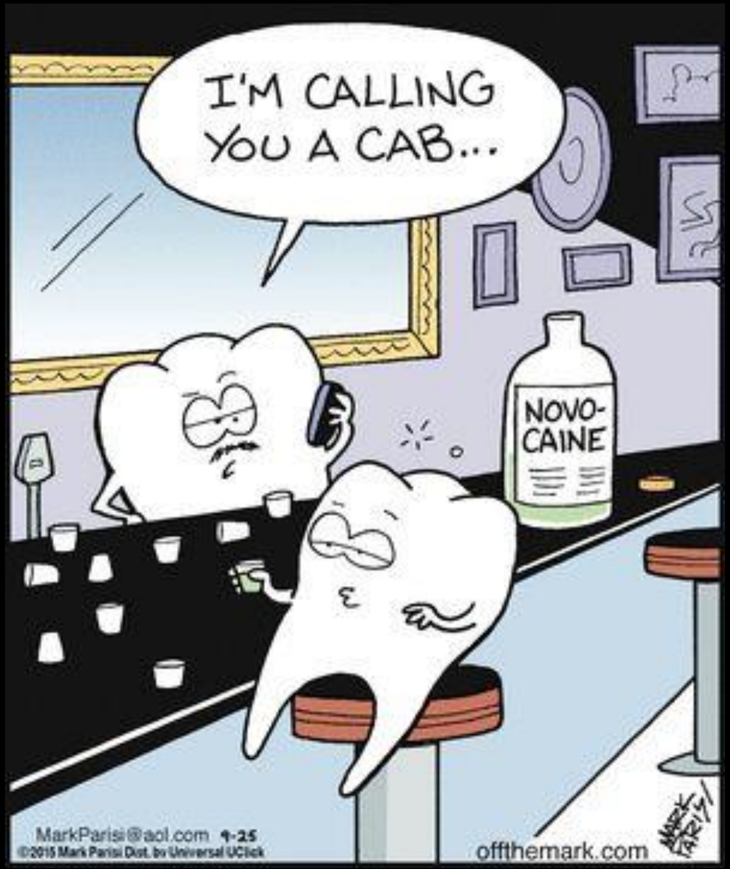
Electrical Properties of Neurons

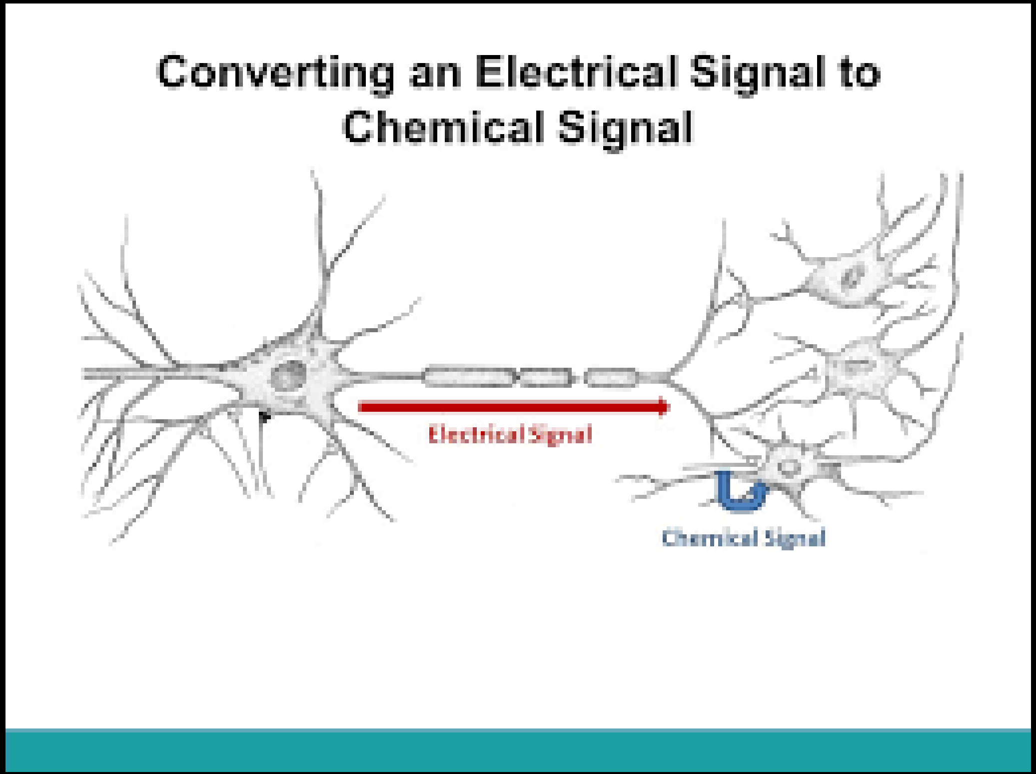


By: Dr. Angela Nietz

How does novocaine work?



How do neurons send signals?



Electrical signals move down the axon within cells

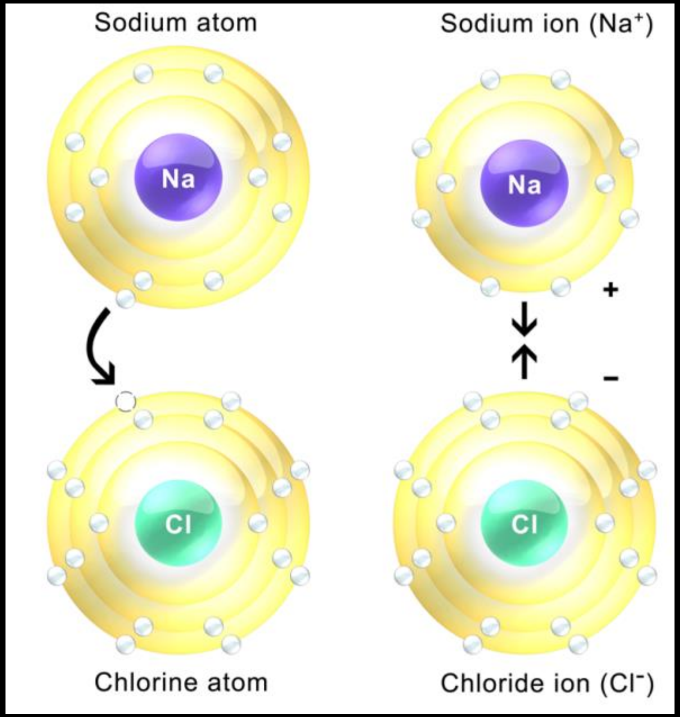
- Electrical signals are carried by ions

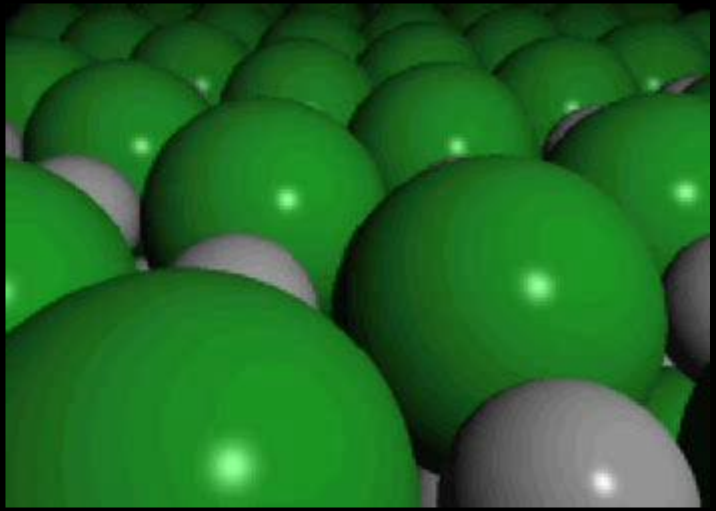
Chemical signals are transmitted between cells

- Neurotransmitters

Ions and Ionization

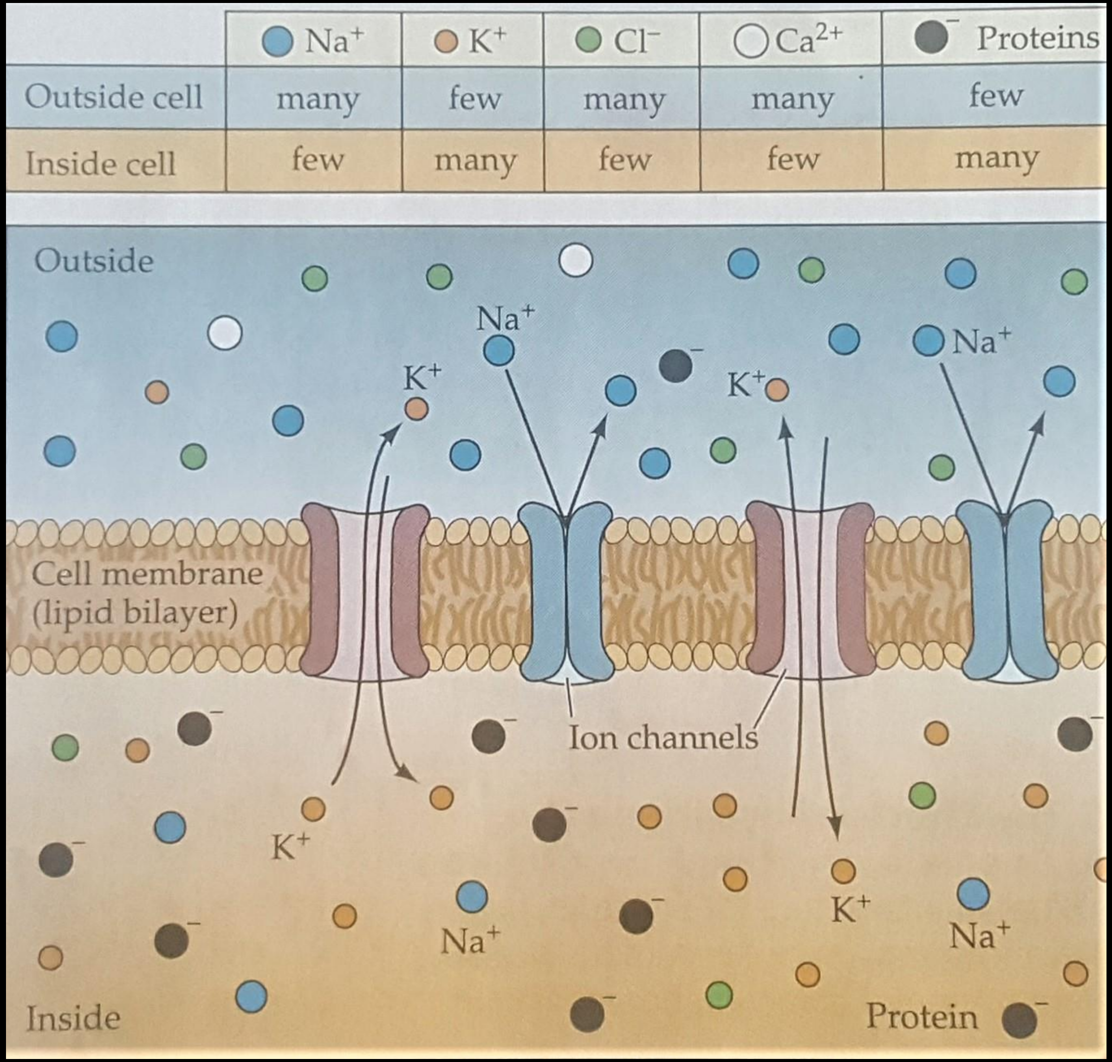
- An ion is an atom or molecule that has an associated charge
  - An atom has lost or gained an electron
  - This gives an element a net positive or negative charge
  - When put in water compounds dissolve and keep their gained/lost electron





What Ions are important for neurons?

- Sodium (Na^+)
- Potassium (K^+)
- Chloride (Cl^-)
  - This is not chlorine (chlorine in your cells would probably kill you)
- Magnesium (Mg^{2+})
- Calcium (Ca^{2+})
  - This one is really important for neurotransmitter release
  - We will come back to it soon!



How do neurons have electrical properties?. . .Ions!

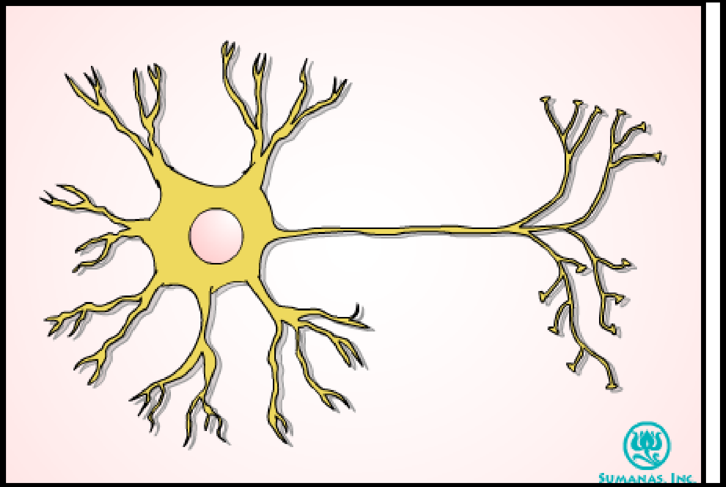
- Ions in solution carry positive and negative charges
- The solutions inside and outside of brain cells have different amounts of ions or different concentrations
- They cannot pass freely across the cell membrane because of the lipid bilayer

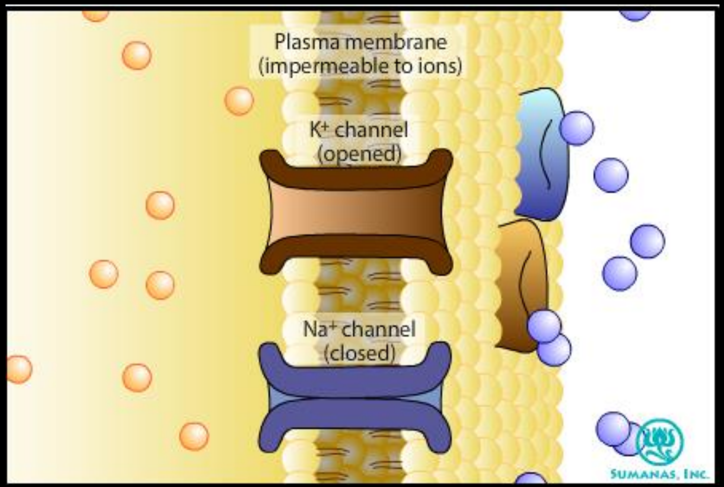
The resting membrane potential

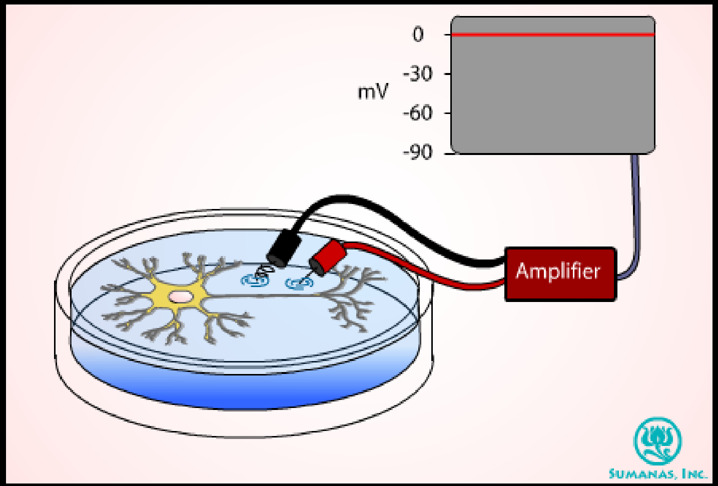
The cell membrane typically does not allow ions to pass between either side **(impermeable)**

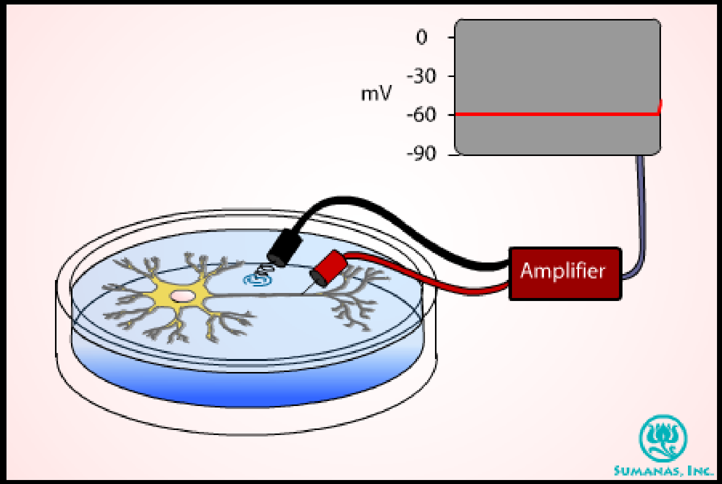
A neuron “at rest” is not sending a signal

The difference in the amount of ions on either side of the membrane when the neuron is in resting state creates a difference in electric charge which we call the **Resting Membrane Potential**

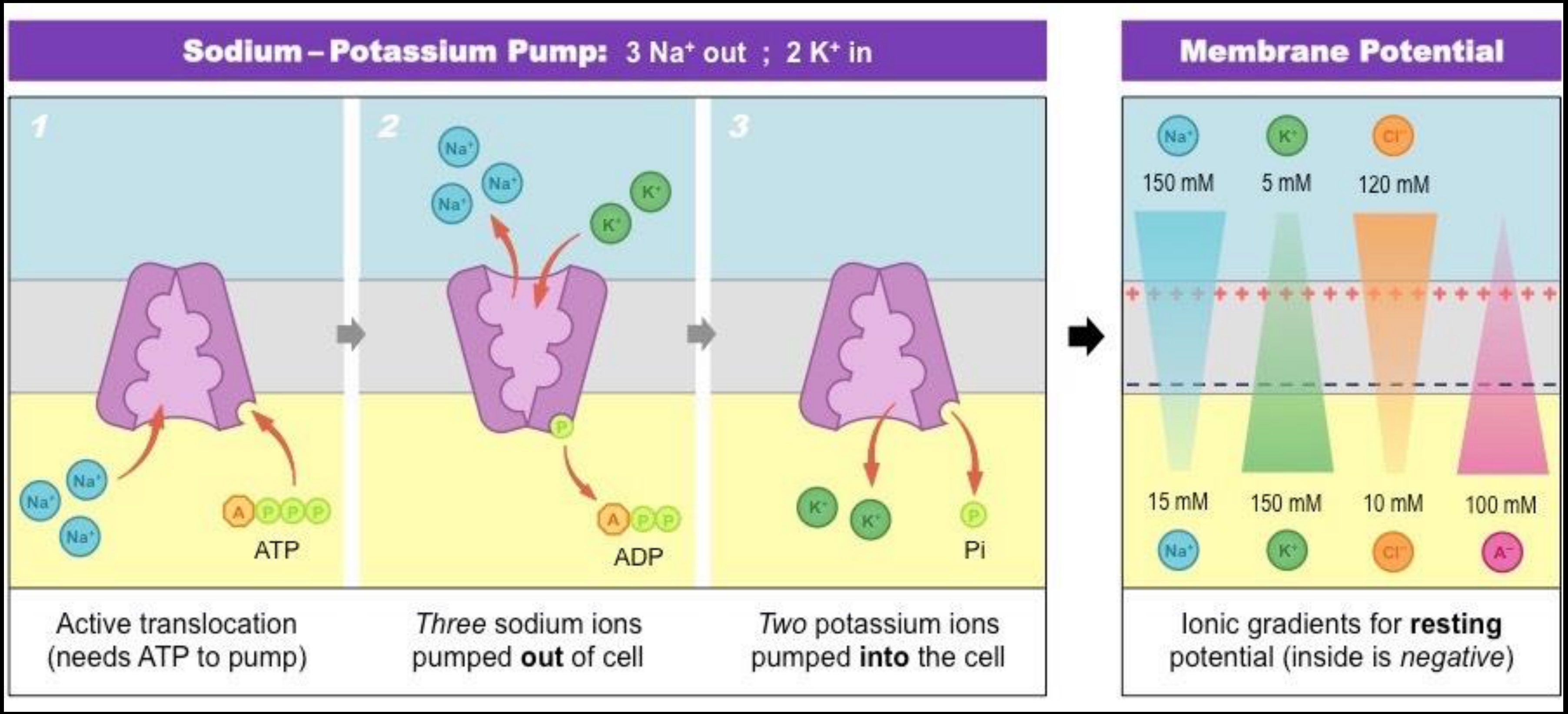








The Sodium-Potassium Pump helps maintain the resting membrane potential



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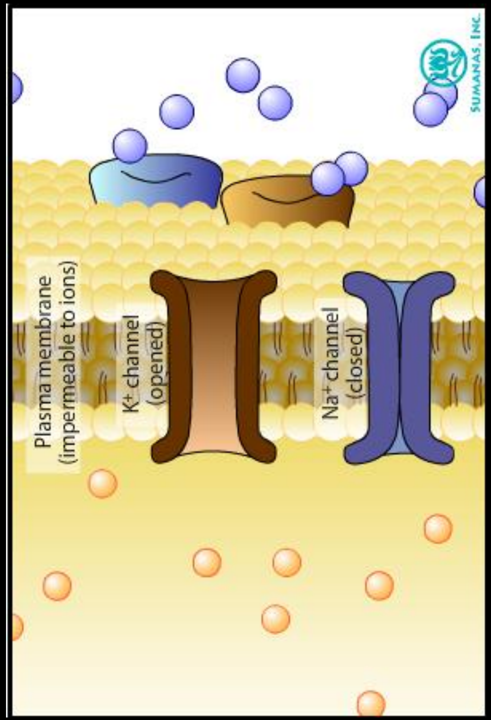
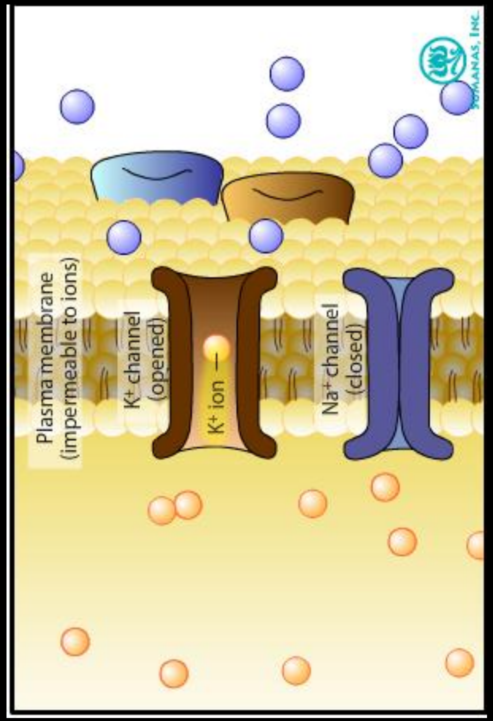
How do ions get in/out of neurons?

The cell membrane typically does not allow ions to pass between either side **(impermeable)**

Ion Channels

- Allow flow of ions across the membrane
- Can be opened or closed
- Specific for particular ions
- Most are closed when at rest (except K^+)



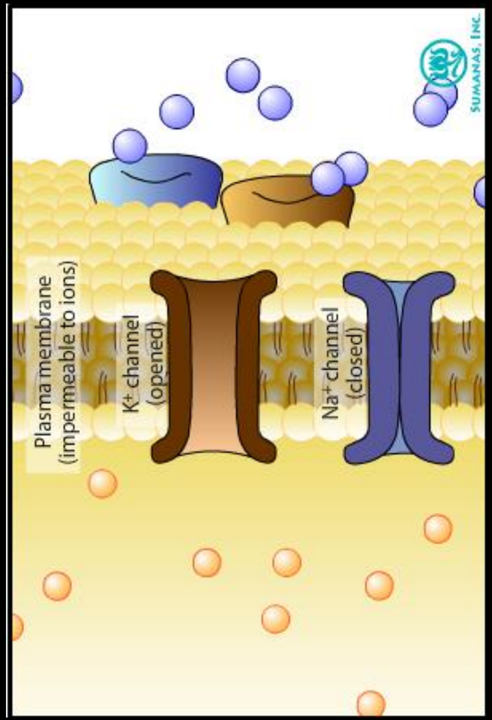


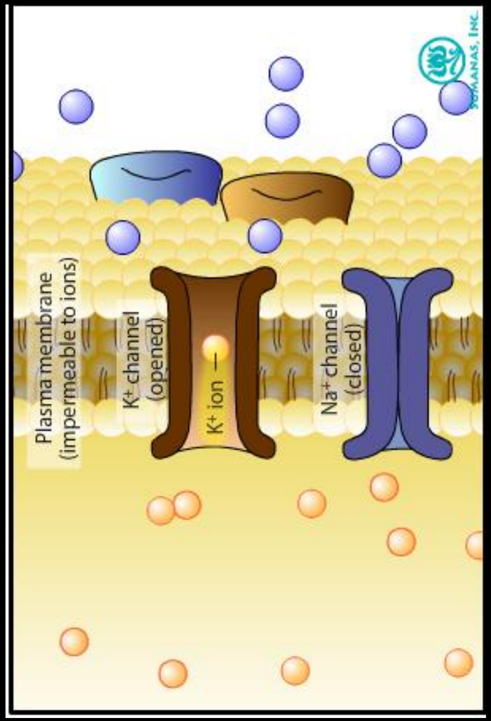
How do ions get in/out of neurons?

- Ions in solution carry positive and negative charges
- The solutions inside and outside of brain cells have different amounts of ions or different concentrations
- They cannot pass freely across the cell membrane because of the lipid bilayer (it’s hydrophobic)
- Generally ions travel from areas of high concentration to low concentration when allowed to freely move until the concentration in uniform

How do ion channels open?

- Ligand binding (neurotransmitters)
- Voltage changes
- Mechanical force
- Passive (always open)

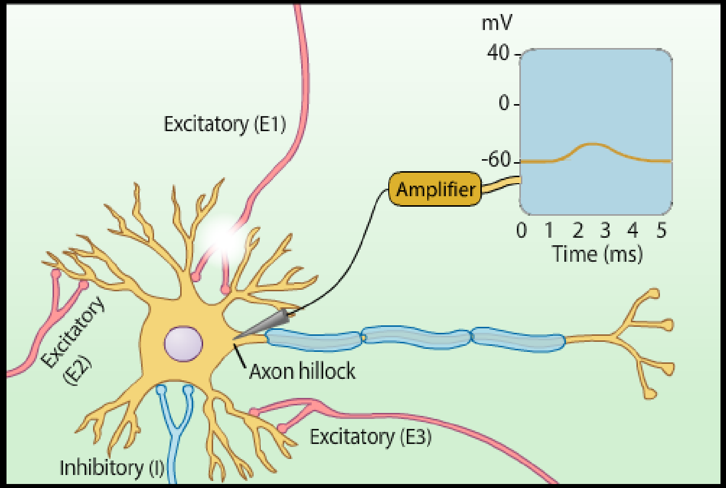




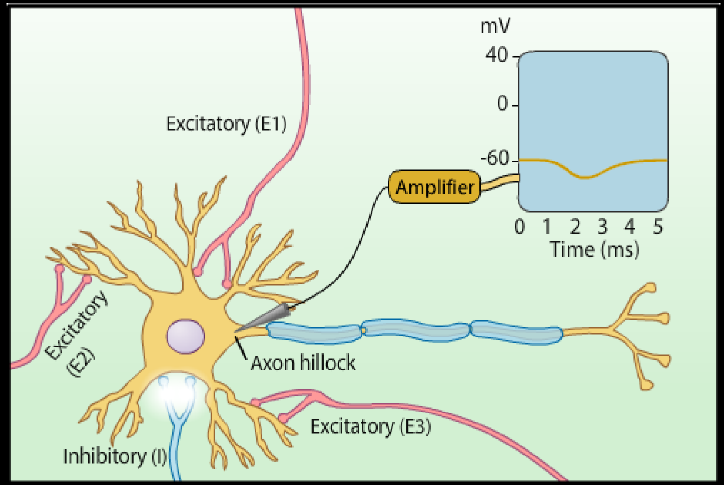
What happens when neurons get signals from other cells?

- Neurotransmitter receptors cause ion channels open
- Ions move into or out of the cell

- Movement of the membrane toward 0 mV is a **depolarization**
  - This excites the cell meaning that it is more likely to fire an action potential
  - positive ions moving in

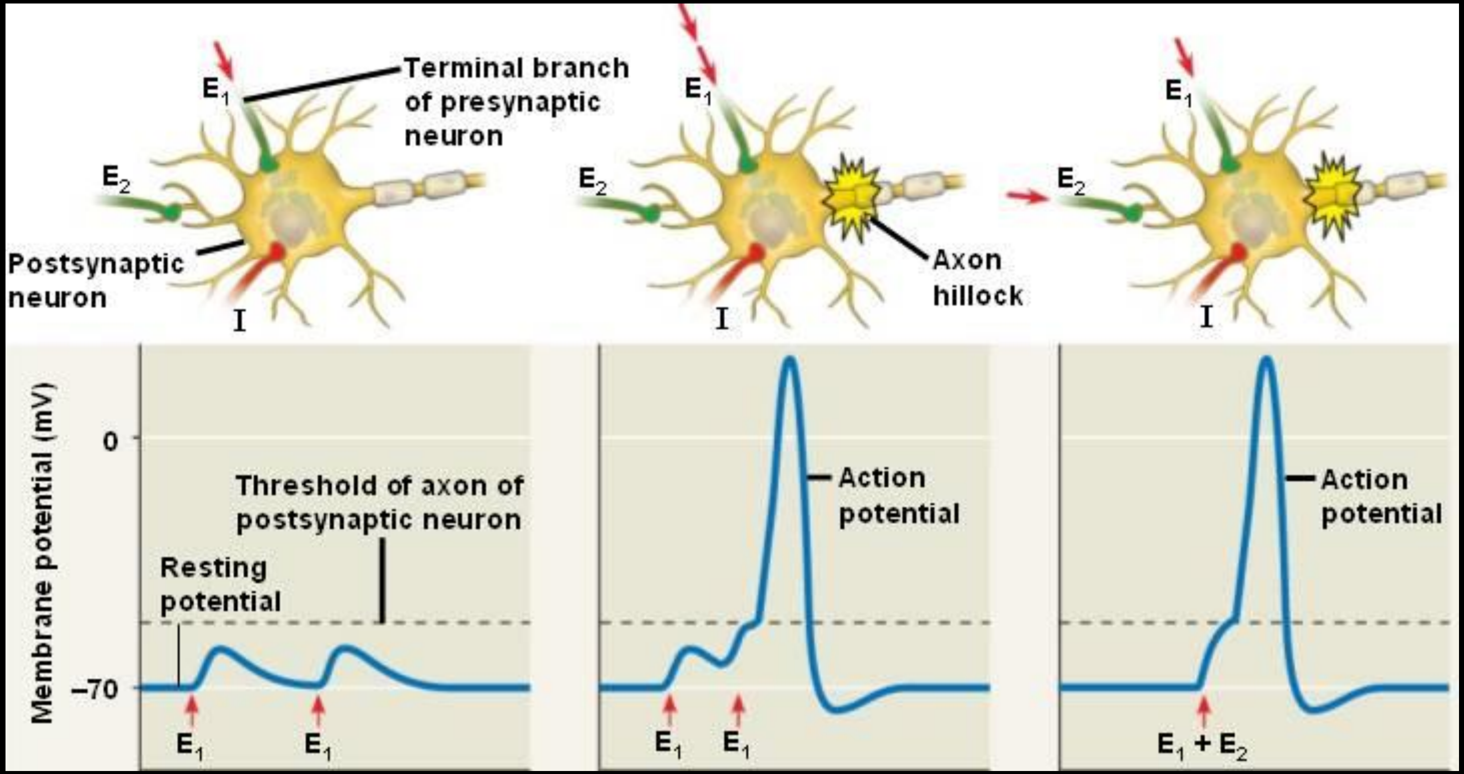


- Movement of the membrane away from 0 mV is a **hyperpolarization**
  - This inhibits the cell meaning it is less likely to fire an action potential
  - positive ions moving out



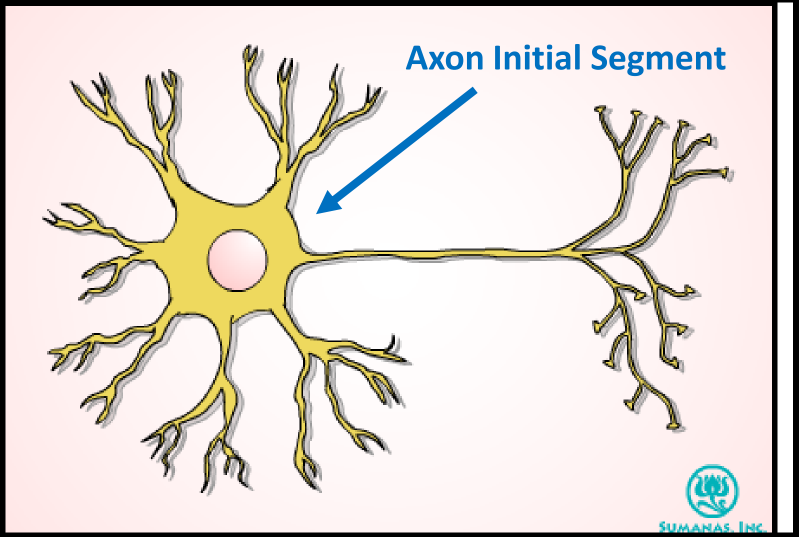
What happens when neurons get multiple signals?

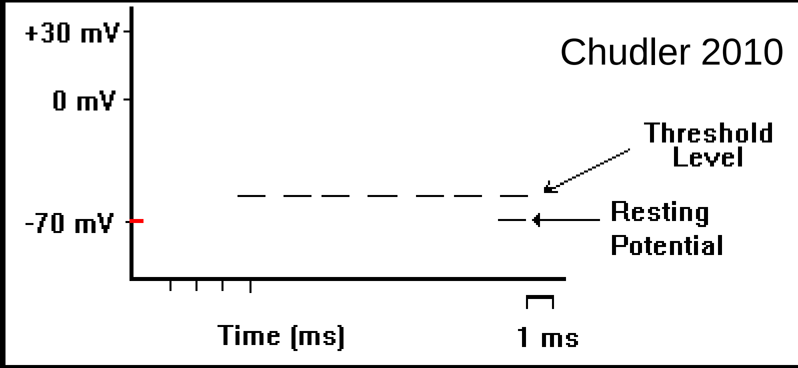
- Signals can either add together or cancel each other out
- Once a neuron is sufficiently depolarized (at **threshold**), an action potential is triggered
- An action potential is an all-or-none event (like the firing of a gun)



How do neurons communicate? The Action Potential

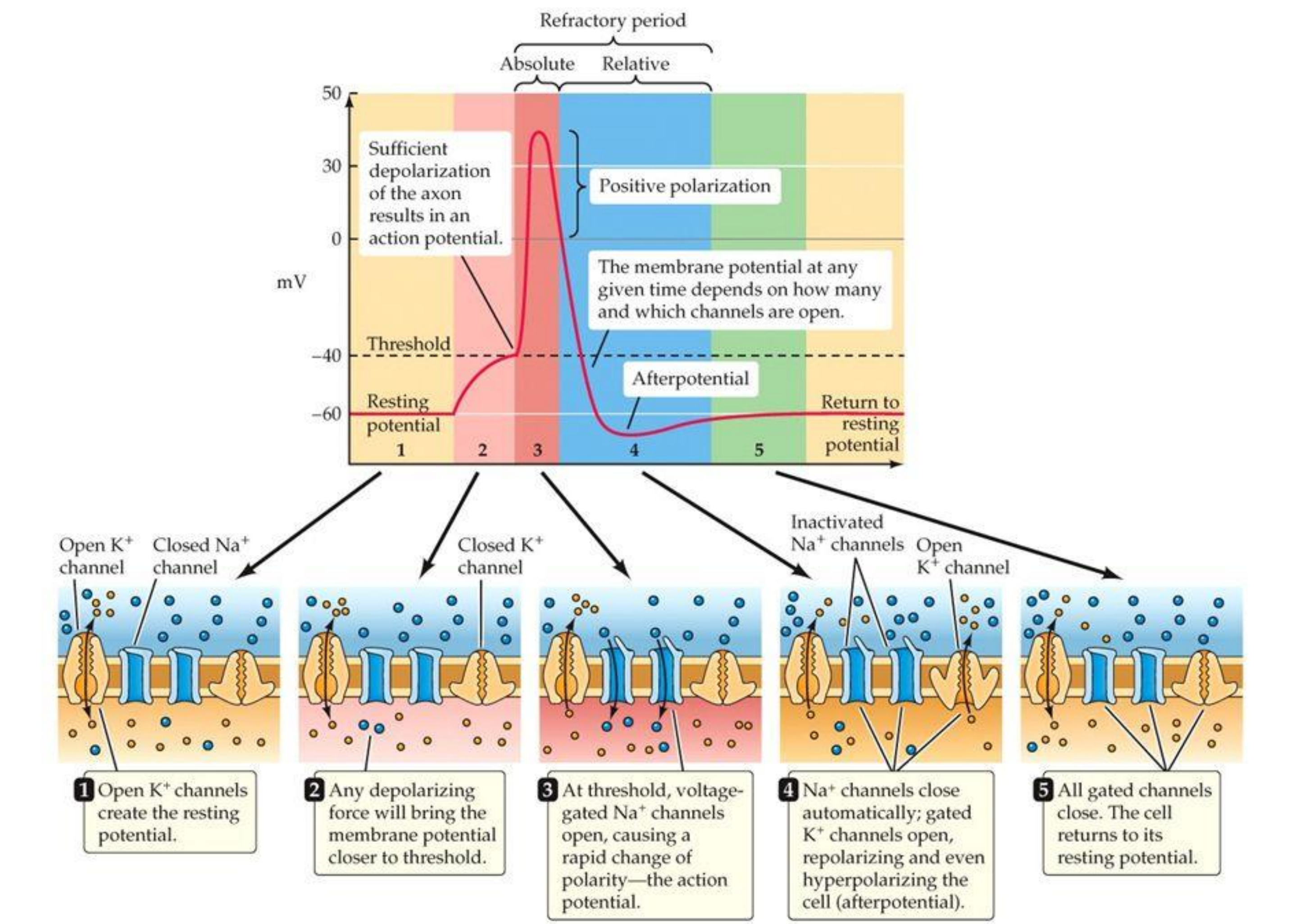
- An electrical signal
  - Caused by rapid opening and closing of ion channels
  - Specifically **Voltage-Gated Sodium Channels**
  - Leads to rapid changes in membrane potential
  - Typically generated by signals received by the cell which are monitored by the **Axon Initial Segment**
  - Once the axon initial segment reaches **threshold** an action potential is generated





Chudler 2010

The Action Potential



***BIOLOGICAL PSYCHOLOGY 7e*, Figure 3.6**

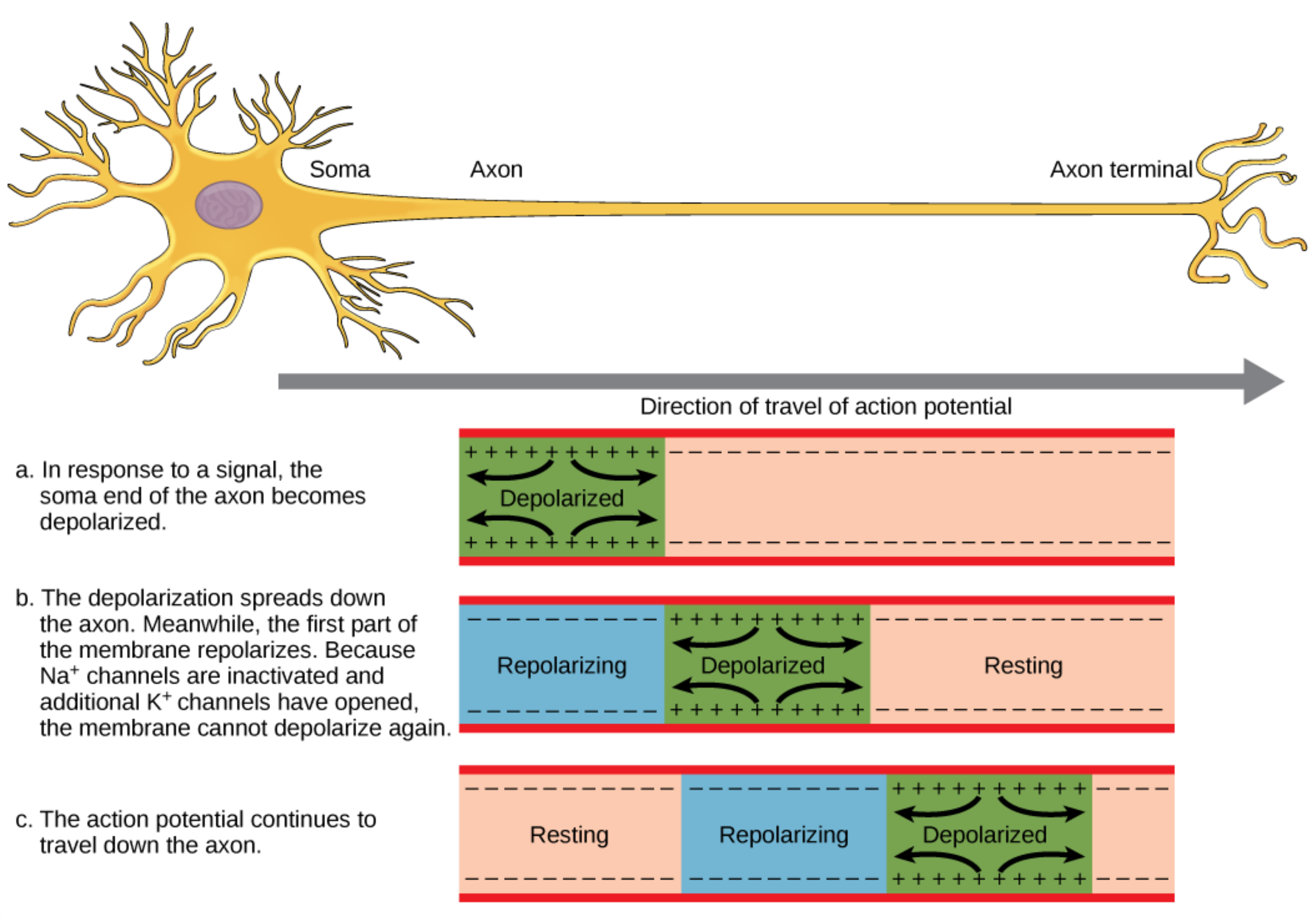
Action Potential Propagation

During an action potential, depolarization spreads down the axon successively opening voltage-gated Na^+ channels

After an action potential, Na^+ channels cannot be reactivated (i.e. they're inactivated) for a period of time. This is the **Refractory Period.**

No new action potentials can be generated during this time.

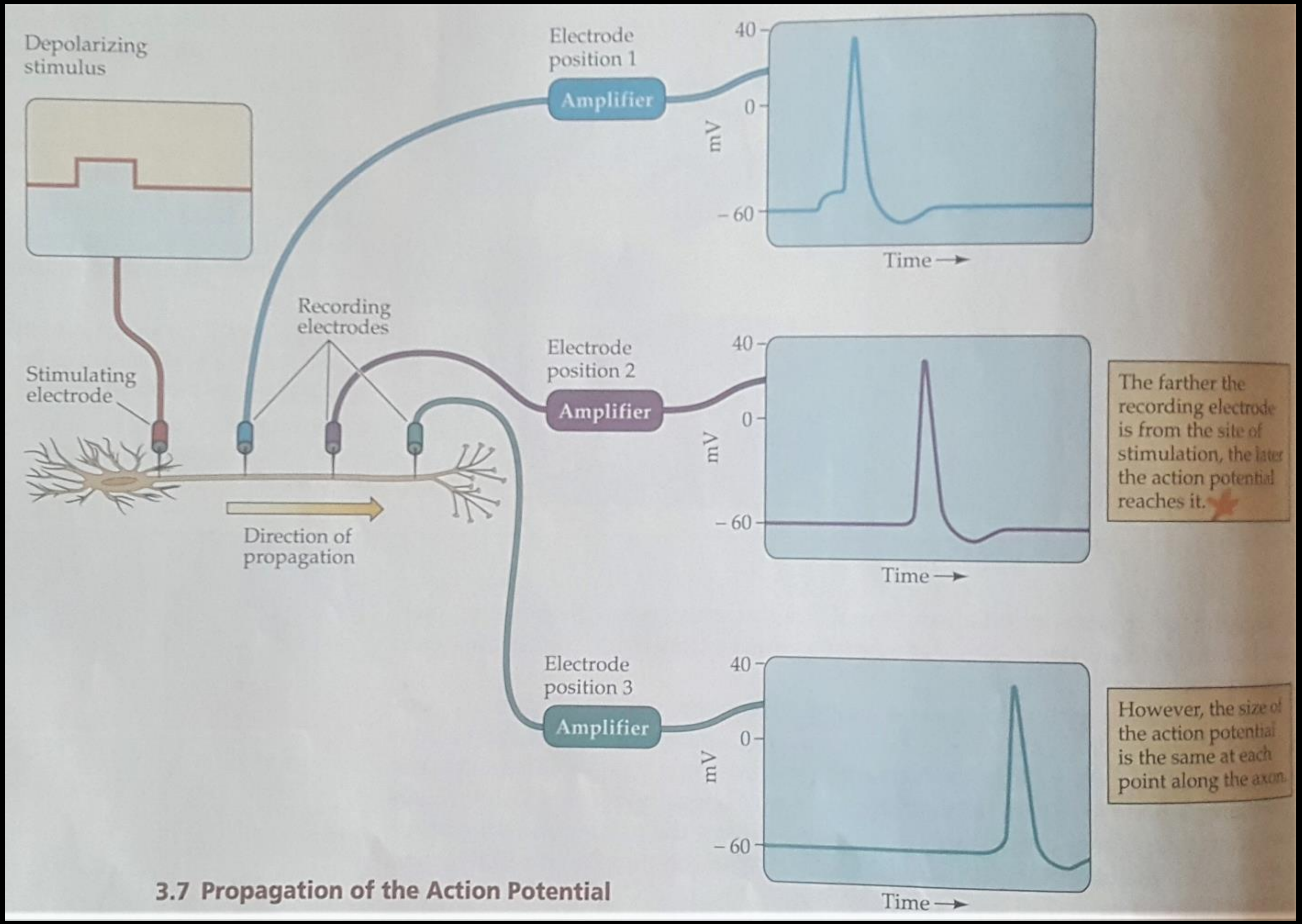
This ensures action potentials cannot change amplitude and limits their frequency.



Action Potential Propagation

The action potential is all-or-none meaning:

- It either happens or doesn't
- It's the same along the length of the axon



3.7 Propagation of the Action Potential

Tetrodotoxin (TTX) and Lidocaine

Puffer fish: can ingest water to inflate many times their normal size

As a defense mechanism their organs contain a poison that is lethal to predators called Tetrodotoxin (TTX)

Works by blocking ion flow of voltage-gated Na^+ channels

This means action potentials can't happen

Ingesting this poison results in death

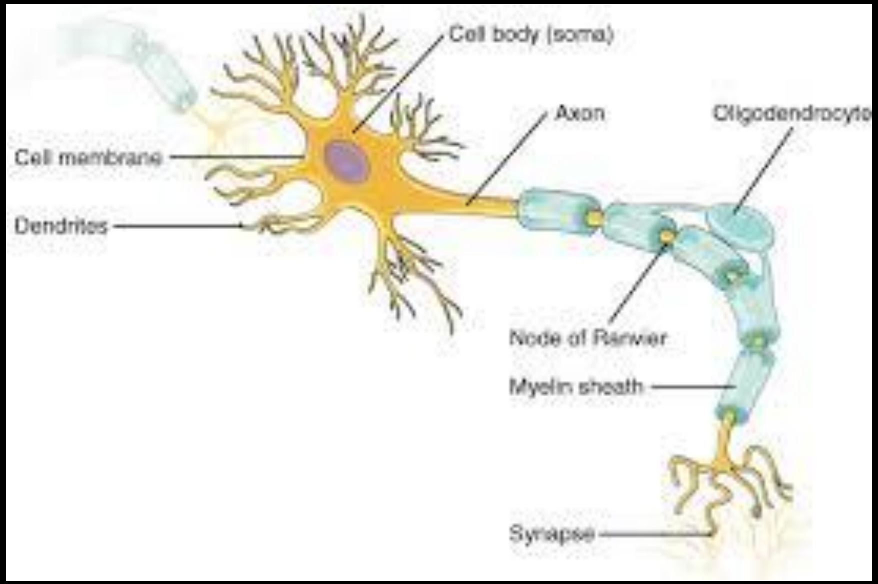
Lidocaine, a common anesthetic also blocks voltage-gated Na^+ channels

Myelin

Myelin forms by glial cells wrapping layers of their membrane around axons

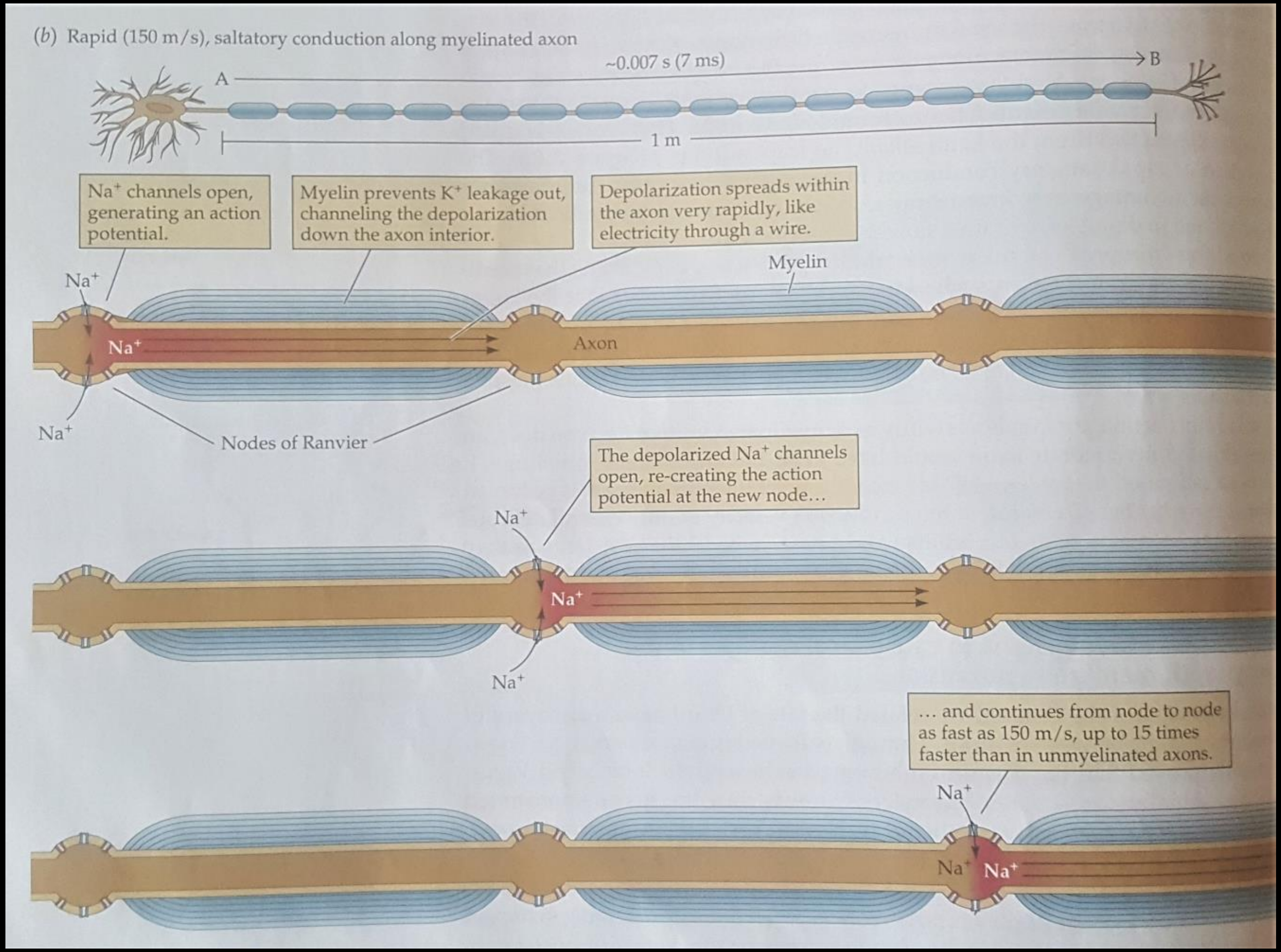
- Oligodendrocytes are the myelinating cells of the CNS
- Schwann cells are the myelinating cells of the PNS

Myelin protects the axon and **speeds nerve conduction**

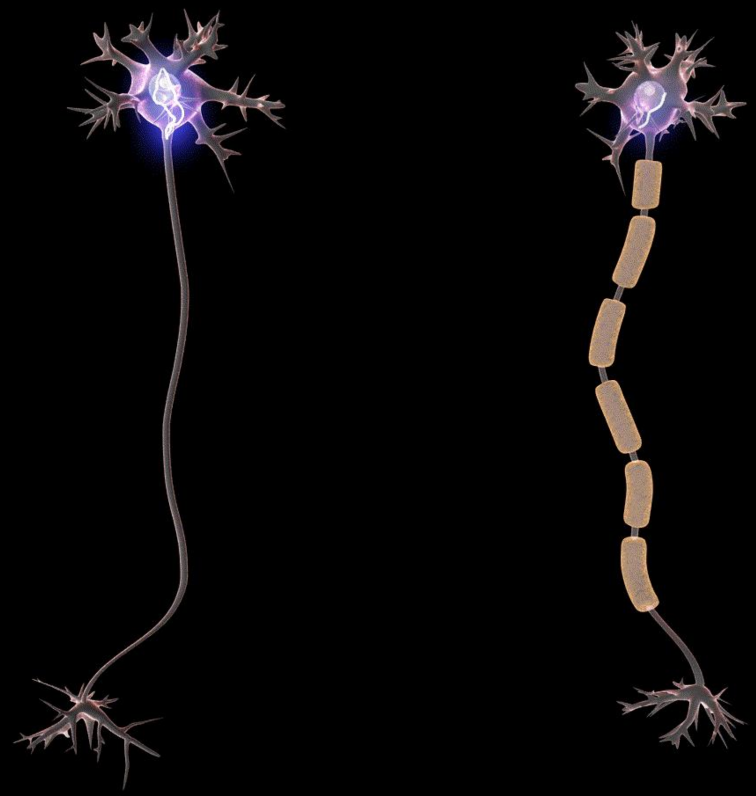


Saltatory Conduction

- There are no ion channels beneath the myelin sheath
- There are a lot of voltage-gated Na^+ channels between myelinated segments at **Nodes of Ranvier**
- This leads to depolarization jumping from node to node and the action potential being rapidly regenerated in a process called **Saltatory Conduction**

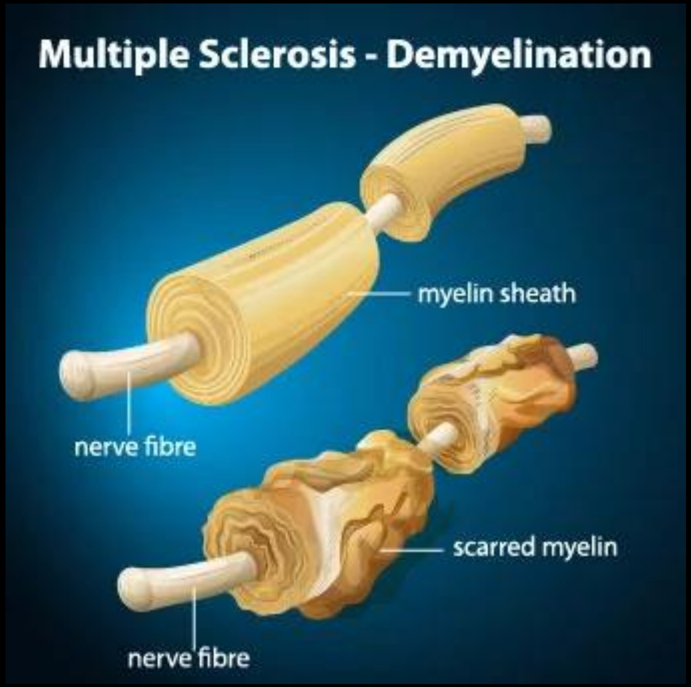


Saltatory Conduction



Multiiple Sclerosis (MS)

- Demyelinating disease of the CNS
- Causes destruction of myelin and slowed nerve conduction
- Often cause poor motor coordination, diminished sensitivity, fatigue, spasticity, and vision problems
- Often manifests in early twenties



What happens at the end of the axon?

- Once the action potential reaches the end of the axon, neurotransmitters are released into the synapse

- This provides a signal to the next cell…..
Which we will cover next class period