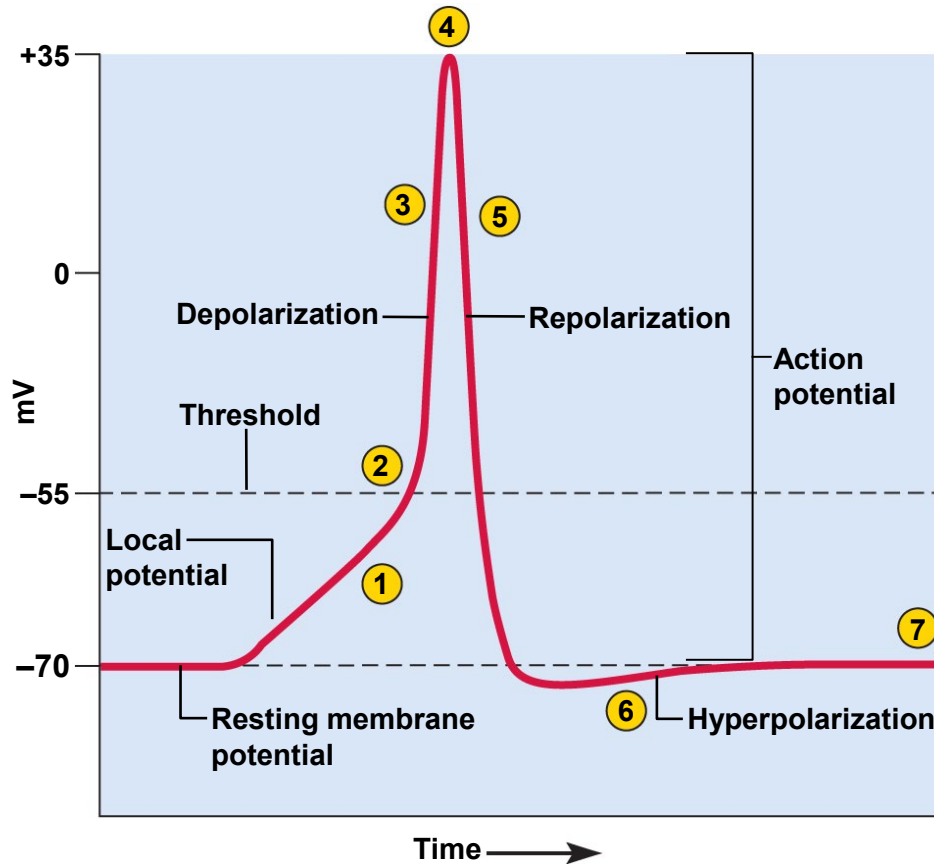


Chapter 12.2

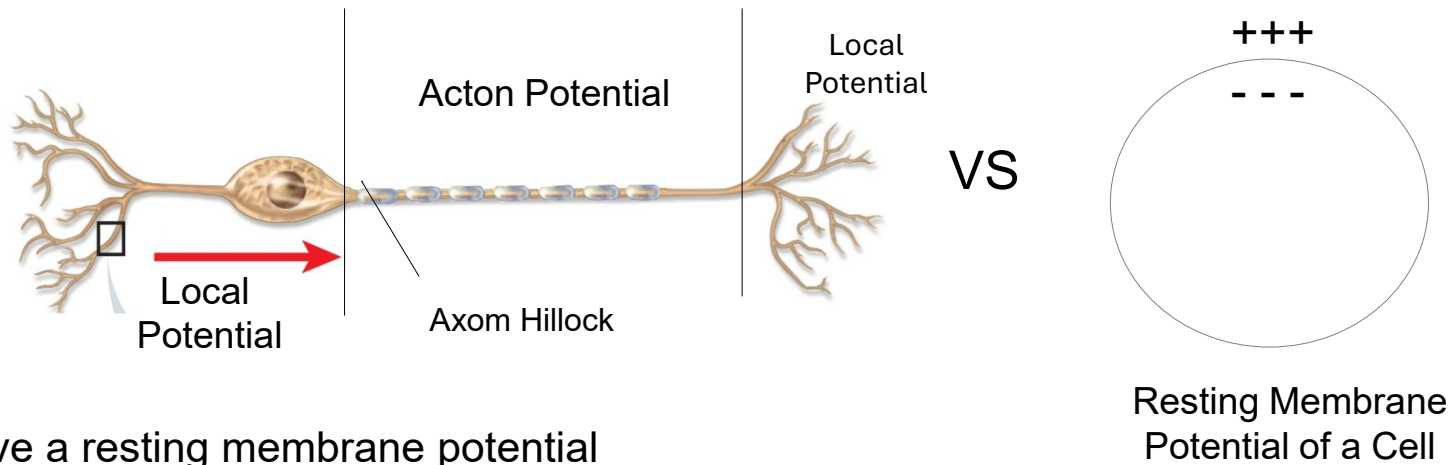
Electrical Potentials



Different Types of Electrical Potentials

- Resting Membrane Potential
- Local Potential
- Action Potential
- Receptor Potential
- End Plate Potential

Local Potential VS Action Potential VS Resting Potential



All cells have a resting membrane potential

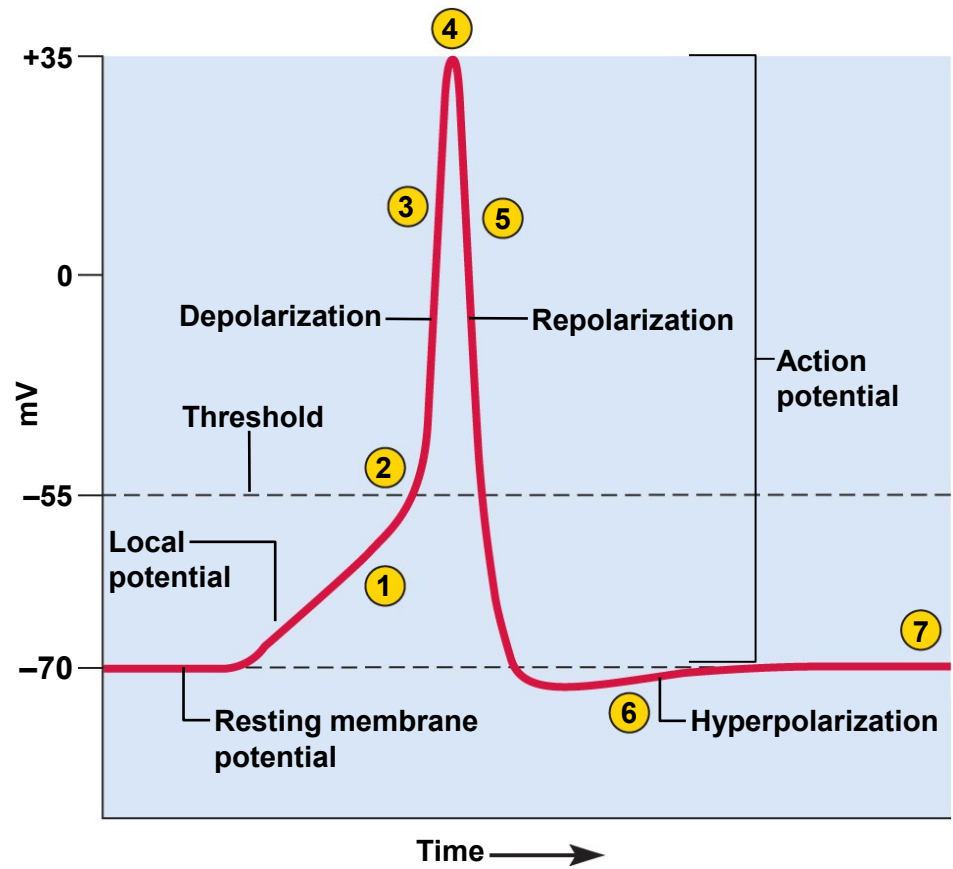
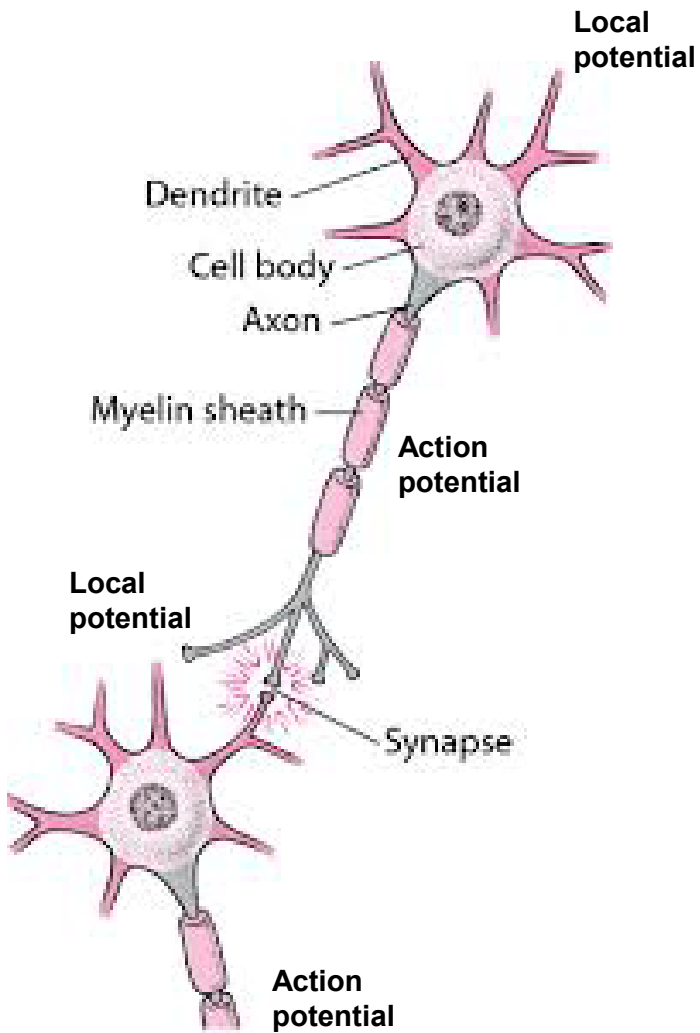
Nerve and muscle may also exhibit a local and/or action potential // these tissues are excitable!

Dendrites exhibit local potentials (like receptor potentials). If the stimulus is great enough, then the local potential may become an action potential at axon hillock. // Similar events at neuromuscular junctions

Local potentials are graded, decremental, reversible, and may either send action potential or inhibit the formation of an action potential to the next neuron

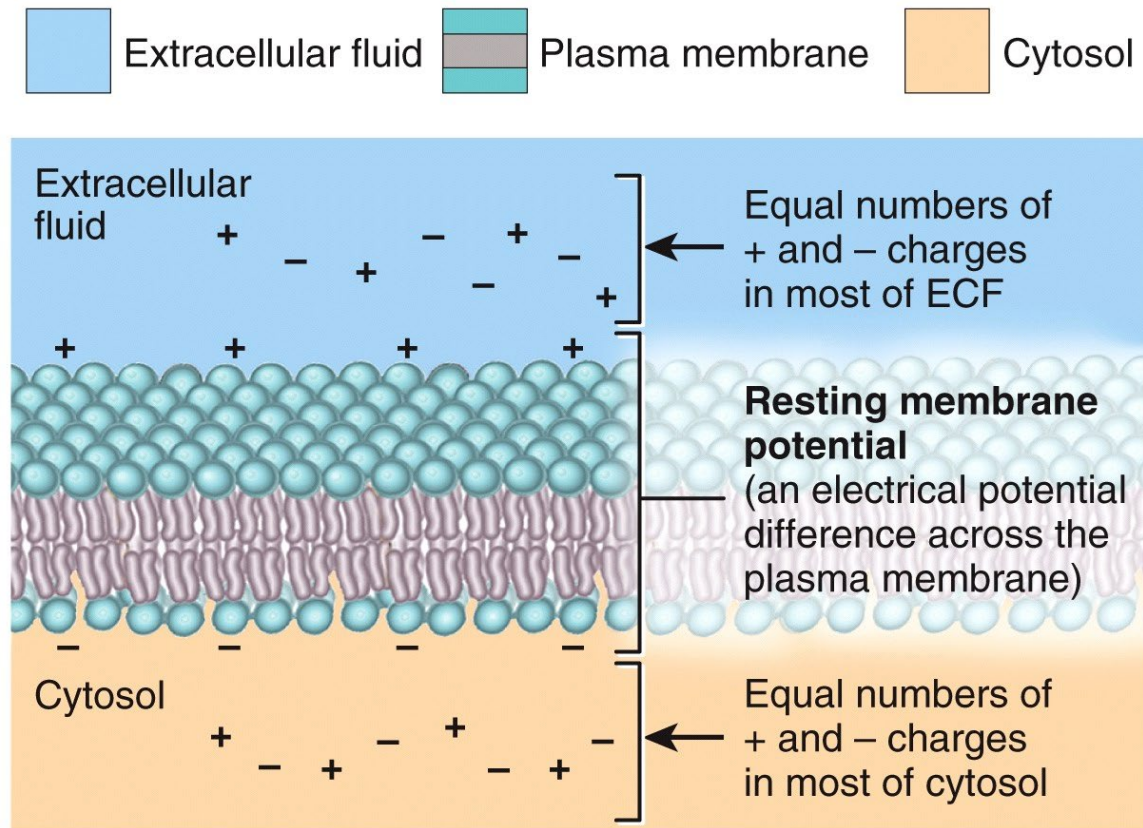
If stimulus is strong enough, local potential spreads to the trigger zone (axon hillock)

If LP stimulus reaches trigger zone, then it initiates an action potential that travels down axon (all or none and action potential is uni-directional)

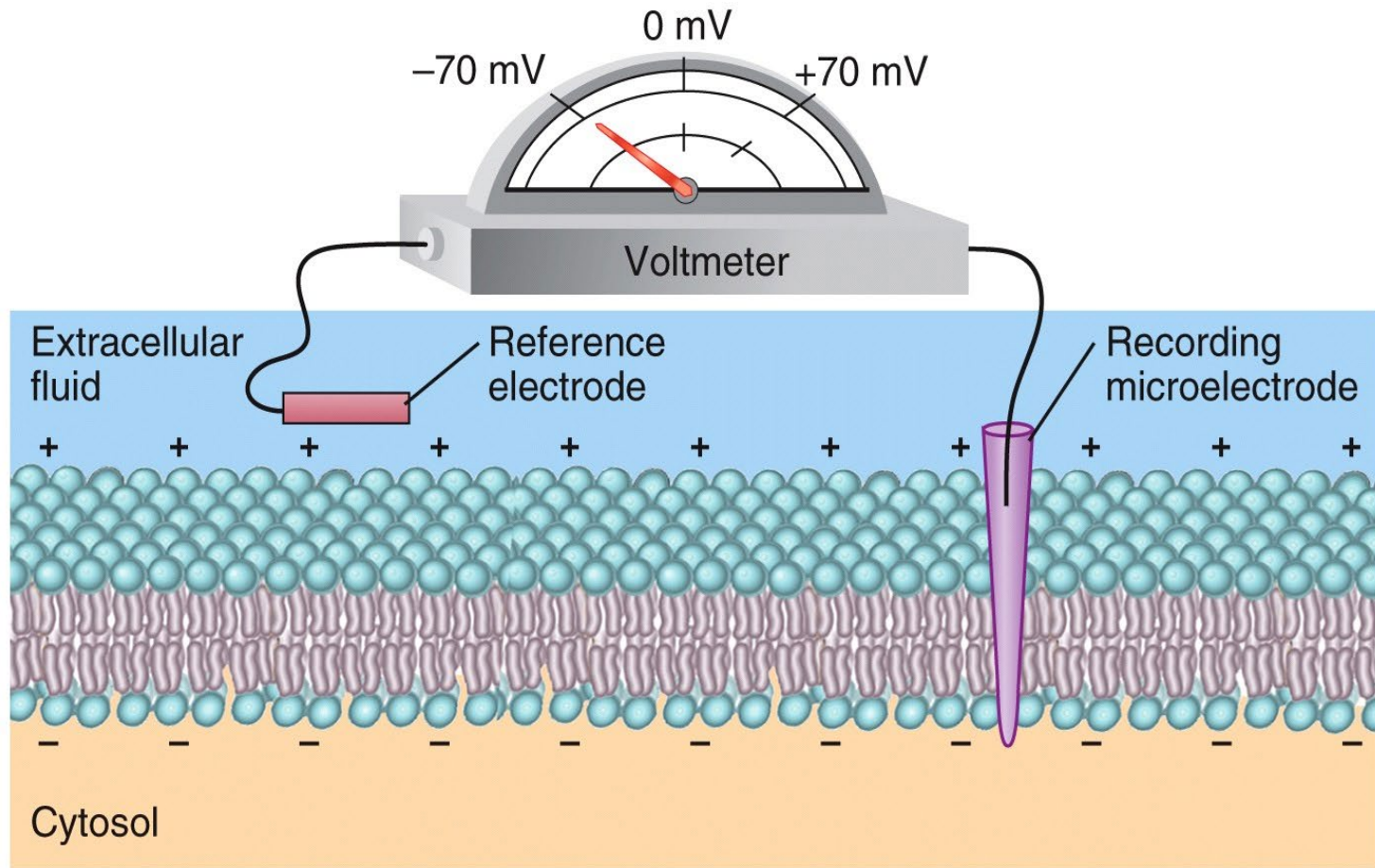


Electrical Potentials

Electrical potential = a difference in the concentration of charged particles separated by a barrier (the unit membrane) // **electrochemical gradient**



(a) Distribution of charges that produce the resting membrane potential of a neuron



(b) Measurement of the resting membrane potential of a neuron

Notes:

- Voltage values may vary depending on tissue type (our benchmark 70mV)
- What is the difference between voltage and current?

Voltage and Current

Voltage = separation of charge (ions across membrane)

Electrical current = the movement of ions

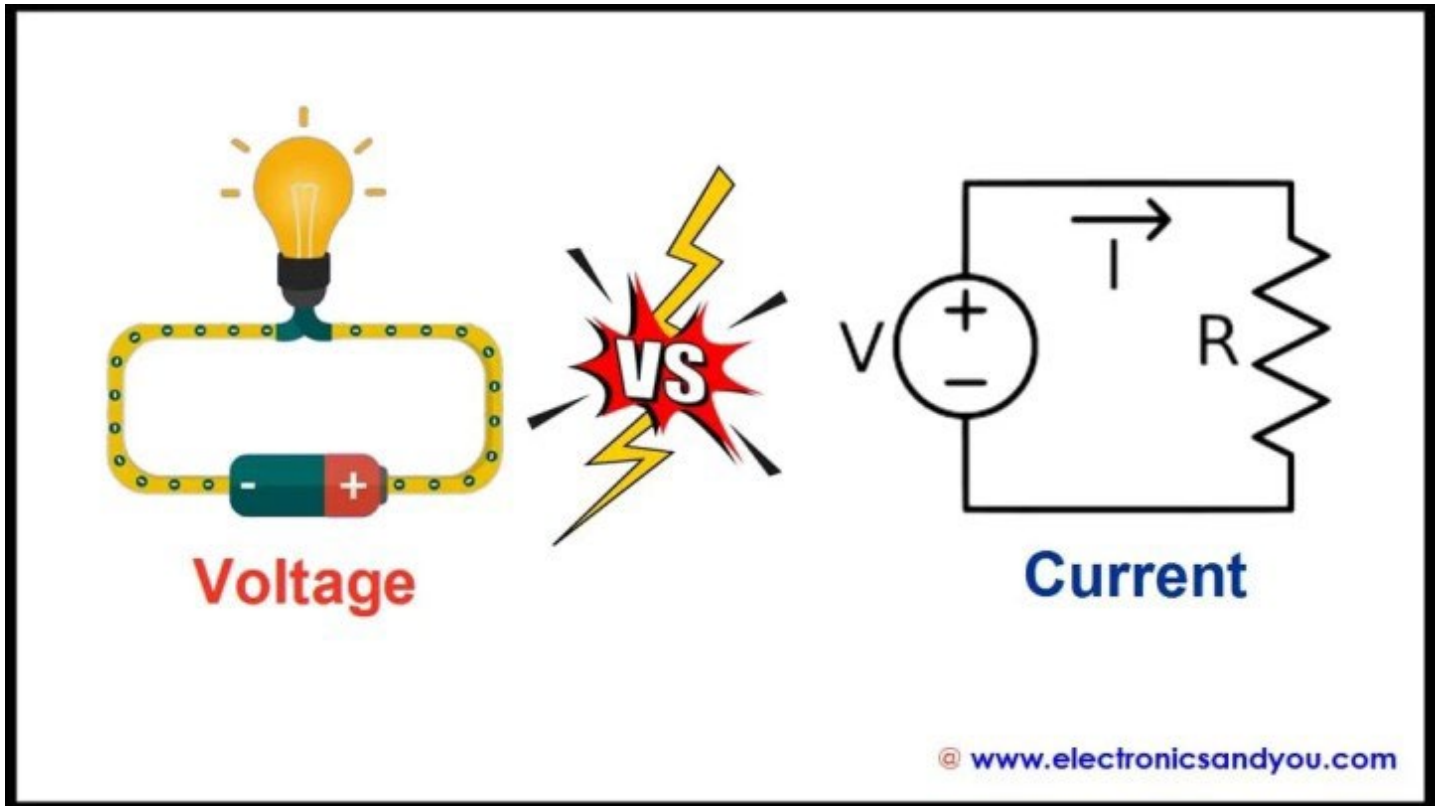
in the body, currents created by movement of ions (e.g. Na^+ , K^+) and Cl^-) through gated channels in the plasma membrane

gated channels are opened or closed by various stimuli (voltage / ligand / mechanical) //

some transmembrane protein channels are not regulated but simply “leak ions” (we will overlook this factor in our discussion of action potentials)

key idea: *regulated gates allow nerves to reverse resting membrane potential and then propagate the focal reversed-charge across membrane /// results in electrical current called the action potential*

Action potentials used to regulate cellular events

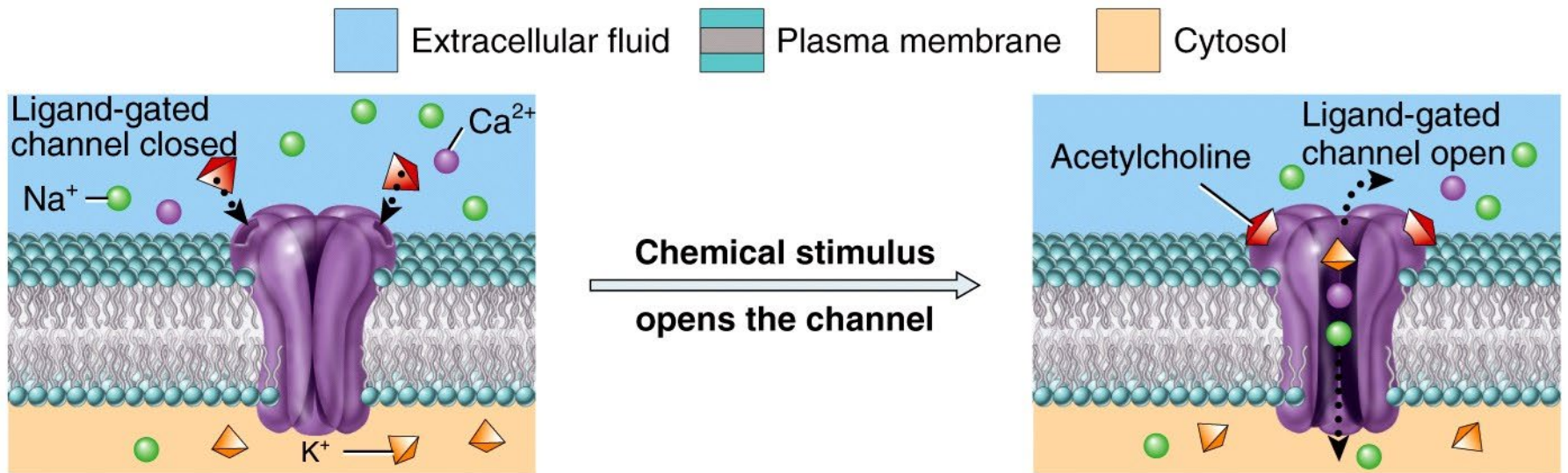


Resting Membrane
Potential

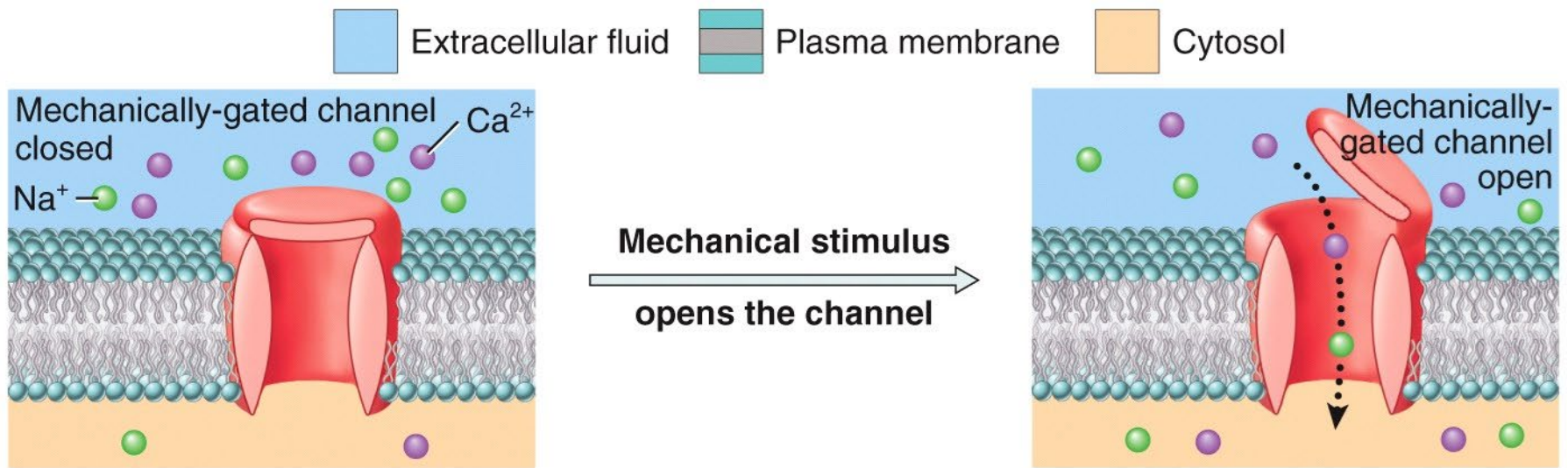
Separation
Of Charge

Action
Potential

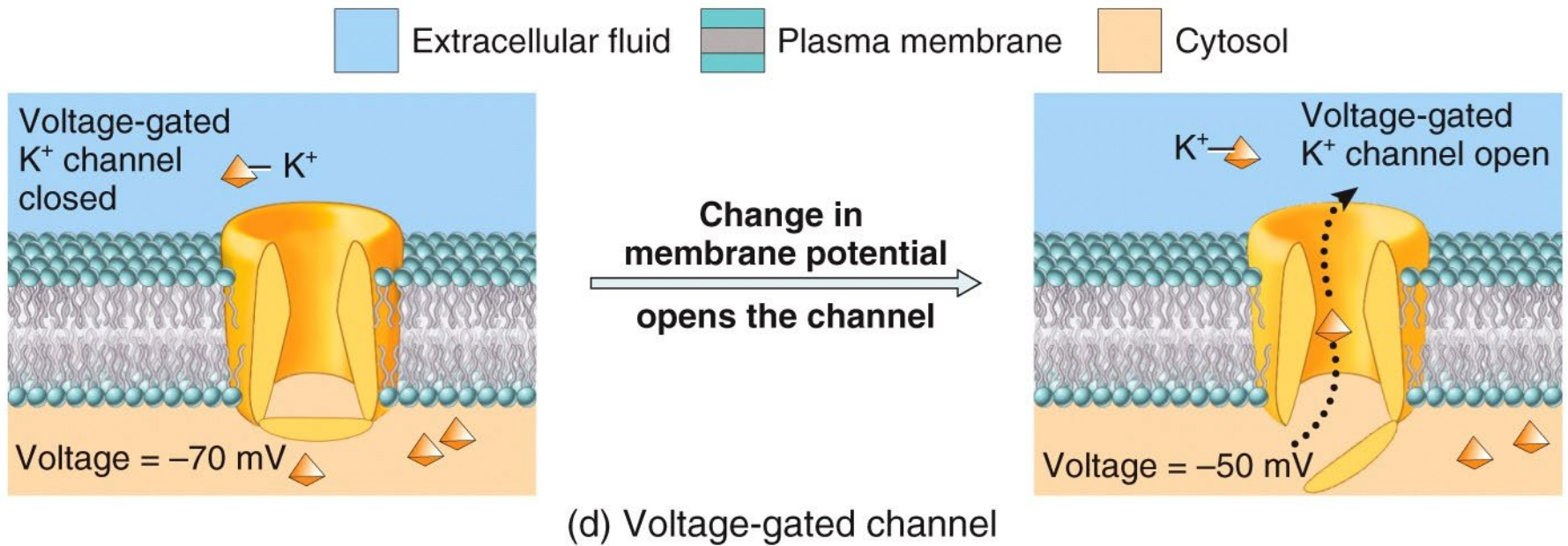
Movement
Of Charge



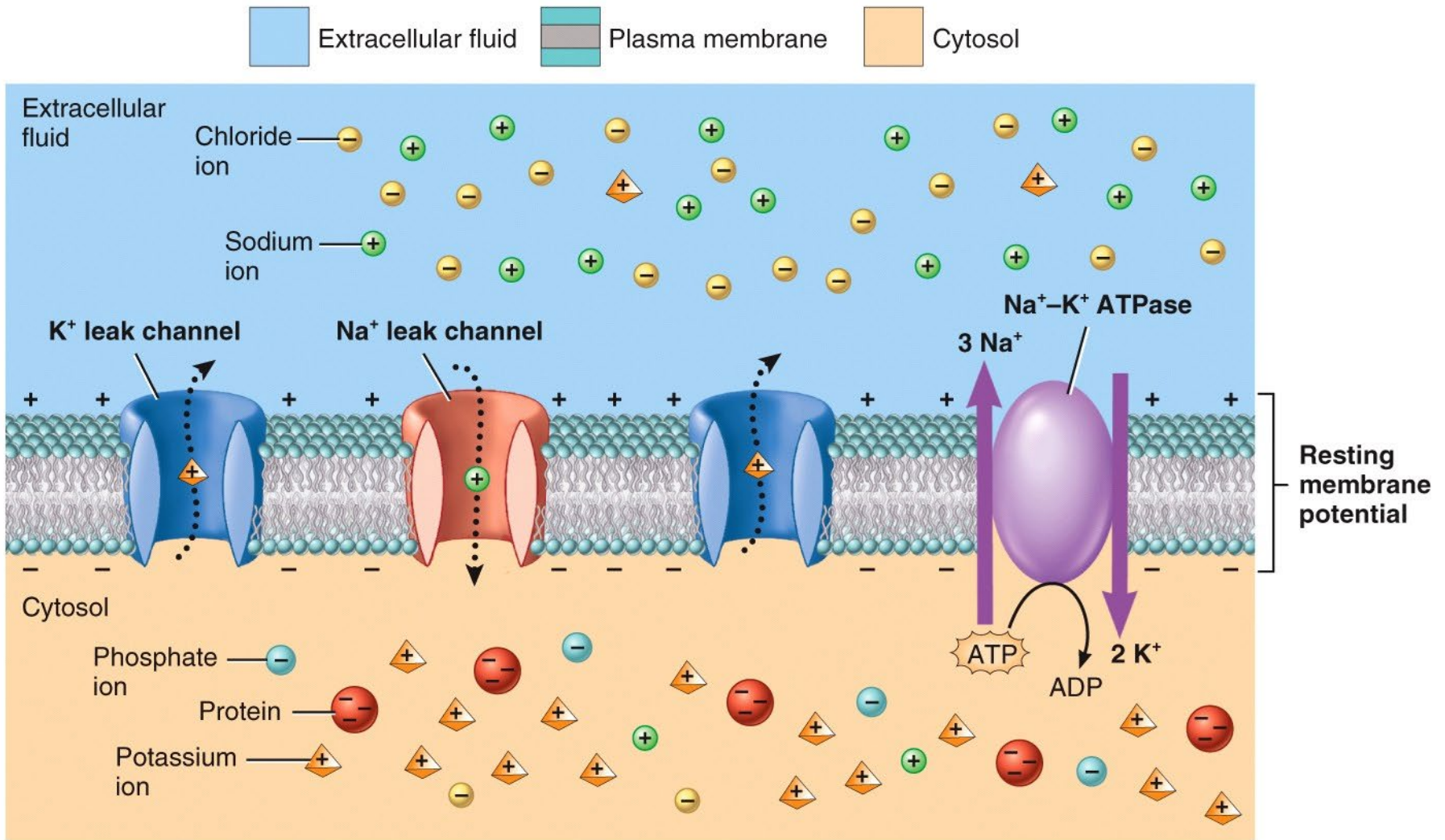
(b) Ligand-gated channel



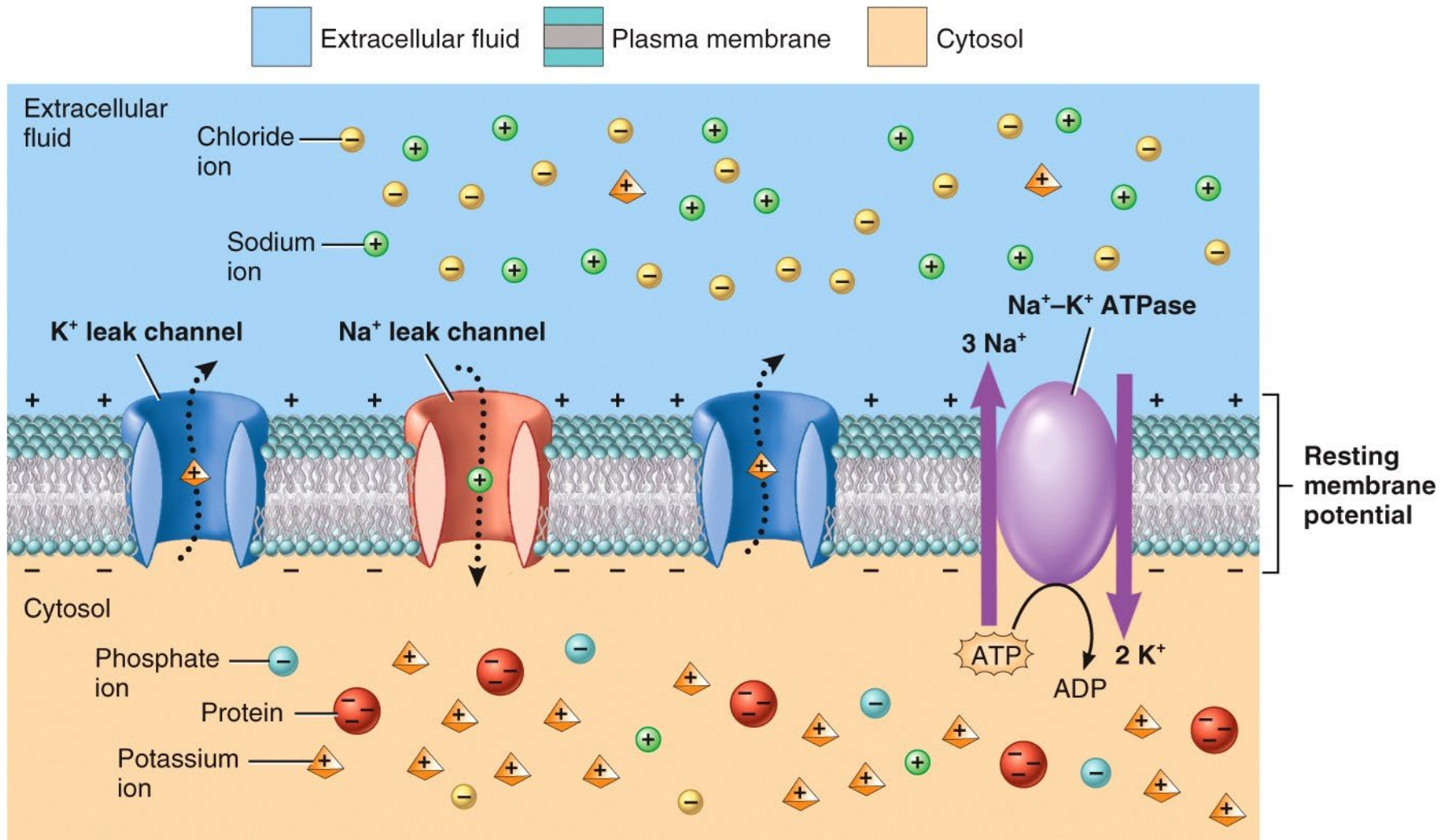
(c) Mechanically-gated channel



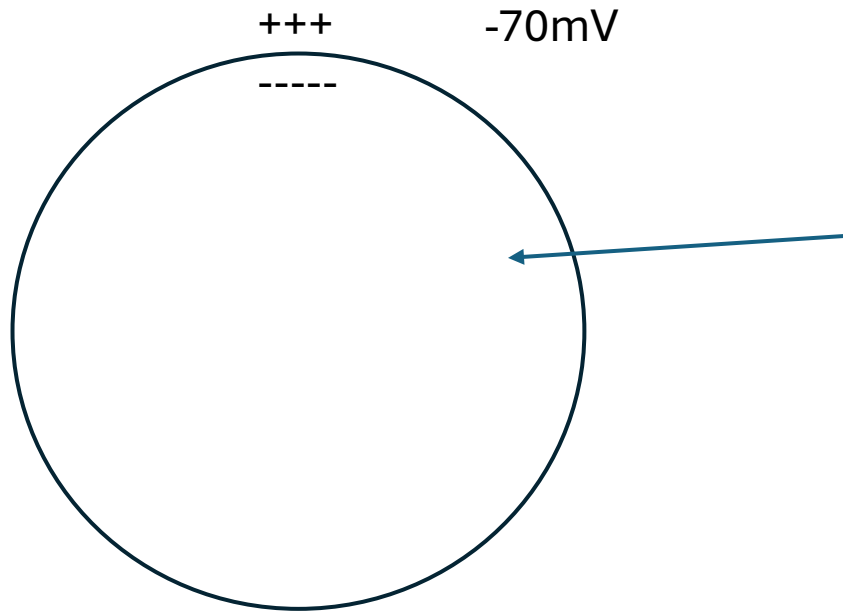
Note: Sodium channels maybe open, closed, or blocked.



Proteins are mostly negatively charged // therefore anions of the proteins are “trapped” inside the cell // major factor in determining negative charge on inner face of plasma membrane

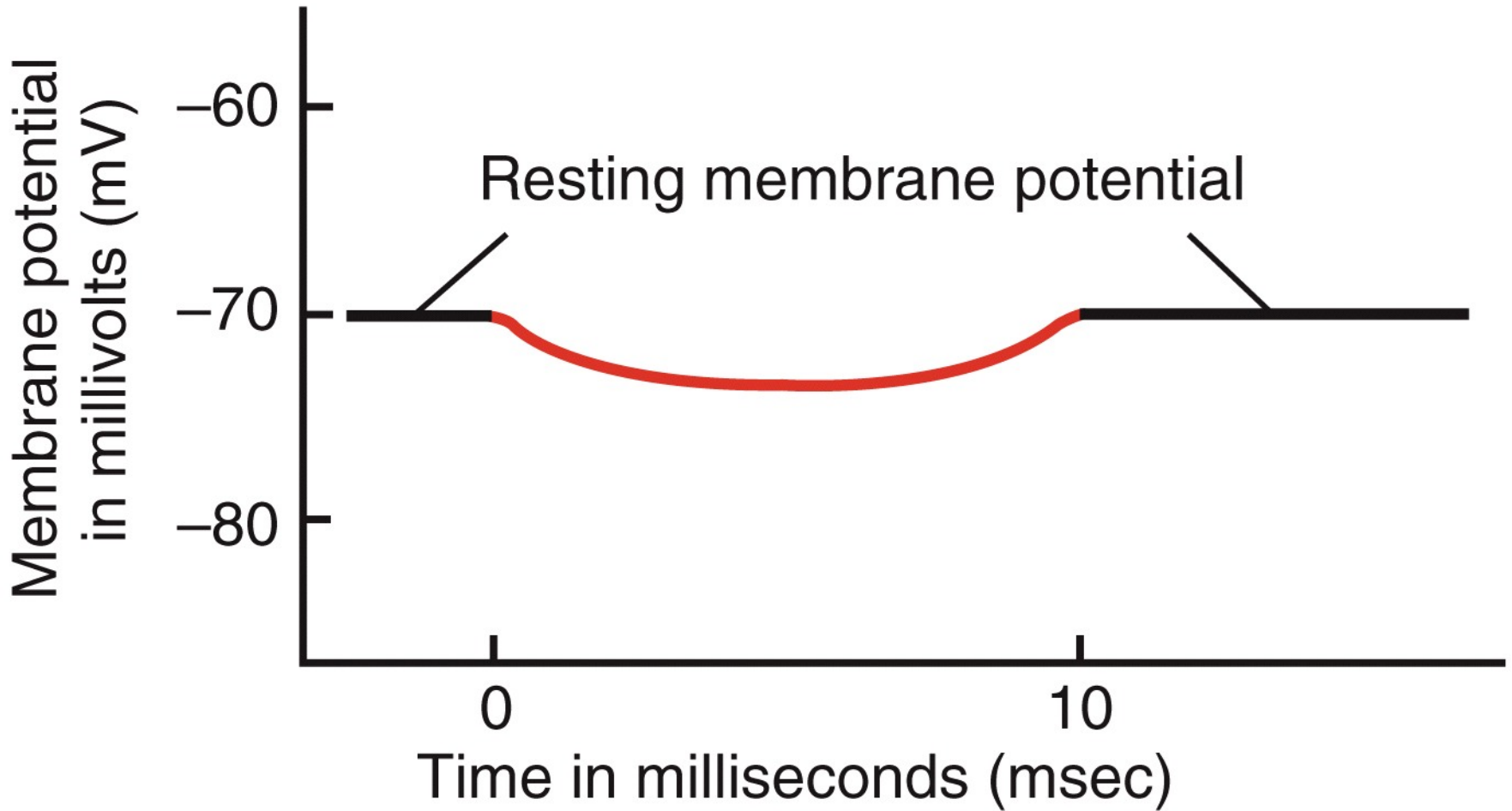


The sodium-potassium ATP pump's function is to maintain the resting membrane potential // also to restore the potential if a positive or negative graded potential occurs.



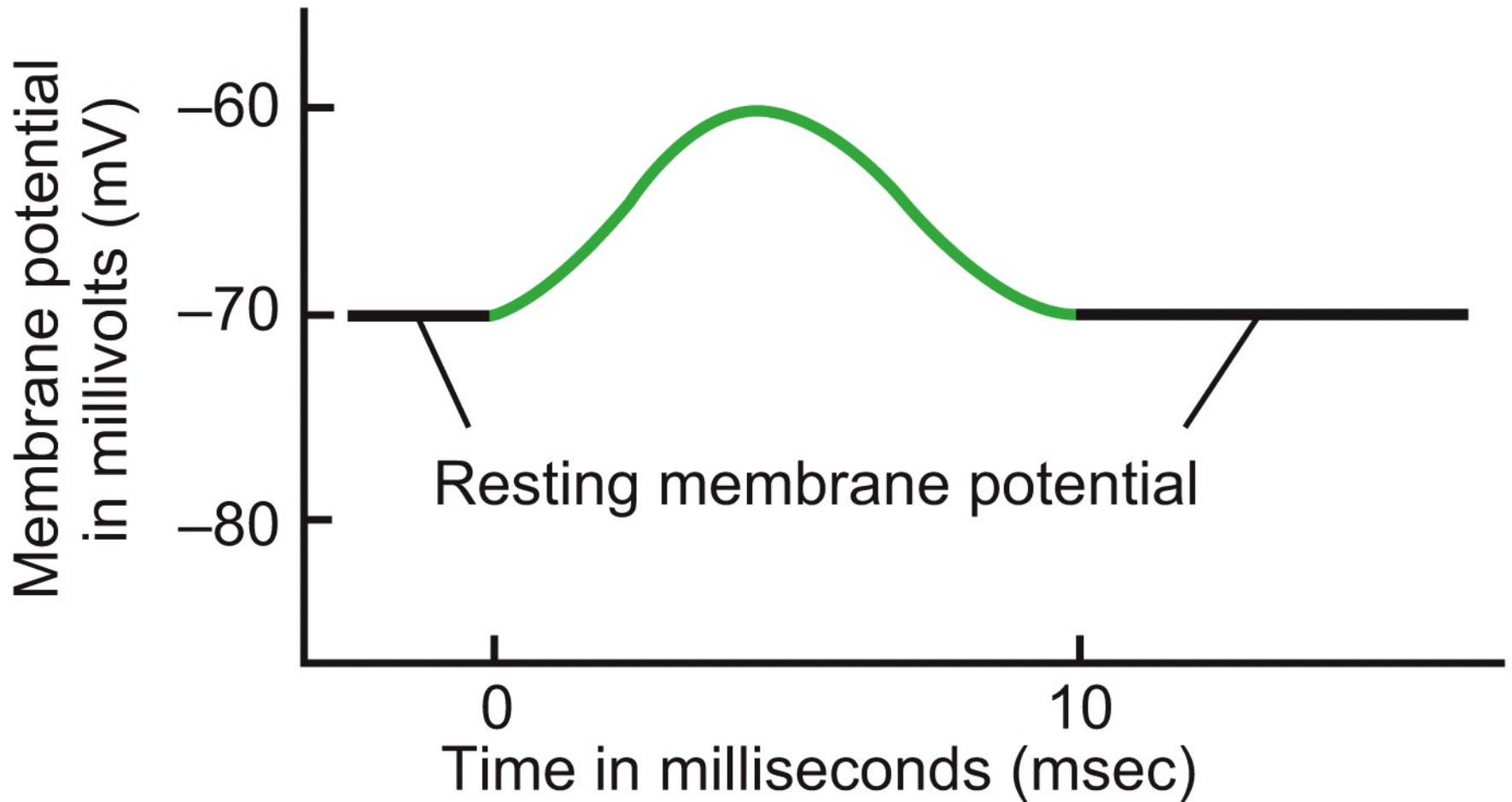
What happens to voltage across membrane if cations added to cytoplasm?

What happens to voltage across membrane if anions added to cytoplasm?



(a) Hyperpolarizing graded potential

What type of ion entering a neuron through a channel will cause this?



(b) Depolarizing graded potential

What type of ion entering a neuron through a channel will cause this?

Resting Membrane Potential

All living cells are polarized // called the **resting membrane potential (RMP)**

Charge difference across the plasma membrane

-70 mV RMP (inner face of plasma membrane)

Negative value means there are more negatively charged particles on the inside face of the membrane than on the outside face (like a little battery)

Nervous and muscle tissue may alter their resting membrane potential // sequentially opening and closing different gates to first reverse then restore the charge across the membrane // these are the only **excitable tissues**

Neurons may exhibit either a resting membrane potential, graded local potentials or an action potentials

Resting Membrane Potential

RMP exists because of unequal electrochemical gradient across membrane (imbalance of ions)

Occurs between extracellular fluid (ECF) and intracellular fluid (ICF)

RMP results from the combined effect of three factors:

- ions diffuse down their concentration gradient through membrane channels

- plasma membrane channels are selectively permeable and allows some ions to pass easier than others

- electrical attraction of cations and anions to each other

Factors Contributing to the Creation of the Resting Membrane Potential

Large cytoplasmic anions (e.g. proteins) can not escape /// due to size or charge (phosphates, sulfates, small organic acids, proteins, ATP, and RNA)

These all carry negative charges

Potassium ions (K^+) (intracellular cation) are the ions with the greatest influence on RMP

Plasma membrane is more permeable to K^+ than any other ion

Leaks out until electrical charge of cytoplasmic anions attracts it back in and equilibrium is reached and net diffusion of K^+ stops // this occurs at -70 mV

K^+ is about 40 times as concentrated in the ICF as in the ECF

As potassium leaves cytoplasm, the inner face of the plasma membrane becomes more negative (e.g. movement from -60vm to -70 mV)

Factors Contributing to the Creation of Resting Membrane Potential

Membrane much less permeable to high concentration of sodium (Na^+) found outside the cell

Some sodium leak and diffuse into the cell // move down concentration gradient

Na^+ is about 12 times as concentrated in the ECF as in the ICF

Resting membrane is **much less permeable to Na^+ than K^+**

Factor Contributing to the Creation and Maintenance of Resting Membrane Potential

Na⁺/K⁺ ATPase pump // Transmembrane protein channel // moves out 3 Na⁺ and moves in 2 K⁺ for each ATP consumed

Works continuously to compensate for channels that leak Na⁺ and K⁺ ions

Requires great deal of ATP // A single cortical neuron utilizes approximately **4.7 billion ATPs per second** in a resting human brain. (this is impossible to conceptualize!)

After an action potential, the Na/K ATP pump restores the resting potential

Factor Contributing to the Creation and Maintenance of Resting Membrane Potential

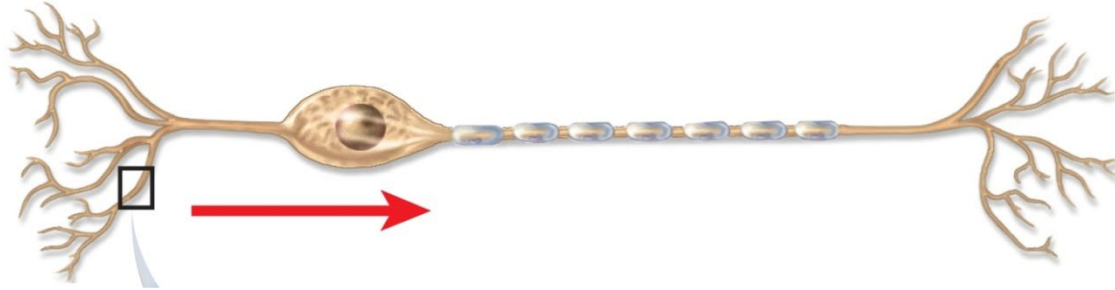
Tracing oxygen consumption, the brain accounts for about 20% of the body's energy consumption, despite representing 2 percent of its weight

That's around 0.3 kilowatt hours (kWh) per day for an average adult, more than 100 times what the typical smartphone requires daily.

Necessitates glucose and oxygen be supplied to nerve tissue (energy needed to create the resting potential) /// pump contributes about -3 mV to the cell's resting membrane potential of -70 mV

After an action potential, the Na/K ATP pump restores the resting potential

Local Potentials



Sodium ions move into neuron at dendrites and/or somas when a neuron is stimulated

Local potential response is initiated at the dendrite then spreads across the soma to trigger zone

If stimulus great enough, then local potential reaches the trigger zone
/// achieves “threshold” and an action potential results

*Other names for local potentials are **end plate potential, receptor potential, and neuromuscular potential***

Local Potentials

Occurs when a **neuron is stimulated** by chemicals, light, heat or mechanical disturbance

Stimulus opens the Na^+ gates and allows Na^+ to rush into the cell

Na^+ inflow neutralizes some of the internal negative charge

Voltage measured across the membrane **drifts toward zero**

This is known as depolarization

Local Potentials

Occurs when membrane voltage shifts to a less negative value

Na⁺ diffuses across plasma membrane producing a current

This depolarizing event moves across neuron's membrane towards the cell's **trigger zone** // located at proximal end of the axon

Current movement across dendrite and soma is the **local potential**

If stimulus causing local potential strong enough so it reaches trigger zone, then an action potential occurs in the axon

Four Characteristics of a Local Potentials

Local potentials behave differently than action potentials:

Graded

- vary in magnitude with stimulus strength
- stronger stimuli open more Na^+ gates

Decremental

- get weaker the farther they spread from the point of stimulation
- voltage shift caused by Na^+ inflow diminishes rapidly with distance

Four Characteristics of a Local Potentials

Reversible

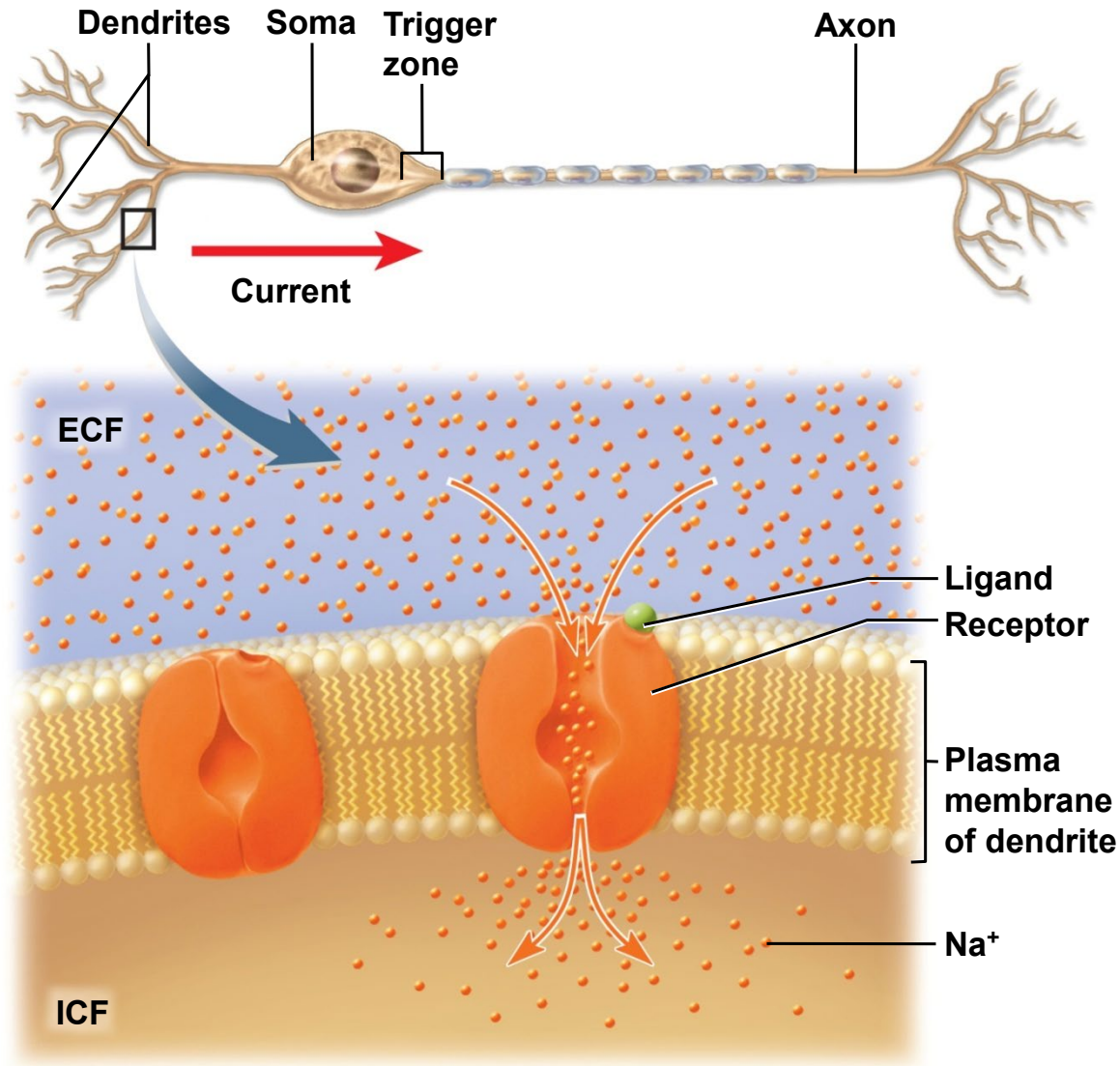
- when stimulation ceases flow of Na stops
- then K^+ diffusion out of cell // returns the cell to its normal resting potential

The stimulus maybe either excitatory or inhibitory

- the neurotransmitter glycine make the membrane potential more negative (inhibitory)
- a hyperpolarize membrane // less likely to produce an action potential
- the neurotransmitter glutamate makes the membrane potential more positive (excitatory)

Why is this significant?

Excitation of a Neuron by a Chemical Stimulus



Depolarize. Why?

Action Potentials

AP is a more dramatic change than local potential // AP is a **positive feedback mechanism**

Produced by voltage-regulated ion gates in the plasma membrane at **axon hillock**

Only occur where there is a high enough density of voltage-regulated gates (axon hillock = trigger zone)

Soma (50 -75 gates per μm^2) - cannot generate an action potential

Trigger zone (350 – 500 gates per μm^2) – where action potential is generated

If local potential spreads all the way to the trigger zone // will open gates at axon hillock to generate an action potential

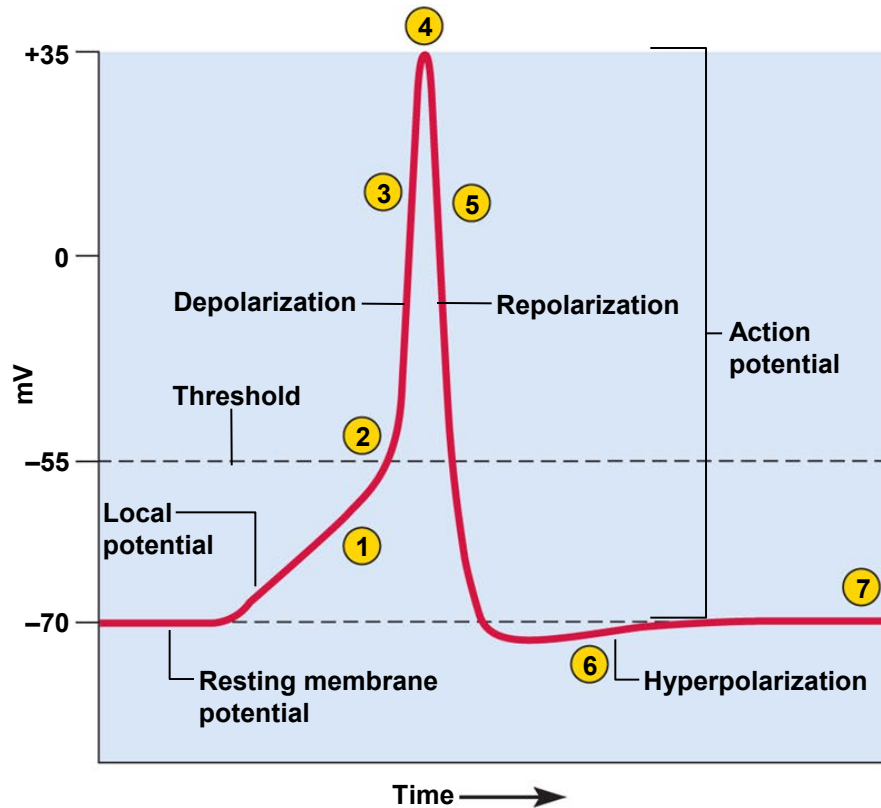
Action Potentials

An action potential is a rapid up-and-down shift in the membrane voltage

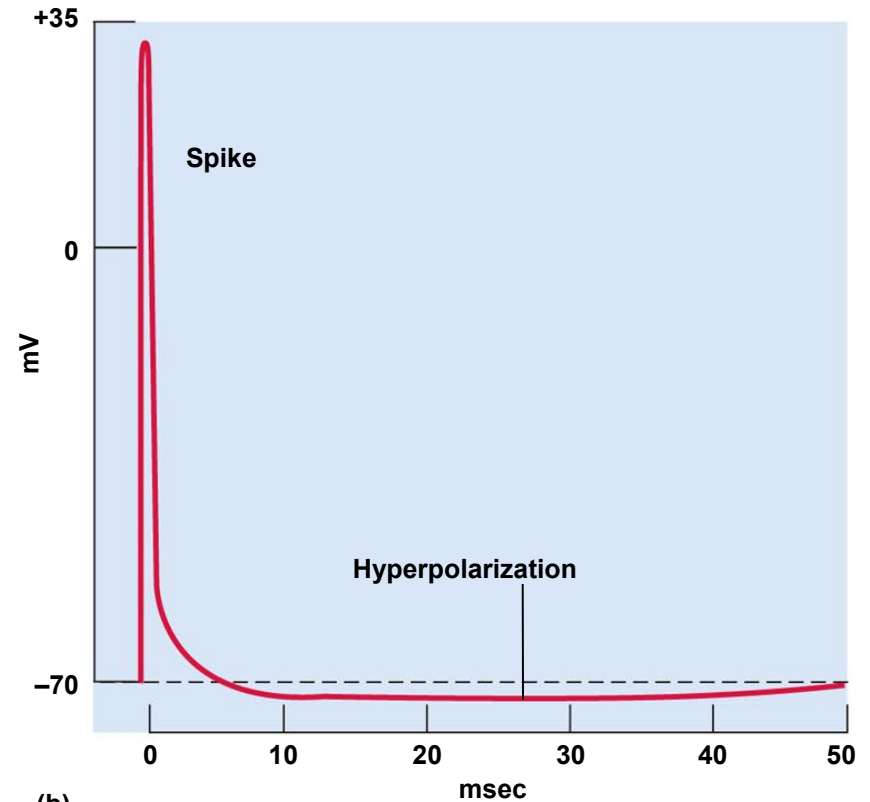
Threshold – critical voltage which local potentials must reach in order to open the voltage-regulated gates at axon hillock

Negative 55mV is **threshold** value in neurons

Action Potential



(a)

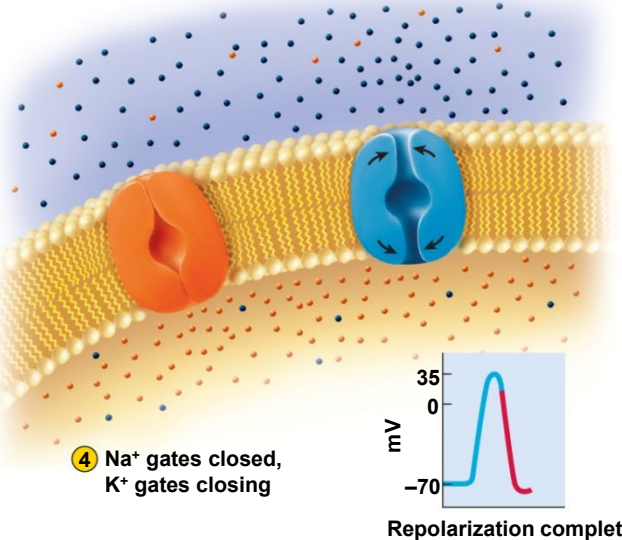
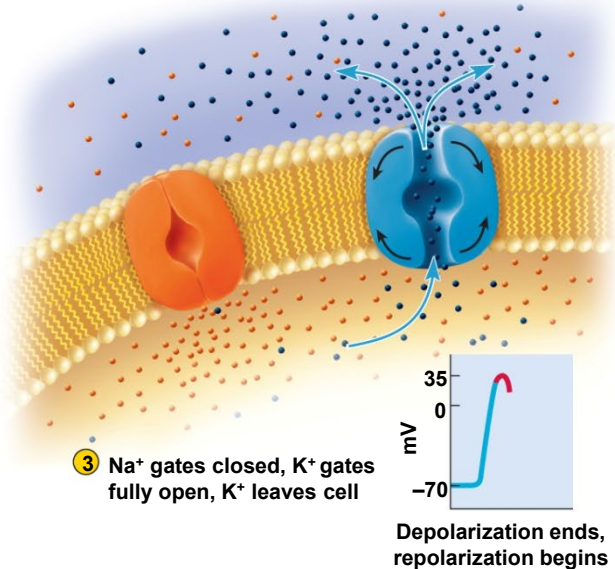
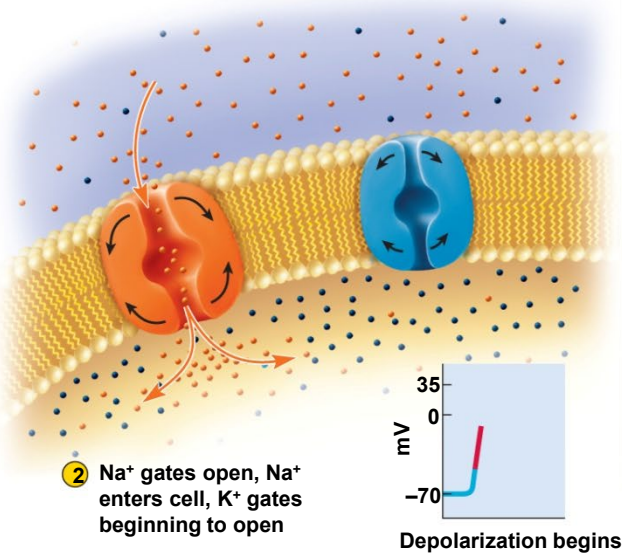
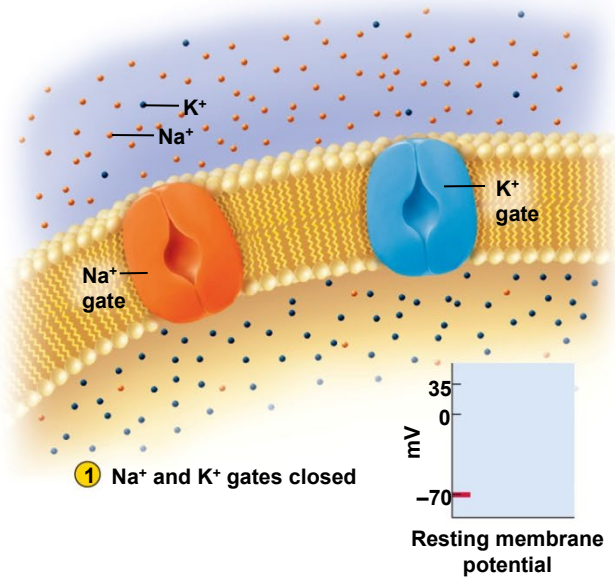


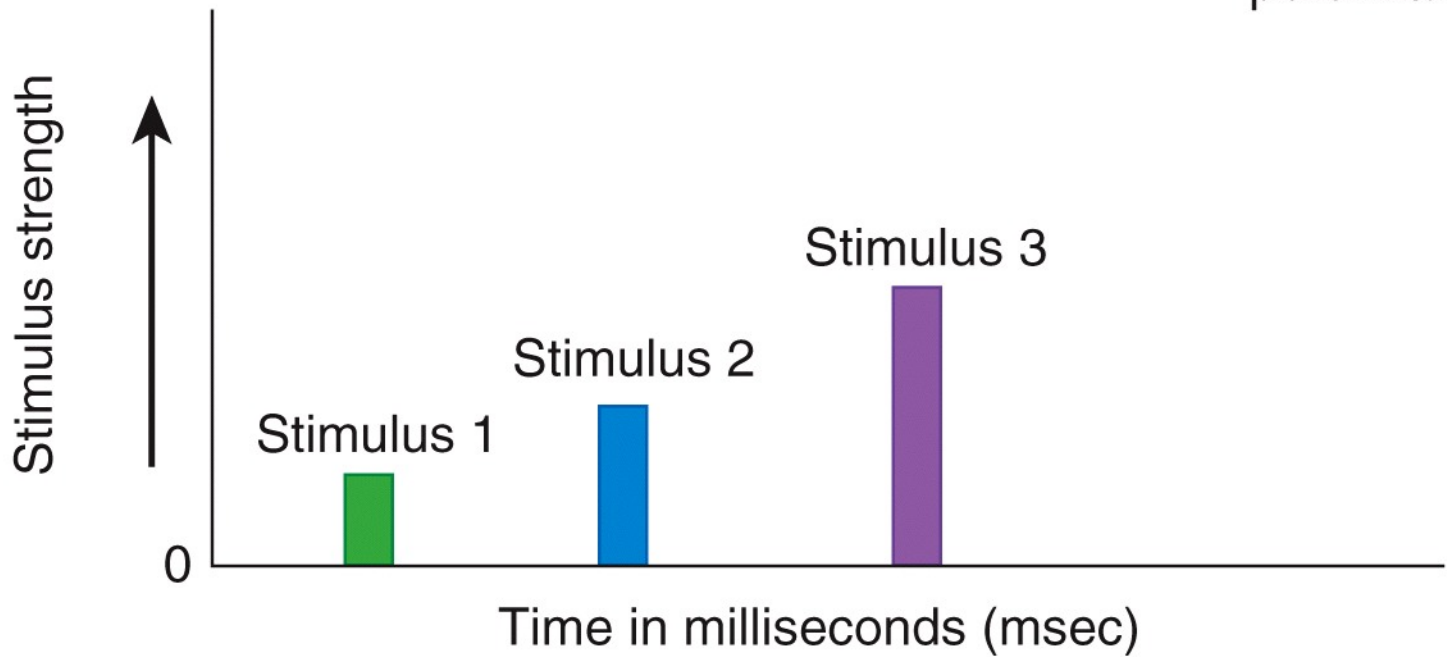
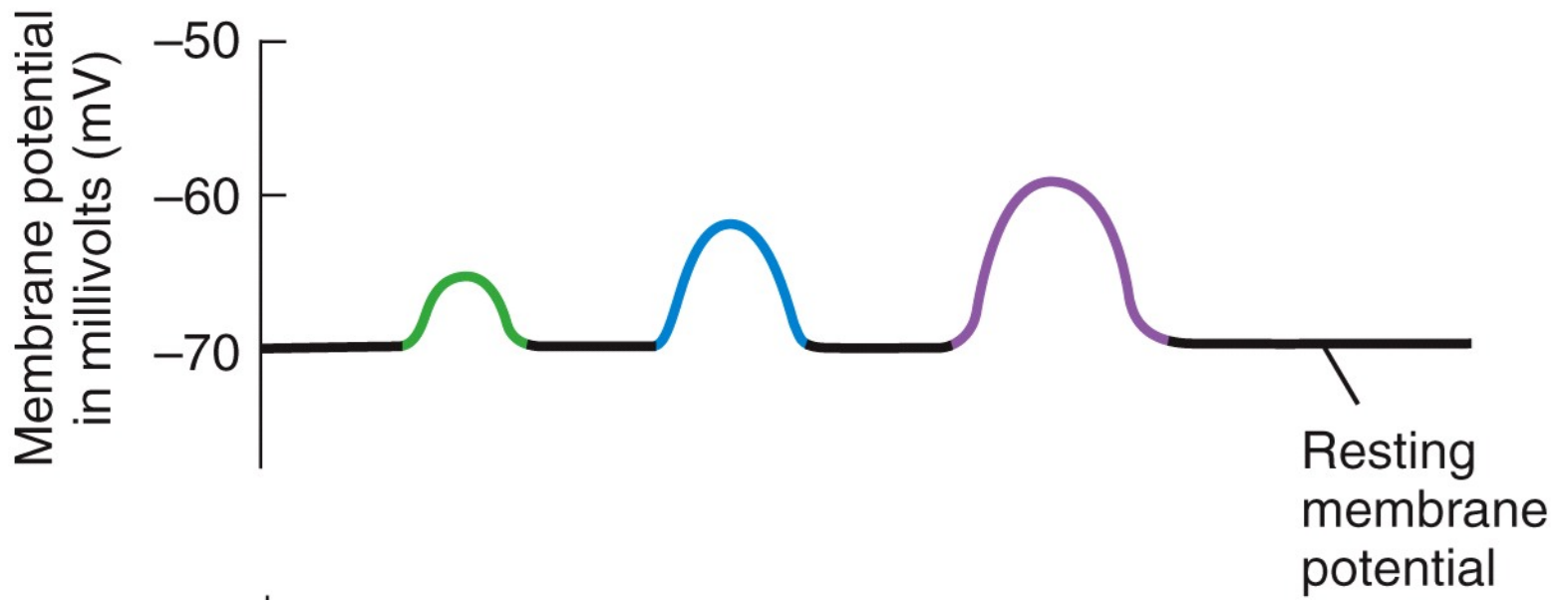
(b)

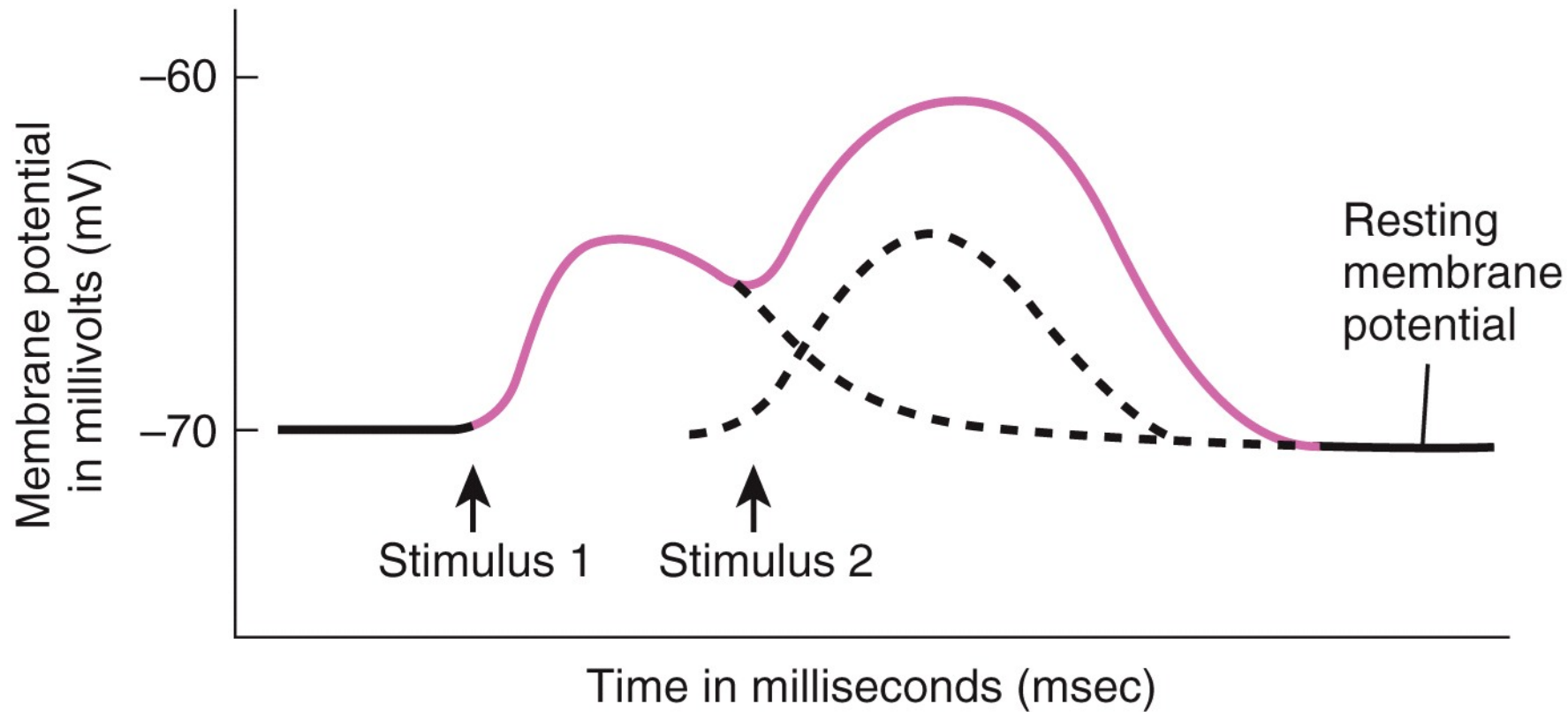
Action potential occurs so fast it is often referred to as a “spike”

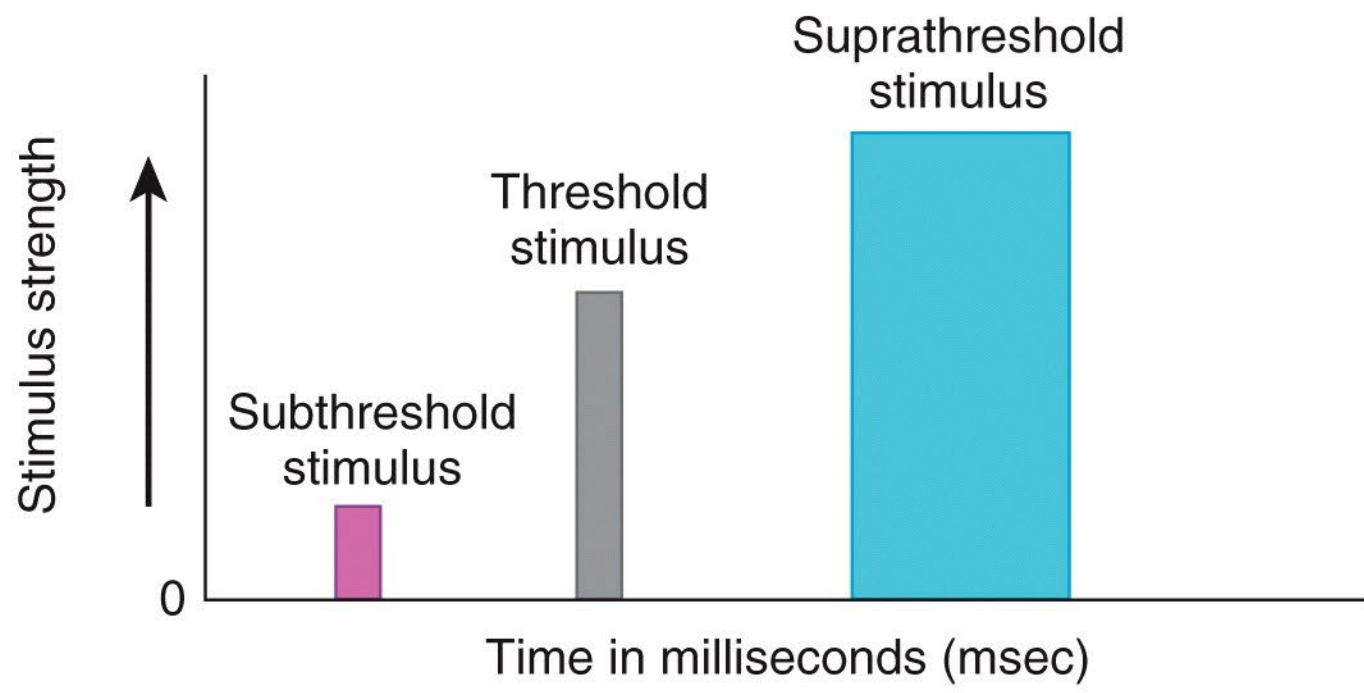
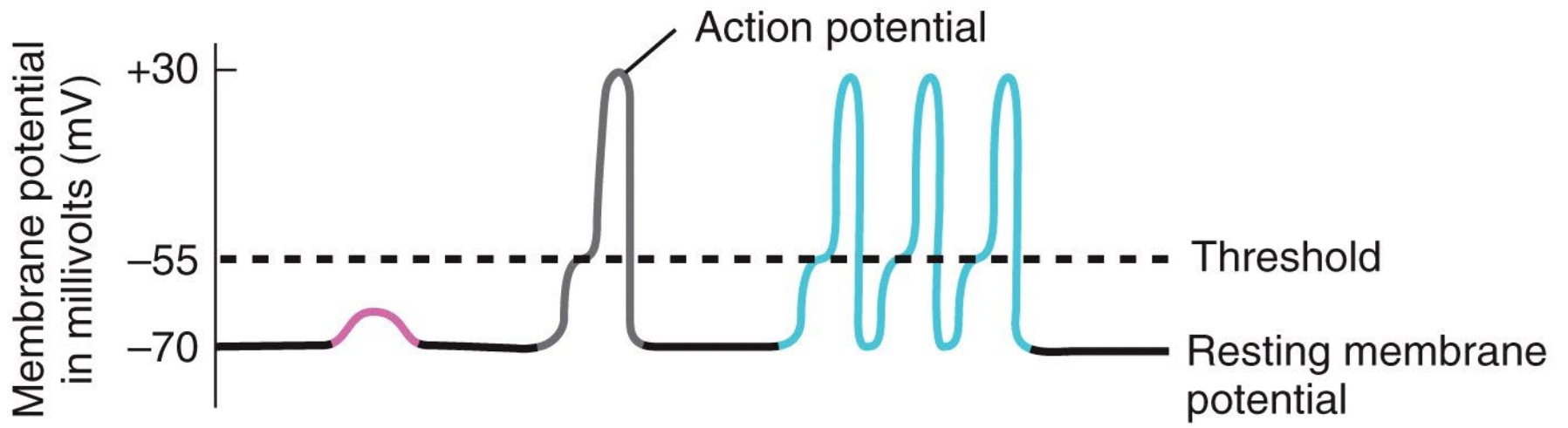
There are four test questions here!

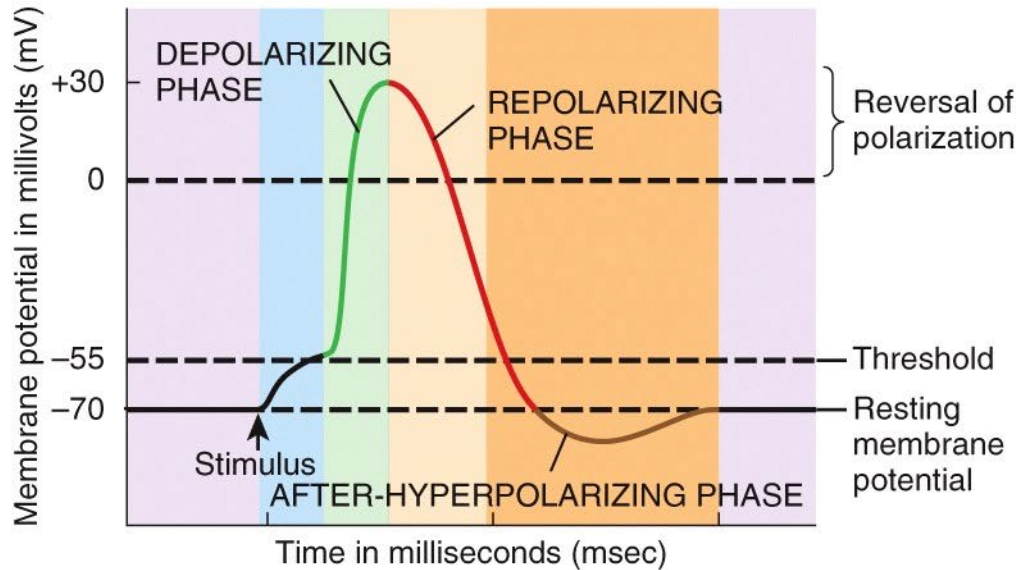
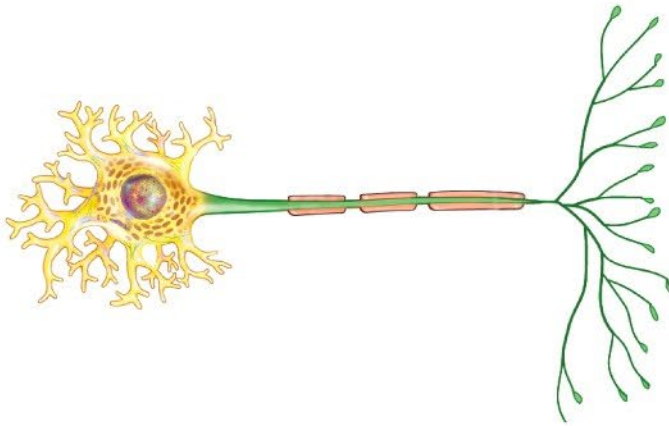
Sodium and Potassium Gates Function During Action Potential







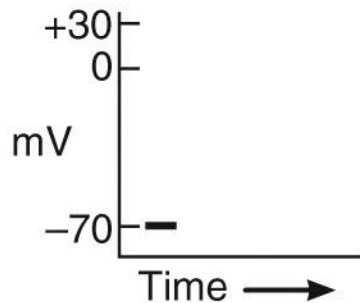
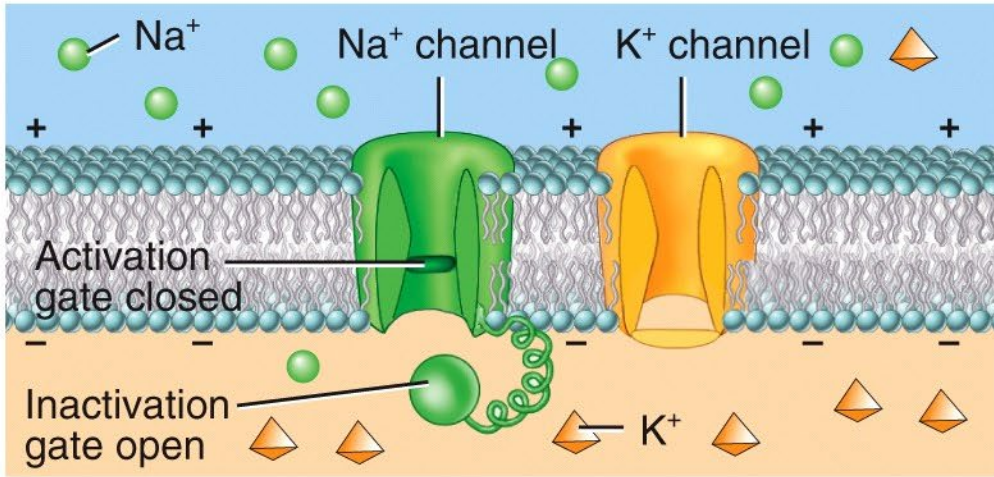
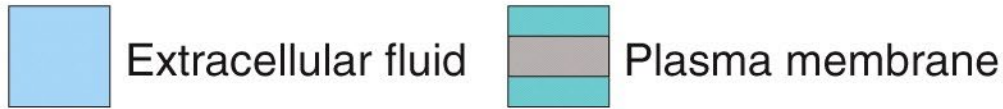




Key:

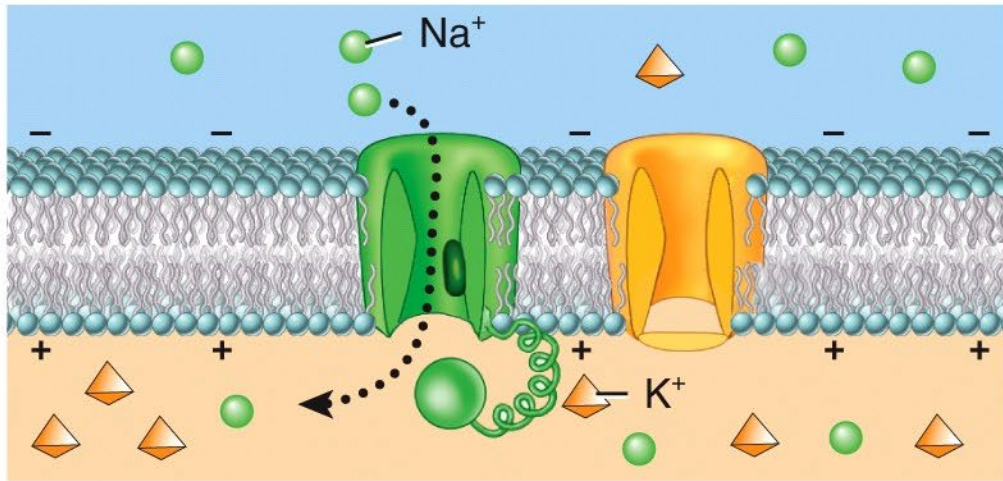
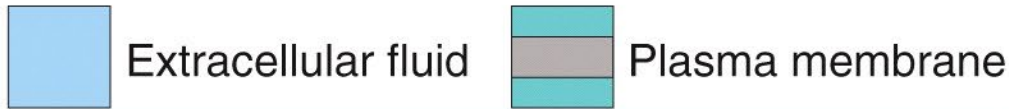
- Resting membrane potential: Voltage-gated Na^+ channels are in the resting state and voltage-gated K^+ channels are closed
 - Stimulus causes depolarization to threshold
 - Voltage-gated Na^+ channel activation gates are open
 - Voltage-gated K^+ channels are open; Na^+ channels are inactivating
 - Voltage-gated K^+ channels are still open; Na^+ channels are in the resting state
- } Absolute refractory period
- } Relative refractory period

Four Phases: Resting – Depolarization – Repolarization - Hyperpolarizing

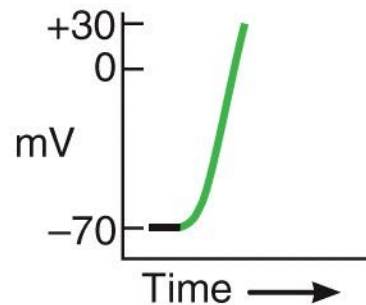


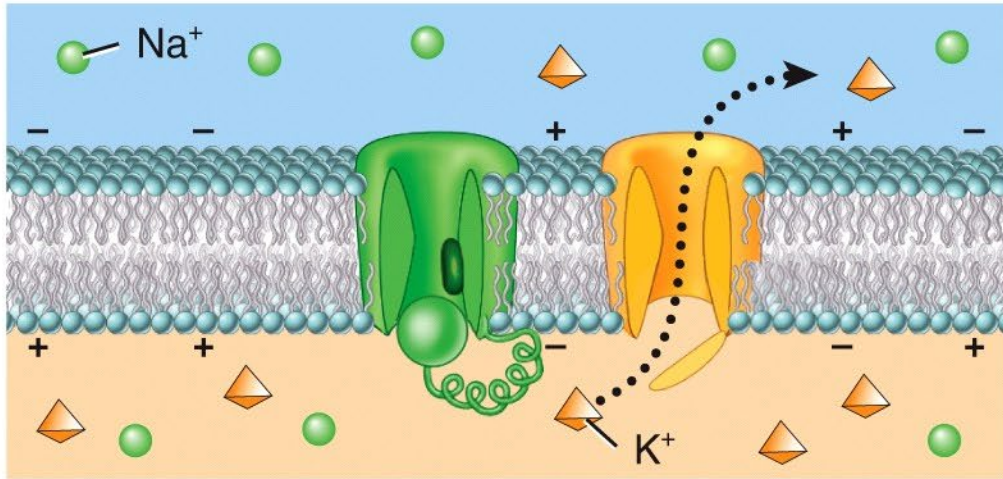
1. Resting state:

All voltage-gated Na⁺ and K⁺ channels are closed. The axon plasma membrane is at resting membrane potential: small buildup of negative charges along inside surface of membrane and an equal buildup of positive charges along outside surface of membrane.

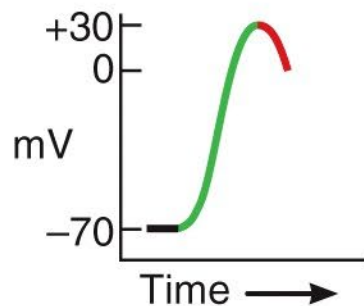


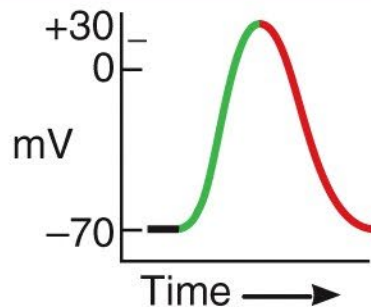
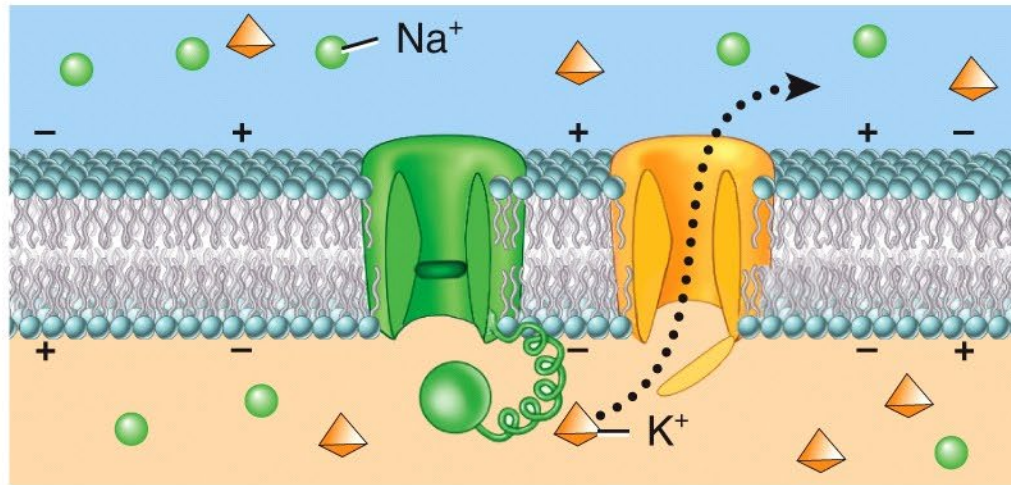
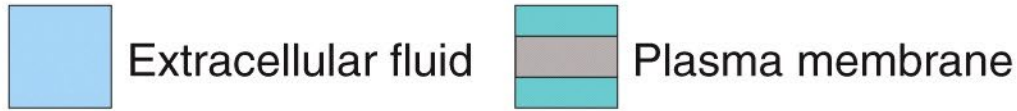
2. Depolarizing phase:
 When membrane potential of axon reaches threshold, the Na^+ channel activation gates open. As Na^+ ions move through these channels into the neuron, a buildup of positive charges forms along inside surface of membrane and the membrane becomes depolarized.





- 3. Repolarizing phase begins:** Na⁺ channel inactivation gates close and K⁺ channels open. The membrane starts to become repolarized as some K⁺ ions leave the neuron and a few negative charges begin to build up along the inside surface of the membrane.





4. Repolarization phase continues:

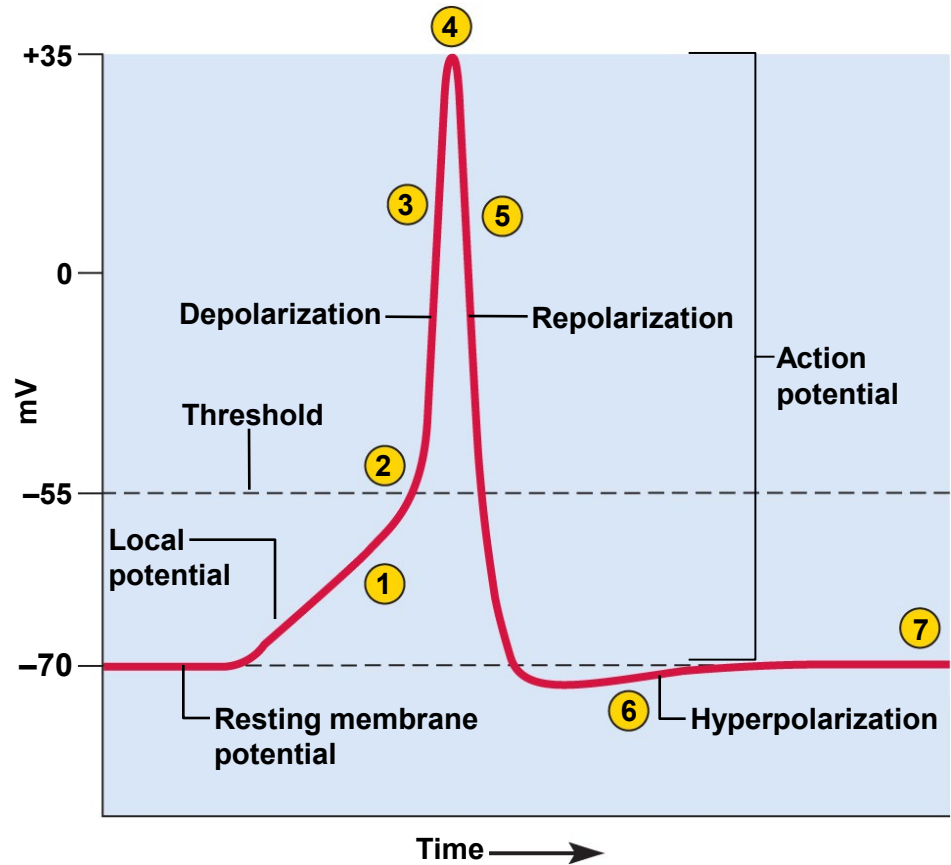
K⁺ outflow continues. As more K⁺ ions leave the neuron, more negative charges build up along inside surface of membrane. K⁺ outflow eventually restores resting membrane potential. Na⁺ channel activation gates close and inactivation gates open. Return to resting state when K⁺ gates close.

Action Potentials

Only a thin layer of the cytoplasmic ions right next to the cell membrane are affected // very few ions are involved

Action potential is often called a **spike**

Called spike because AP happens so fast



Action Potential Characteristics

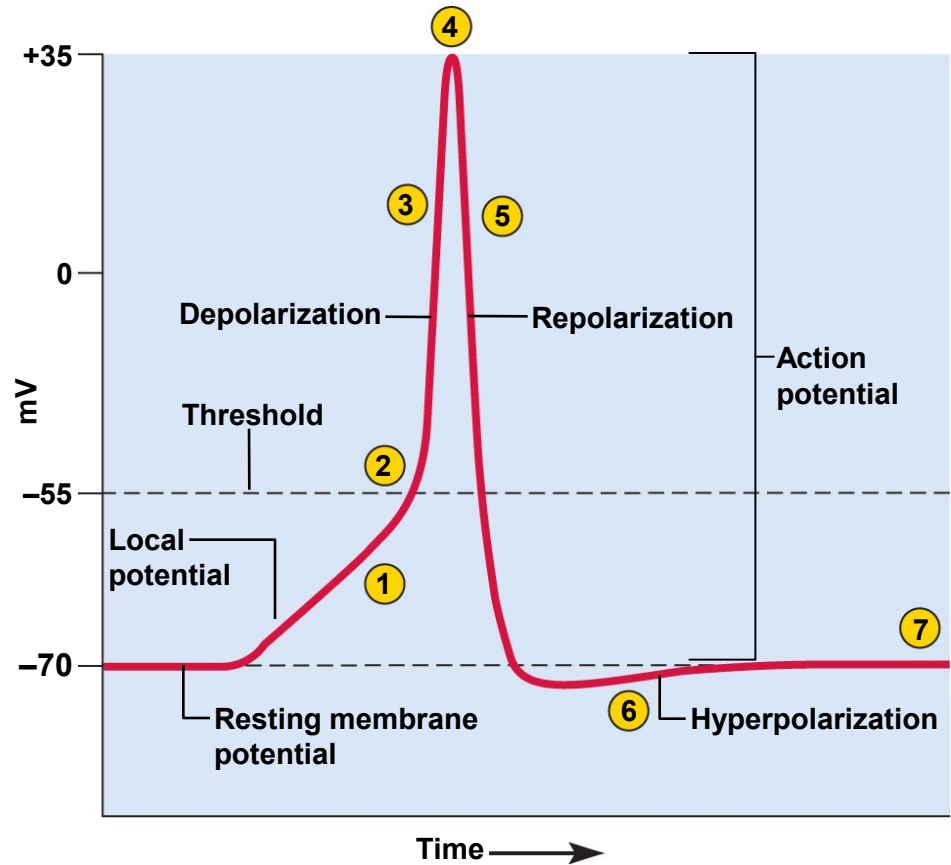
Characteristics of action potential (event in axon) versus a local potential (event in dendrite/soma)

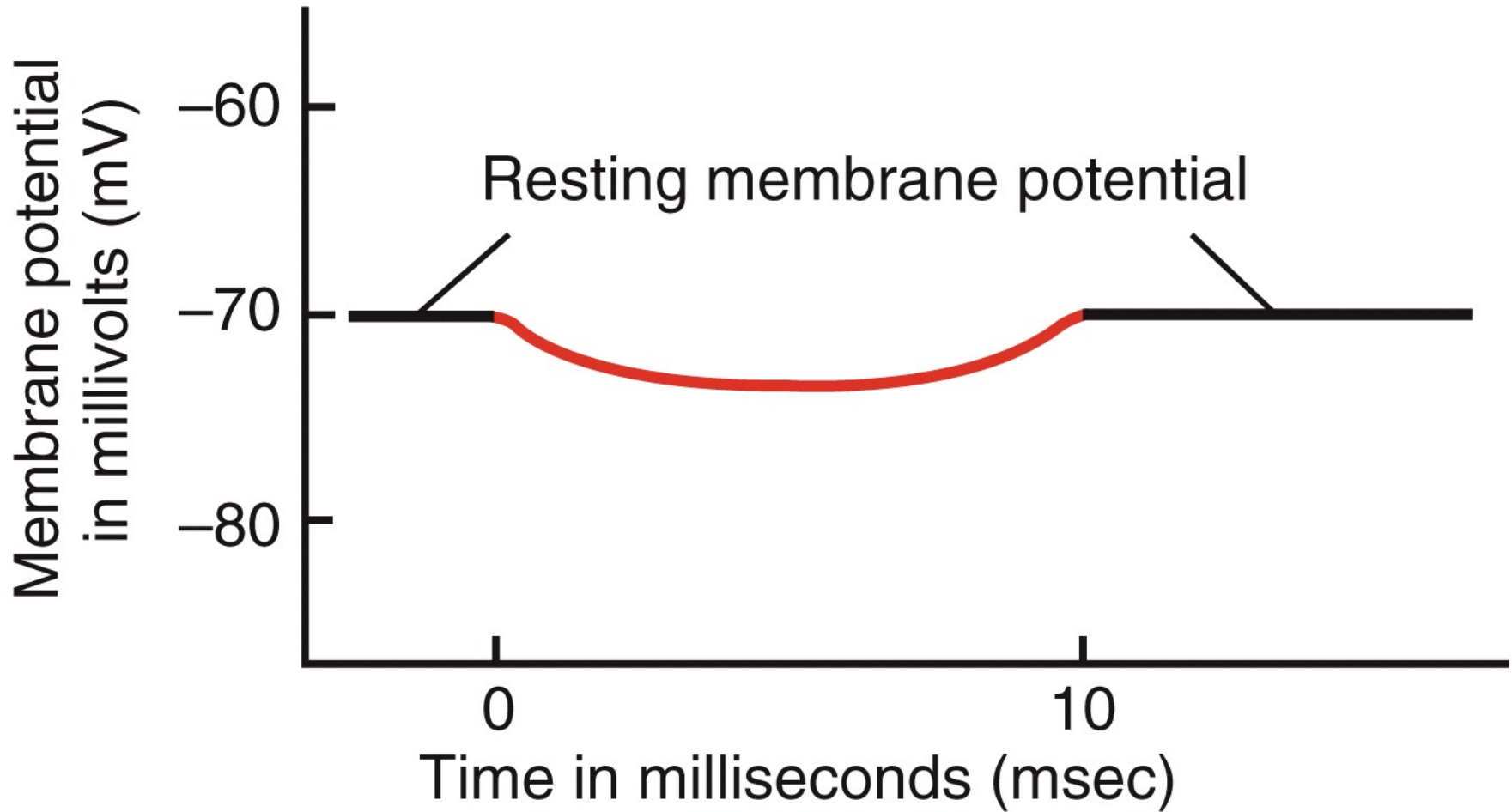
all-or-none law // if threshold is reached, neuron fires at its maximum voltage

if threshold is not reached it does not fire

non-decremental - does not become weaker with distance

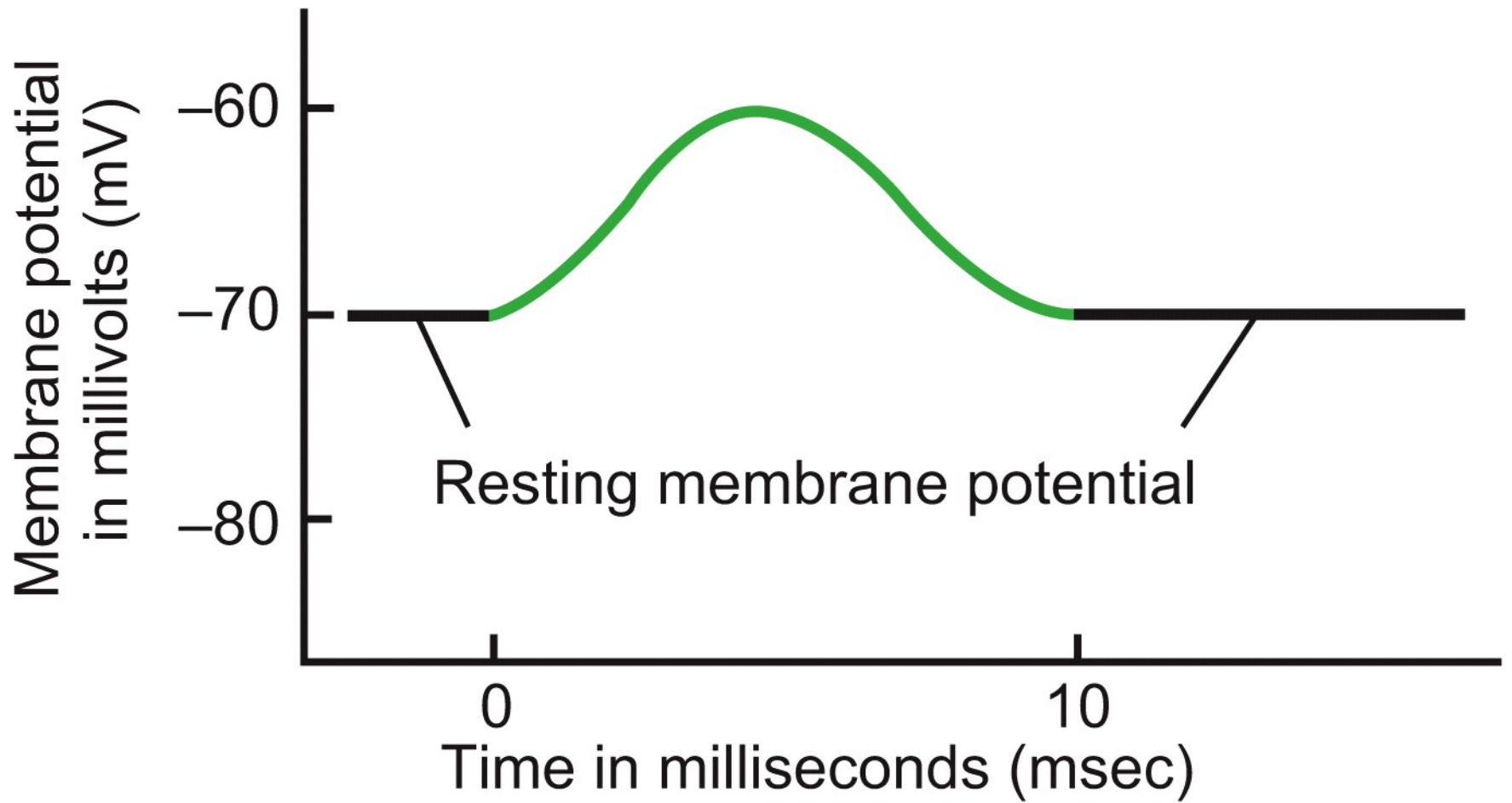
irreversible - once started goes to completion and can not be stopped





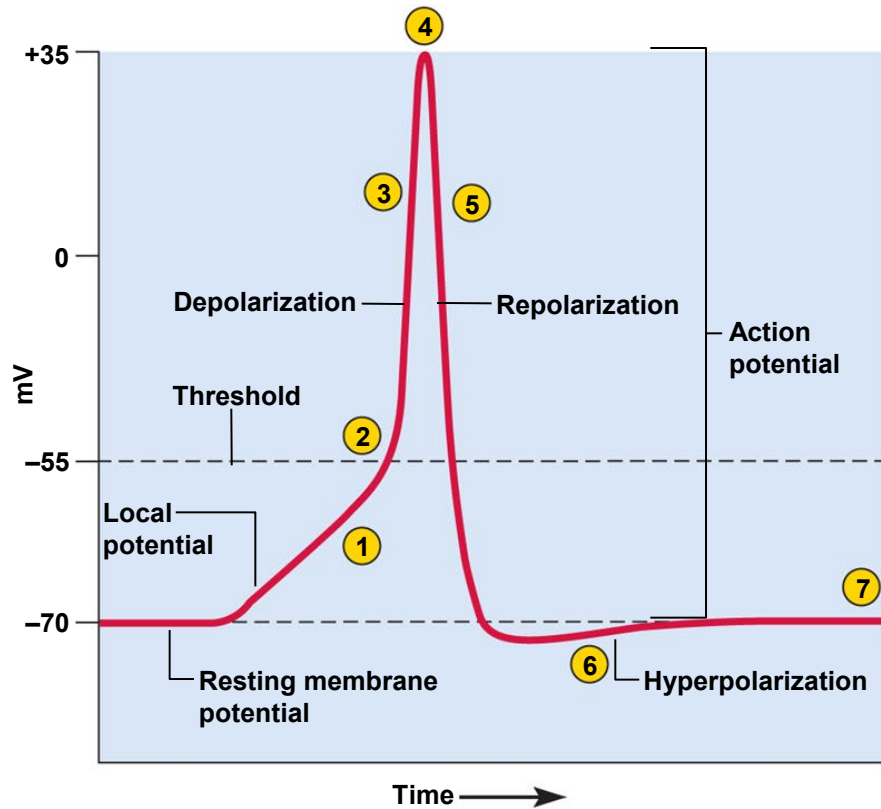
(a) Hyperpolarizing graded potential

What type of ion entering a neuron through a ligand channel may cause this?

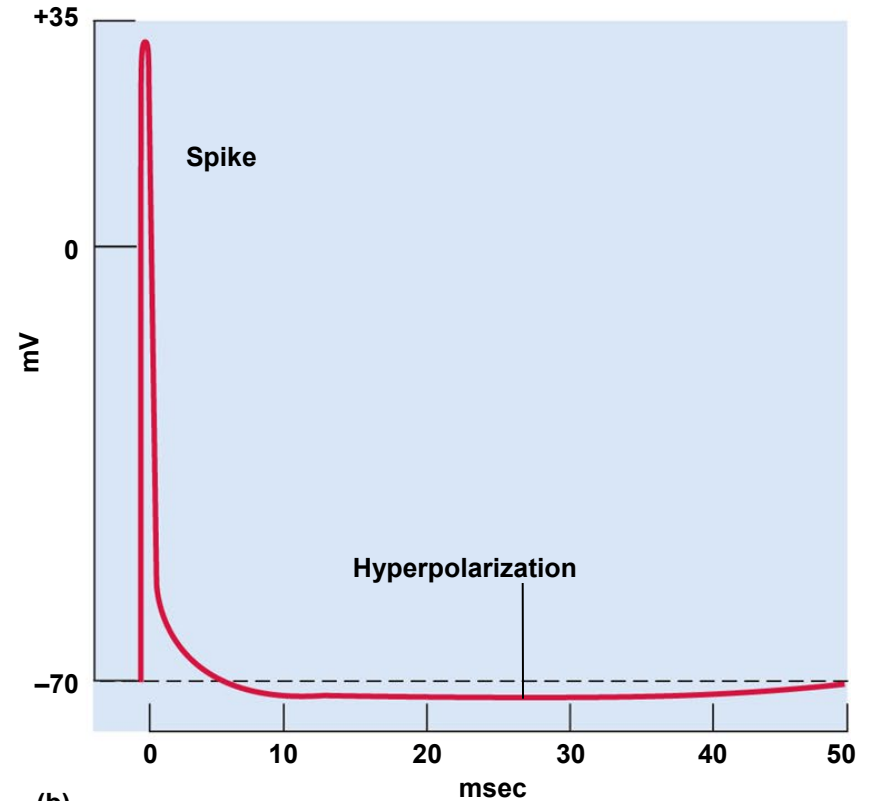


(b) Depolarizing graded potential

Action Potential



(a)



(b)

Action potential occurs so fast it is often referred to as a “spike”

The Refractory Period

Refractory period – the period of resistance to stimulation

During an **action potential** and for a few milliseconds after, it is difficult or impossible to stimulate that region of a neuron to fire again.

Two phases of the refractory period

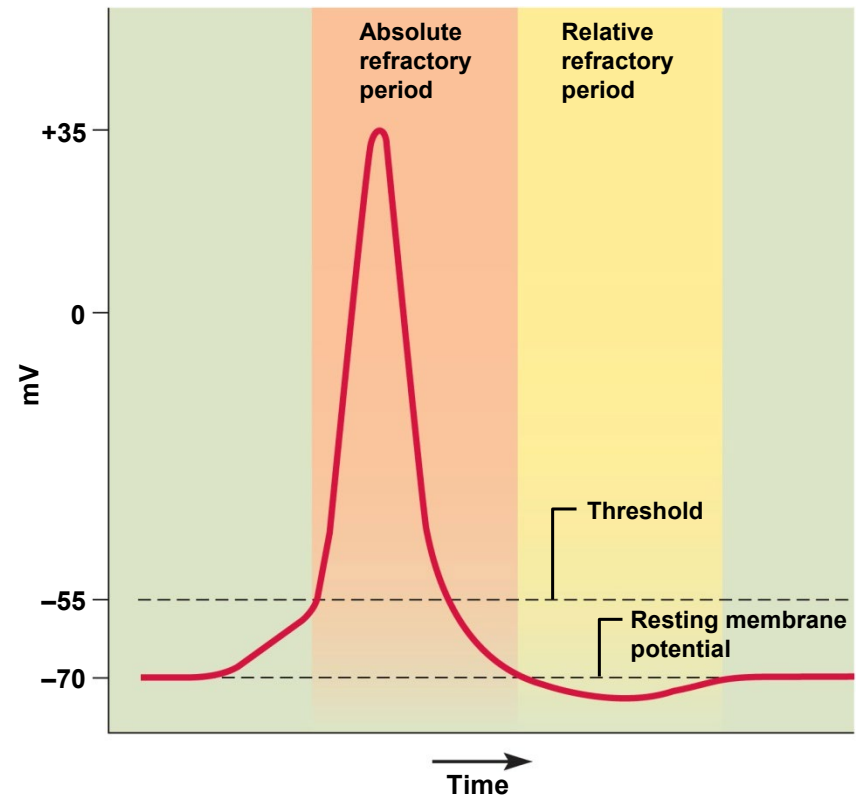
Absolute refractory period

No stimulus of any strength will trigger AP

As long as Na^+ gates are open

From action potential to RMP

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The Refractory Period

Two phases of the refractory period

Relative refractory period

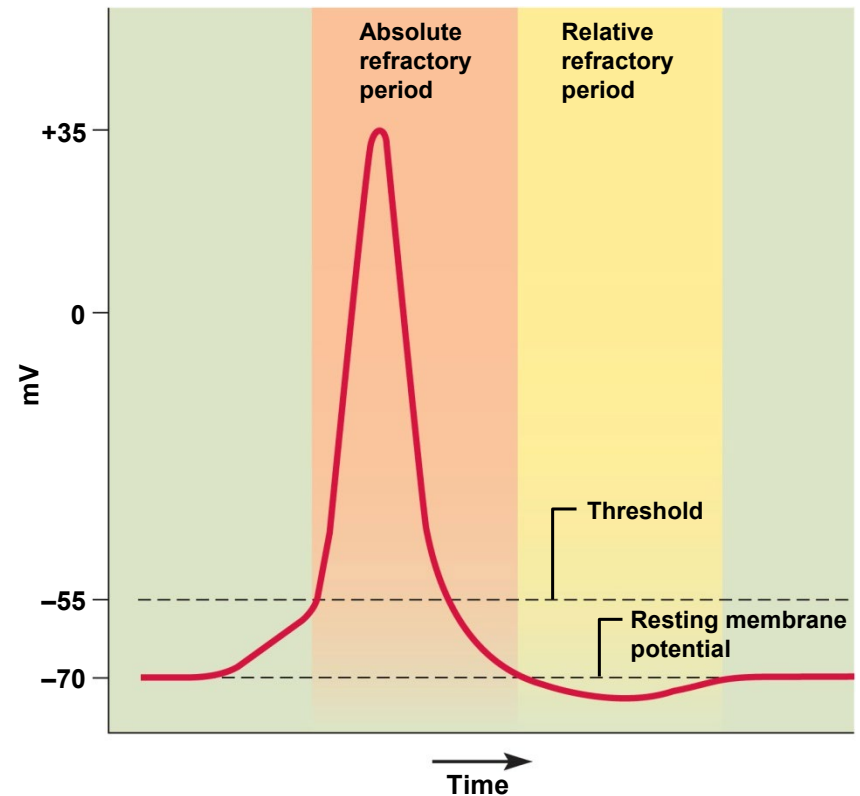
Only especially strong stimulus will trigger new AP

K^+ gates are still open and any affect of incoming Na^+ is opposed by the outgoing K^+

Refractory period is occurring only at a small patch of the neuron's membrane at one time

Other parts of the neuron can be stimulated while the small part is in refractory period

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Signal Conduction in Un-myelinated Fibers

For an AP conduction to occur, the **nerve signal must travel to the end of the axon (reach synaptic knobs)**

Unmyelinated fiber have voltage-regulated ion gates along its entire length

Action potential from the trigger zone causes Na^+ to enter the axon and diffuse into adjacent regions beneath the membrane

The depolarization excites voltage-regulated gates immediately distal to the action potential.

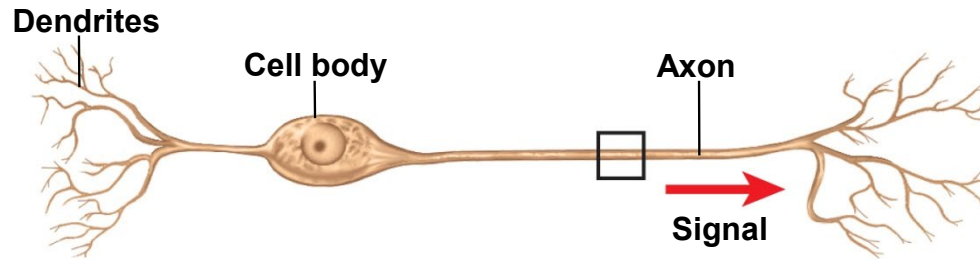
Na^+ and K^+ gates open and close producing a new action potential




By repetition the membrane distal to that is excited

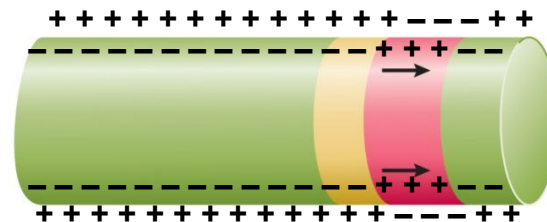
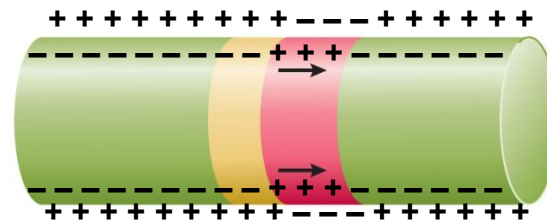
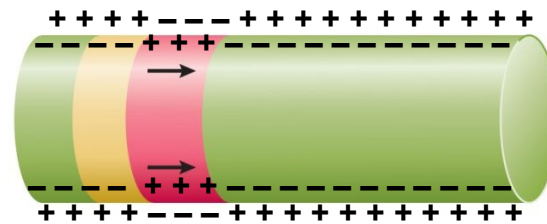
Chain reaction continues to the end of the axon

Unidirectional

Nerve Signal Conduction Unmyelinated Fibers



-  Action potential in progress
-  Refractory membrane
-  Excitable membrane



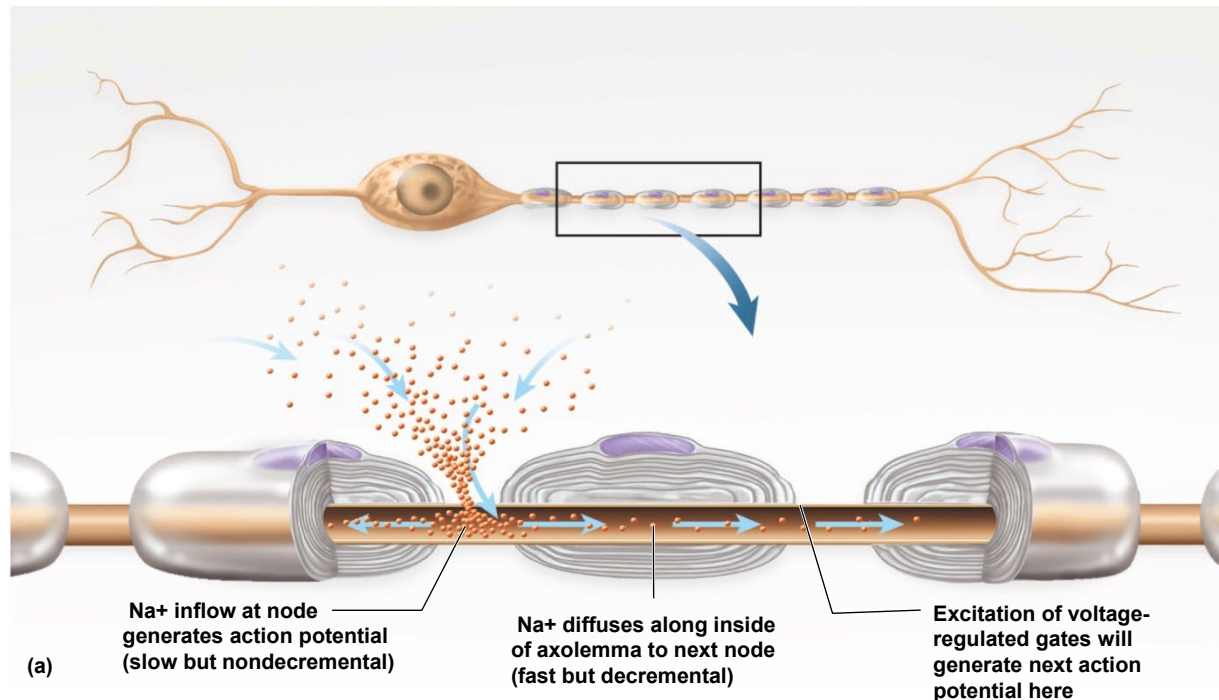
Saltatory Conduction in Myelinated Axons

Voltage-gated channels needed for AP

- fewer than 25 per μm^2 in myelin-covered regions (internodes)
- up to 12,000 per μm^2 in nodes of Ranvier

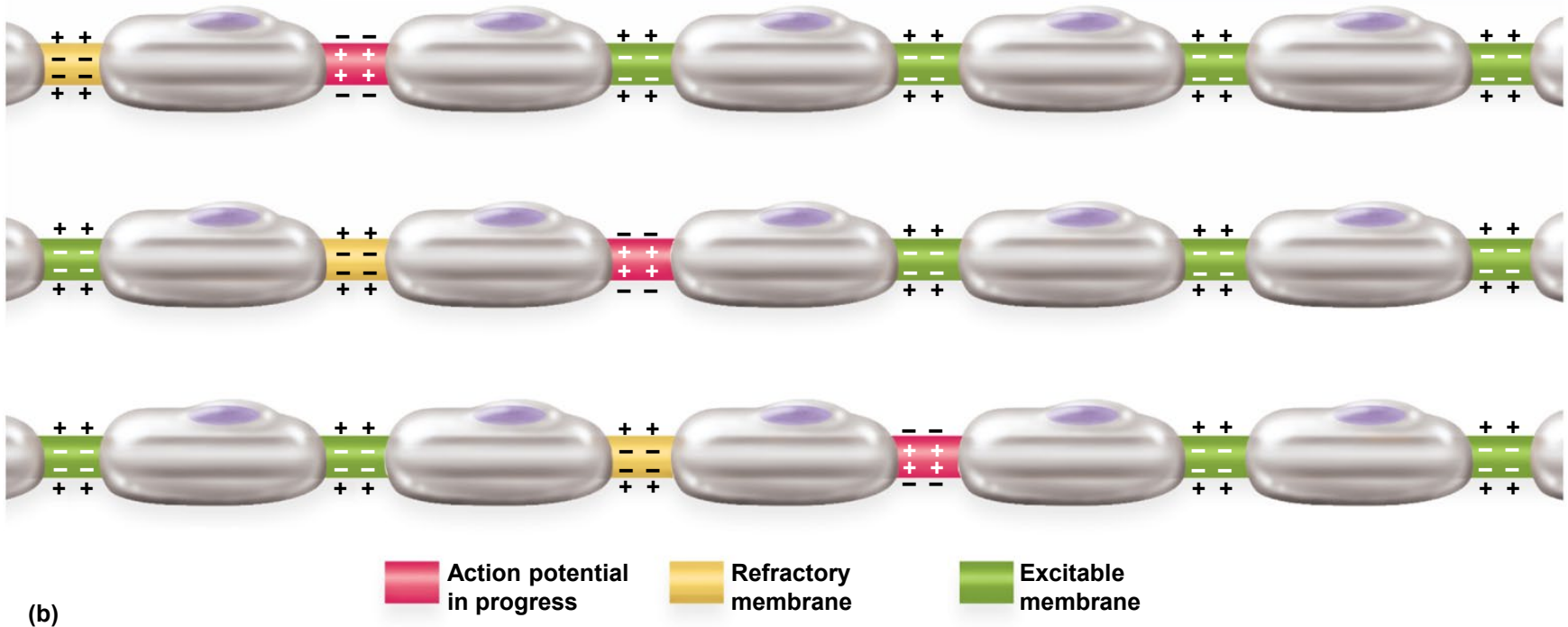
Fast Na^+ diffusion occurs between nodes // signal weakens under myelin sheath, but still strong enough to stimulate an action potential at next node

Saltatory conduction – the nerve signal seems to jump from node to node // faster than in unmyelinated axons

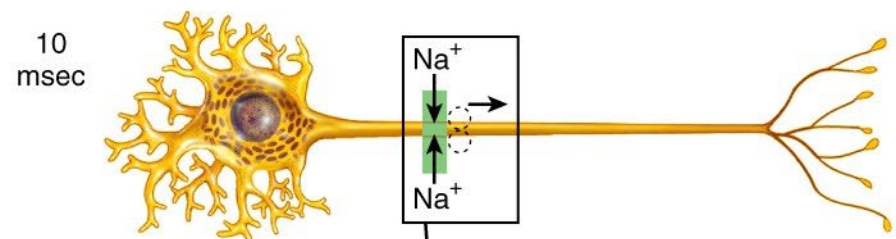
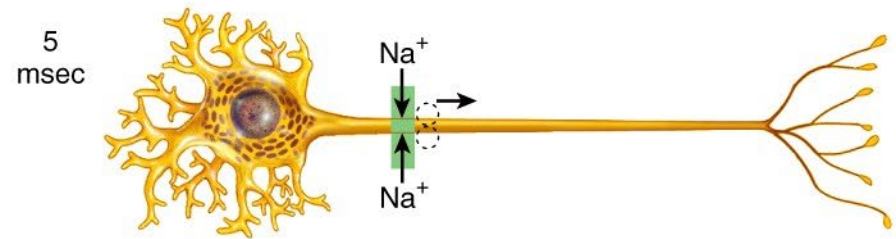
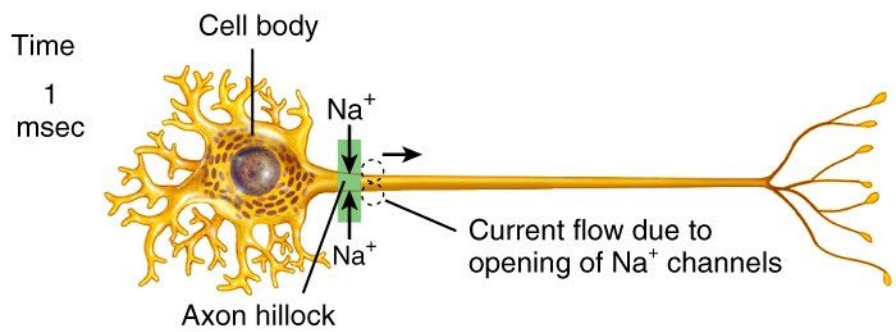


Saltatory Conduction

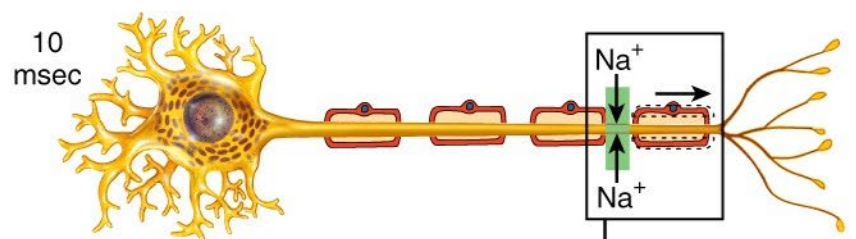
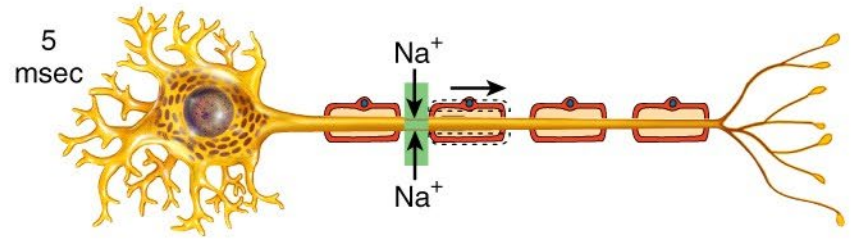
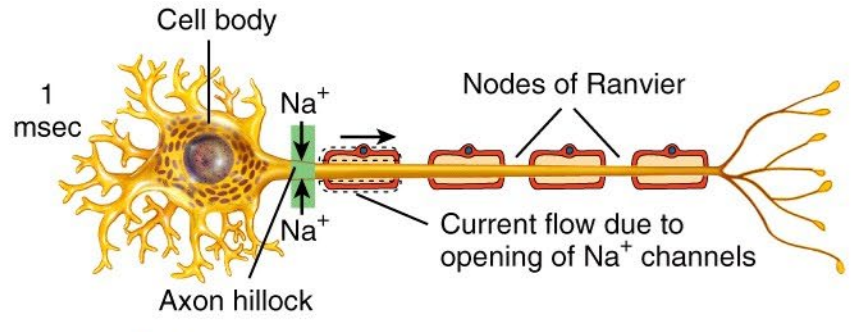
Action potential “skips” from one node to the next!



Faster than the conduction speed in an unmyelinated axons



(a) Continuous conduction



(b) Saltatory conduction

Leading edge of action potential

