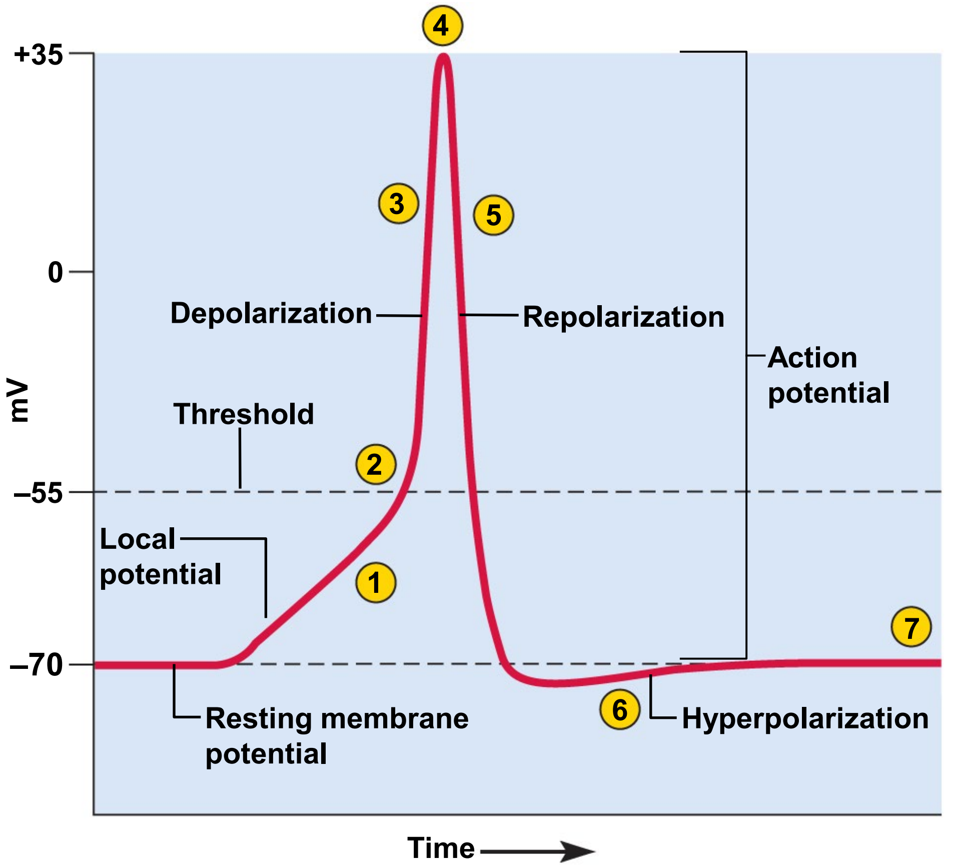
Chapter 12.2

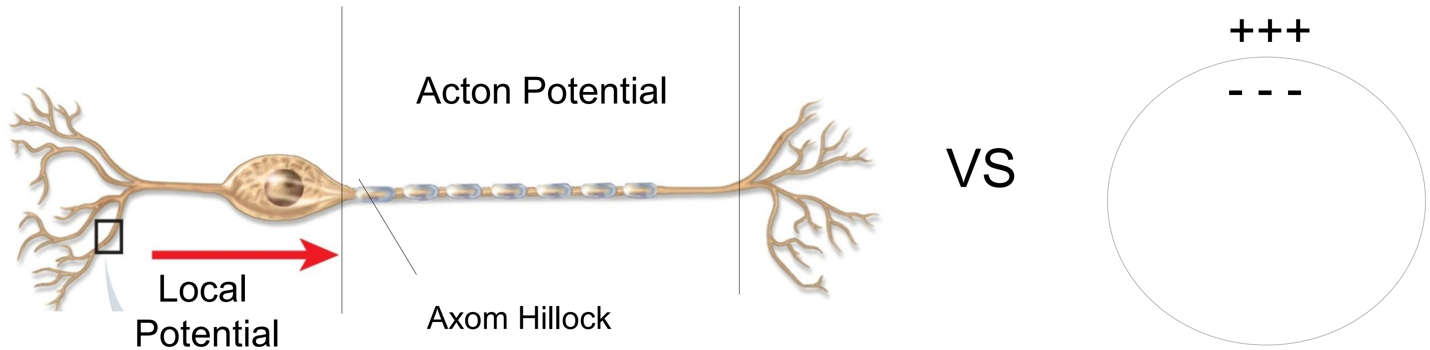
Electrical Potentials



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



Resting Membrane Potential of a Cell

All cells have a resting membrane potential

Nerve and muscle tissues have a resting potential when they are not stimulated

Dendrites exhibit local potentials (similar to receptor potentials). If the stimulus is great enough, then the local potential may become an action potential at axon hillock.

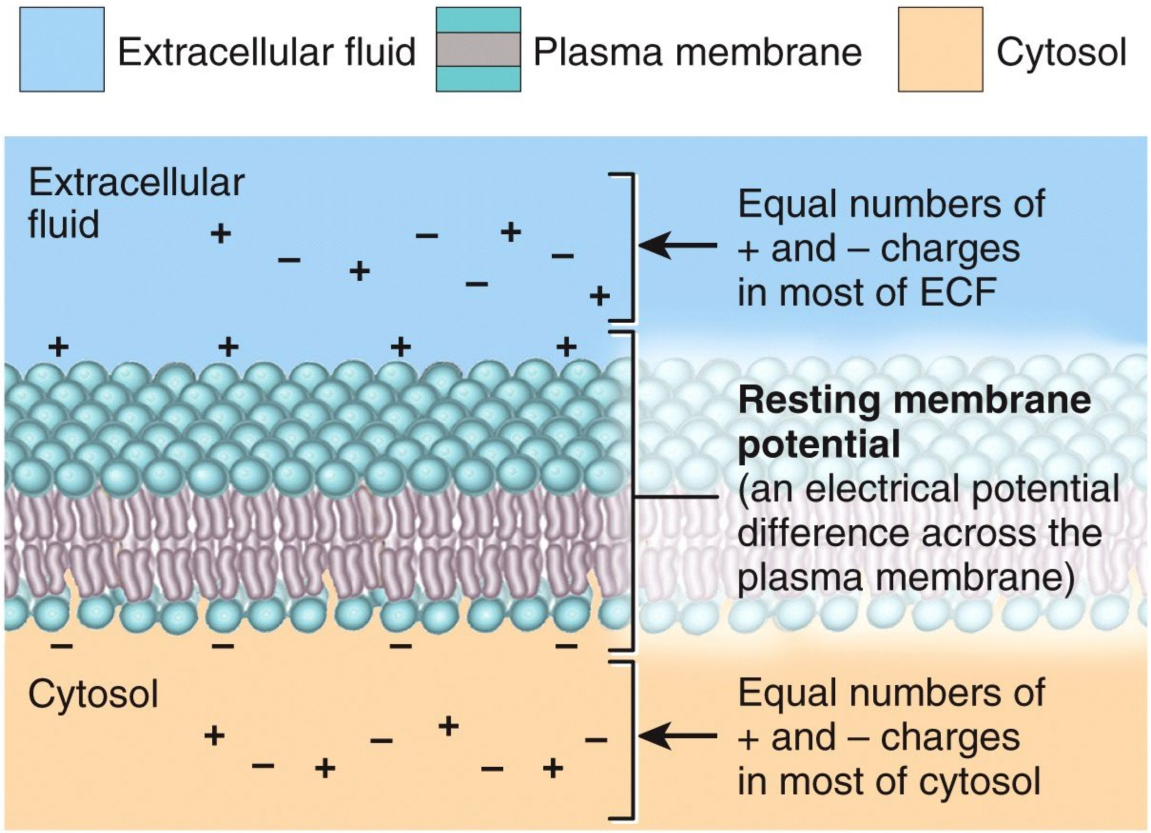
Local potentials are graded, decremental, reversible, and may either send signal to next neuron or inhibit the formation of an action potential on the next neuron

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

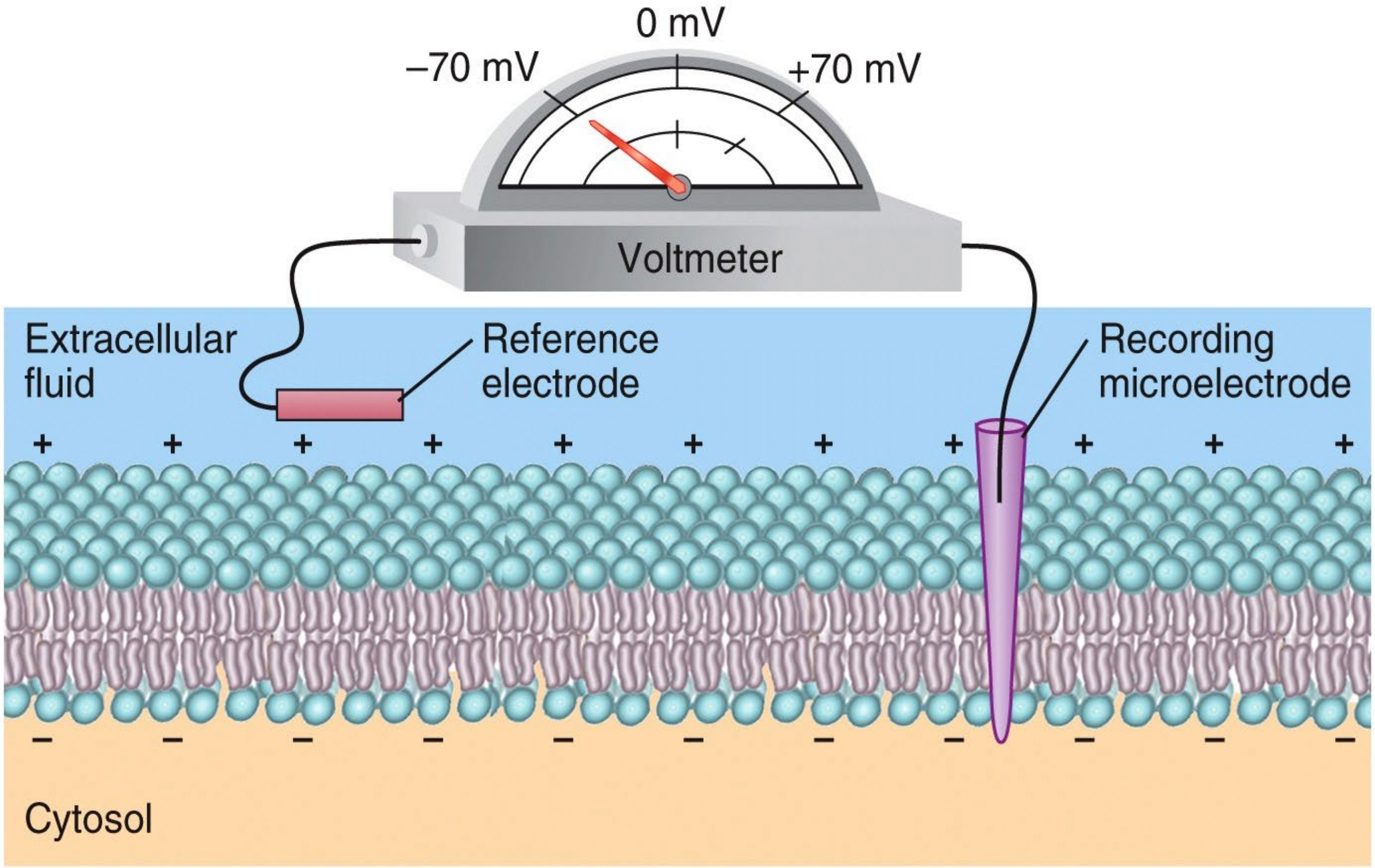
If LP stimulus reaches trigger zone, then it initiates an action potential that travels down axon (all or none and action potential is uni-directional)

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
- What is the difference between voltage and current?

Voltage and Current

Voltage = separation of charge (ions across membrane)

Electrical current = the movement of ions

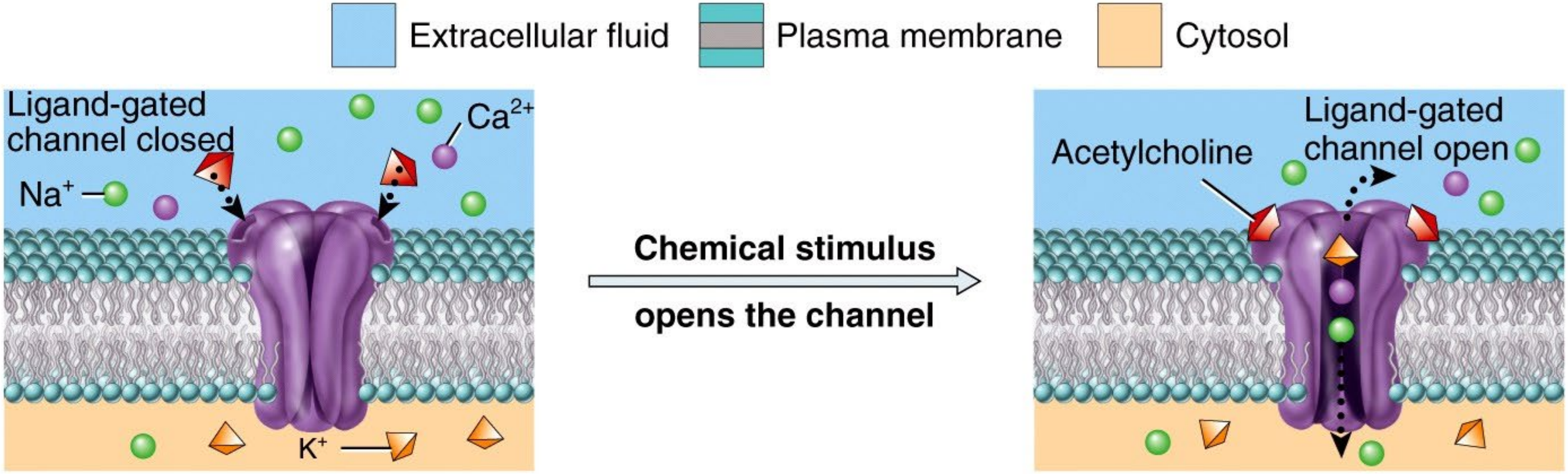
in the body, currents created by movement of ions (e.g. Na^{+}, K^{+}) and Cl^{-}) through gated channels in the plasma membrane

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

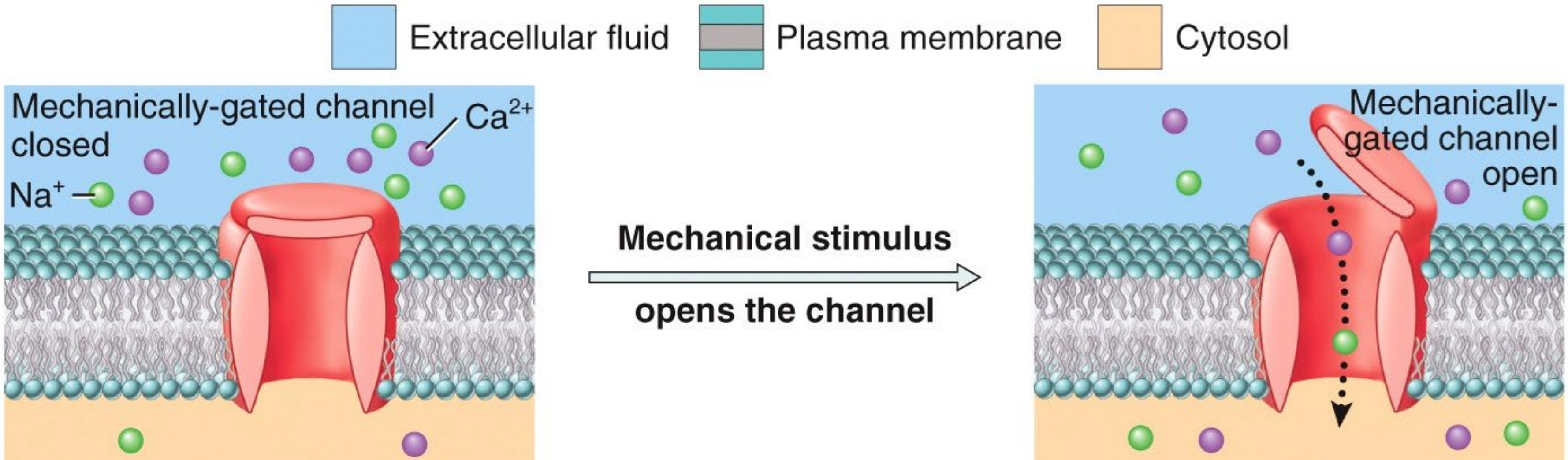
some transmembrane protein channels are not regulated but simply “leak ions” (we will overlook this factor in our discussion of action potentials)

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

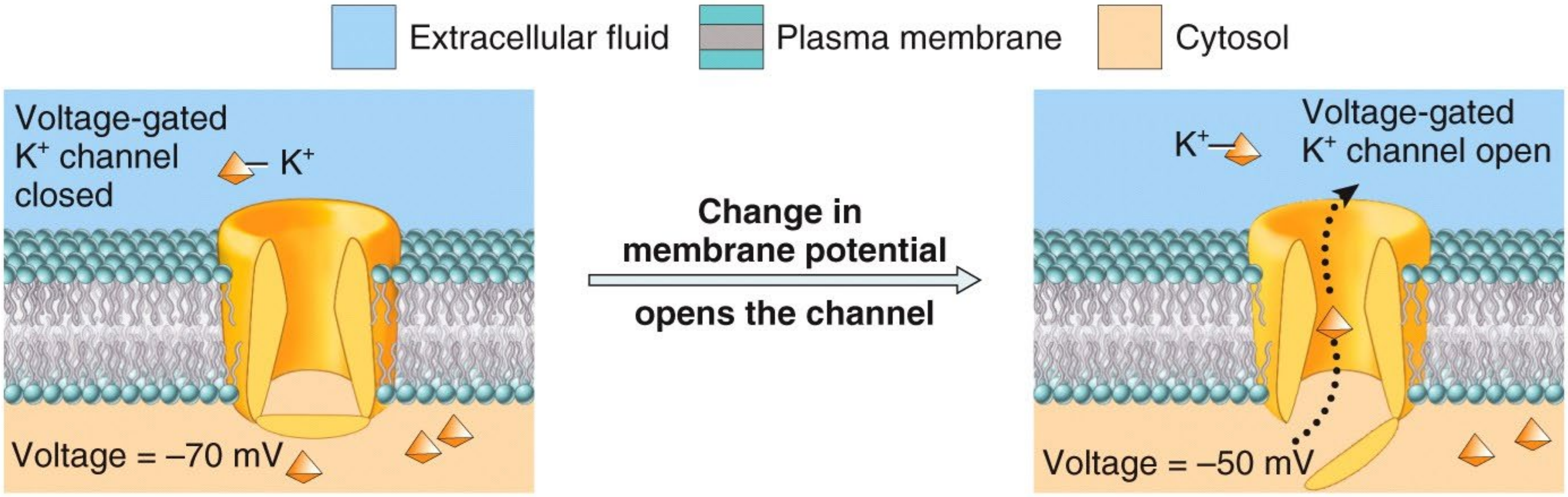
Action potentials used to regulate cellular events



(b) Ligand-gated channel

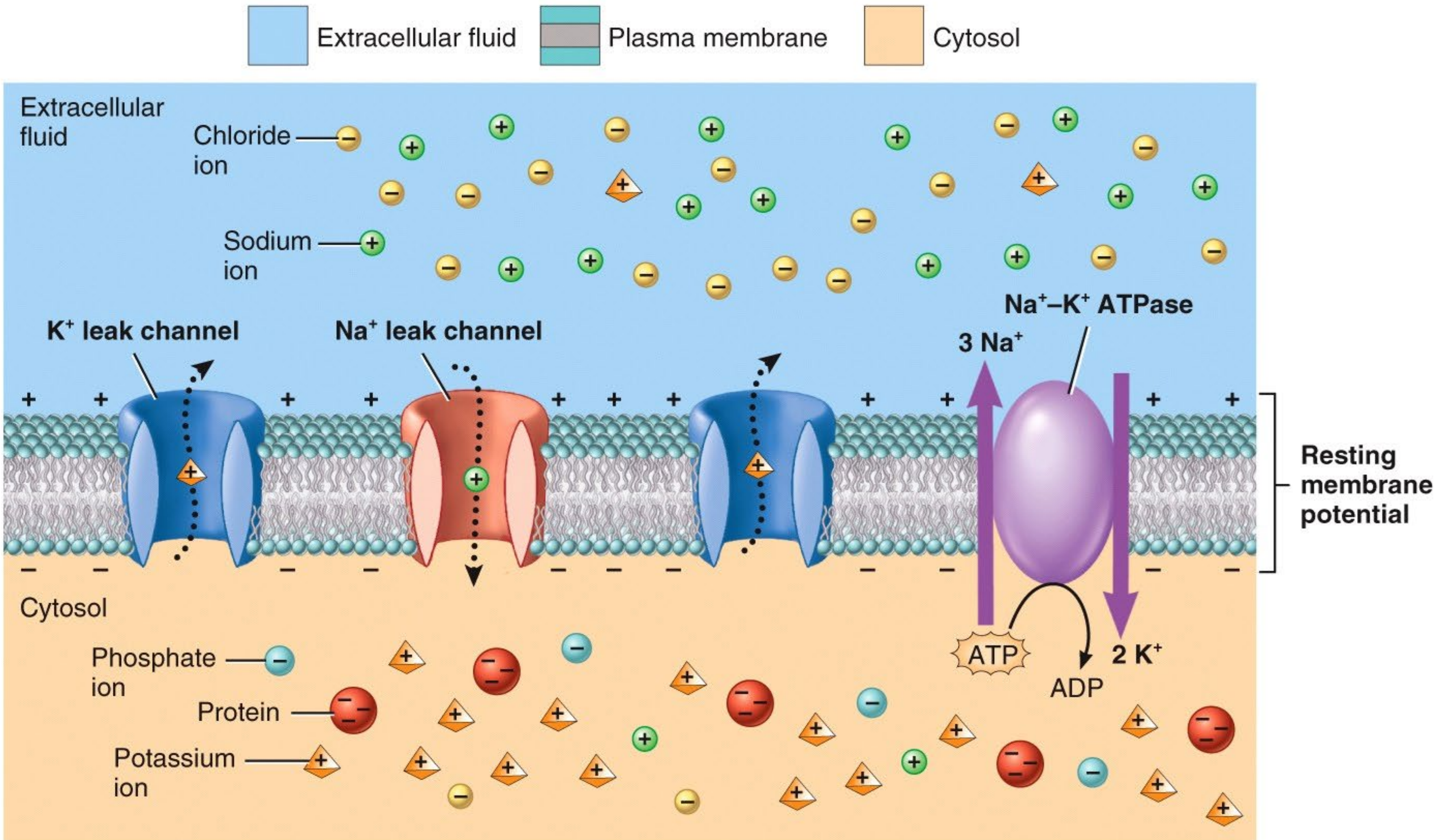


(c) Mechanically-gated channel

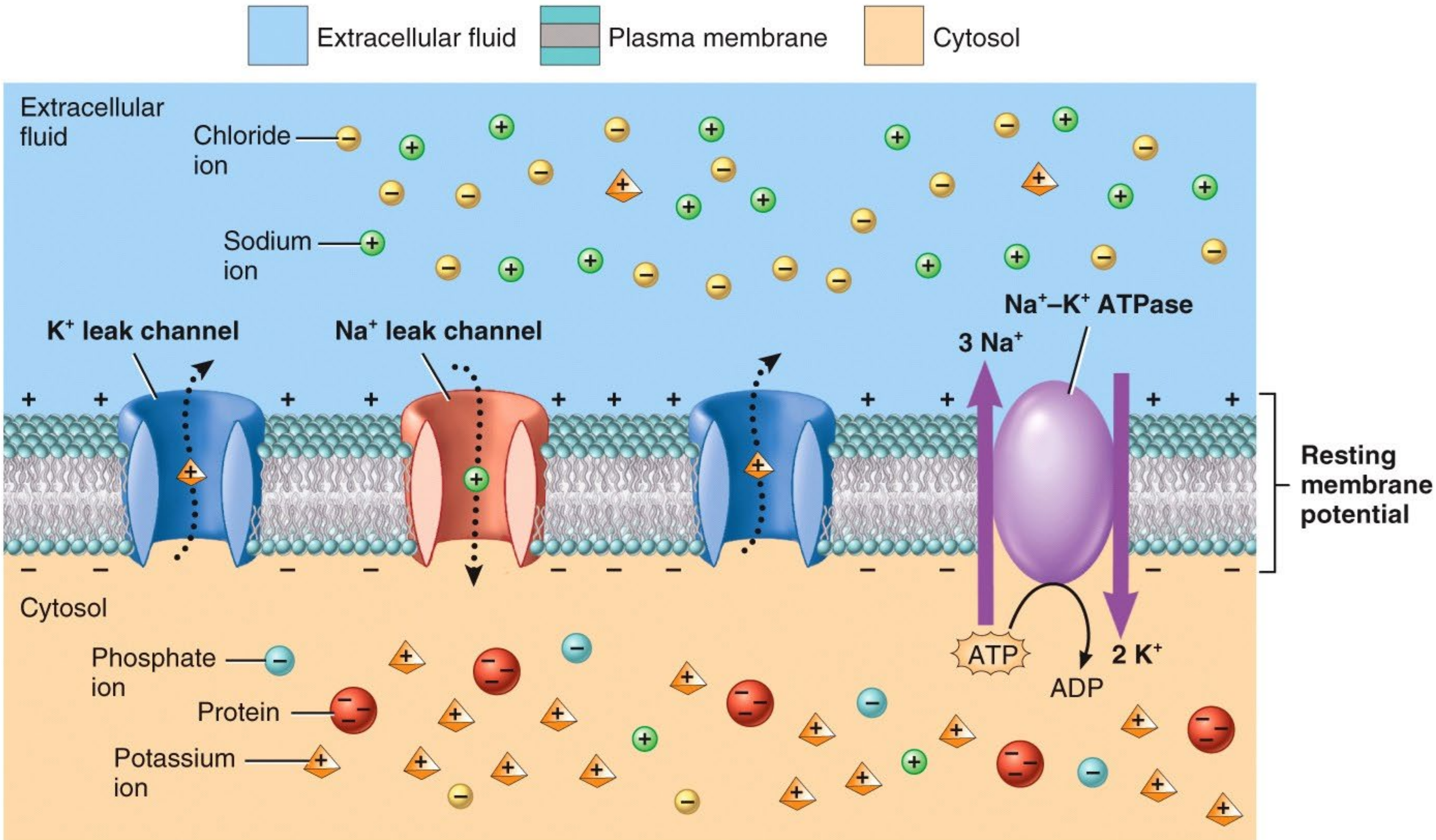


(d) Voltage-gated channel

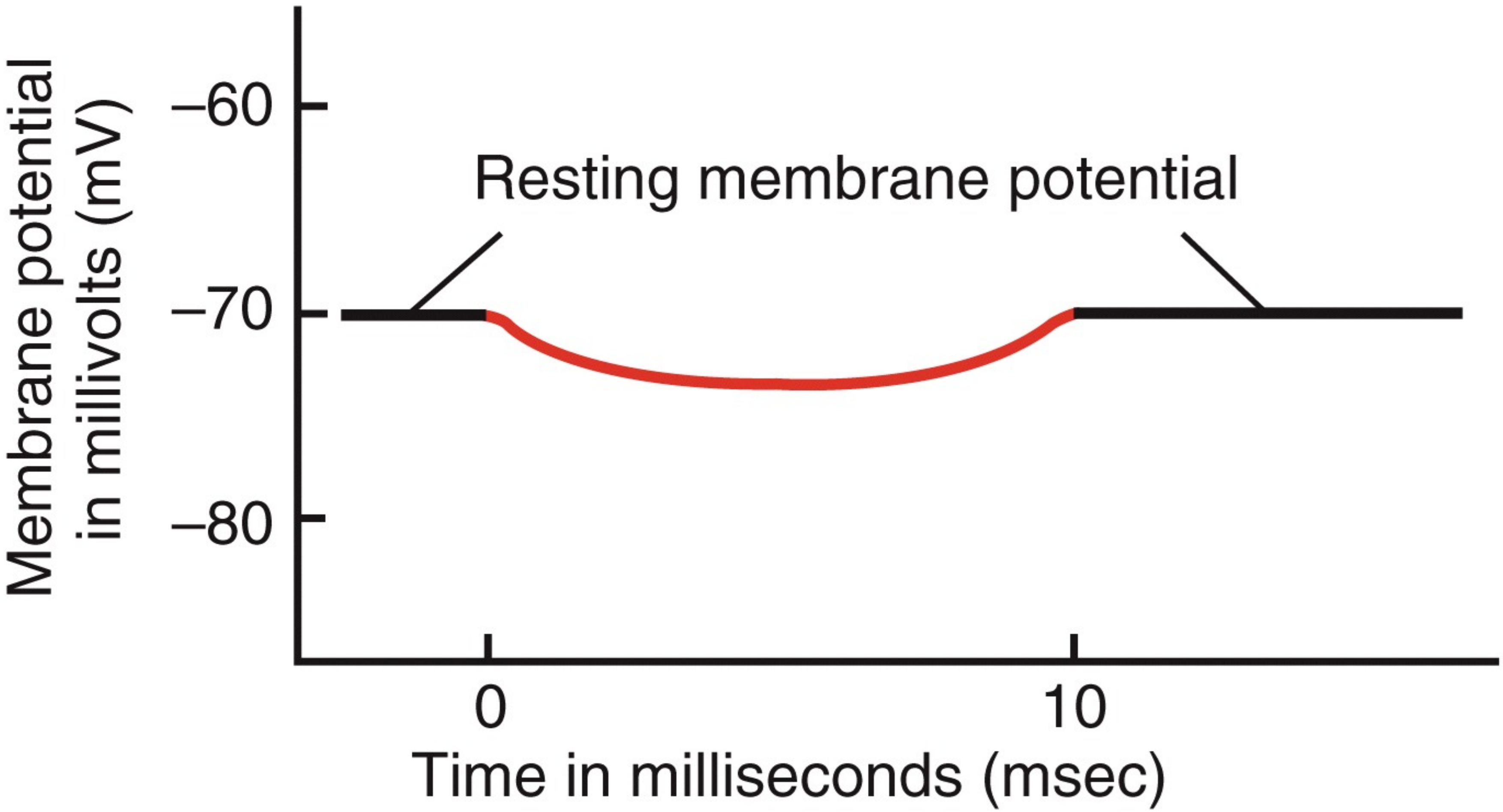
Note: Sodium channels maybe open, closed, or blocked.



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

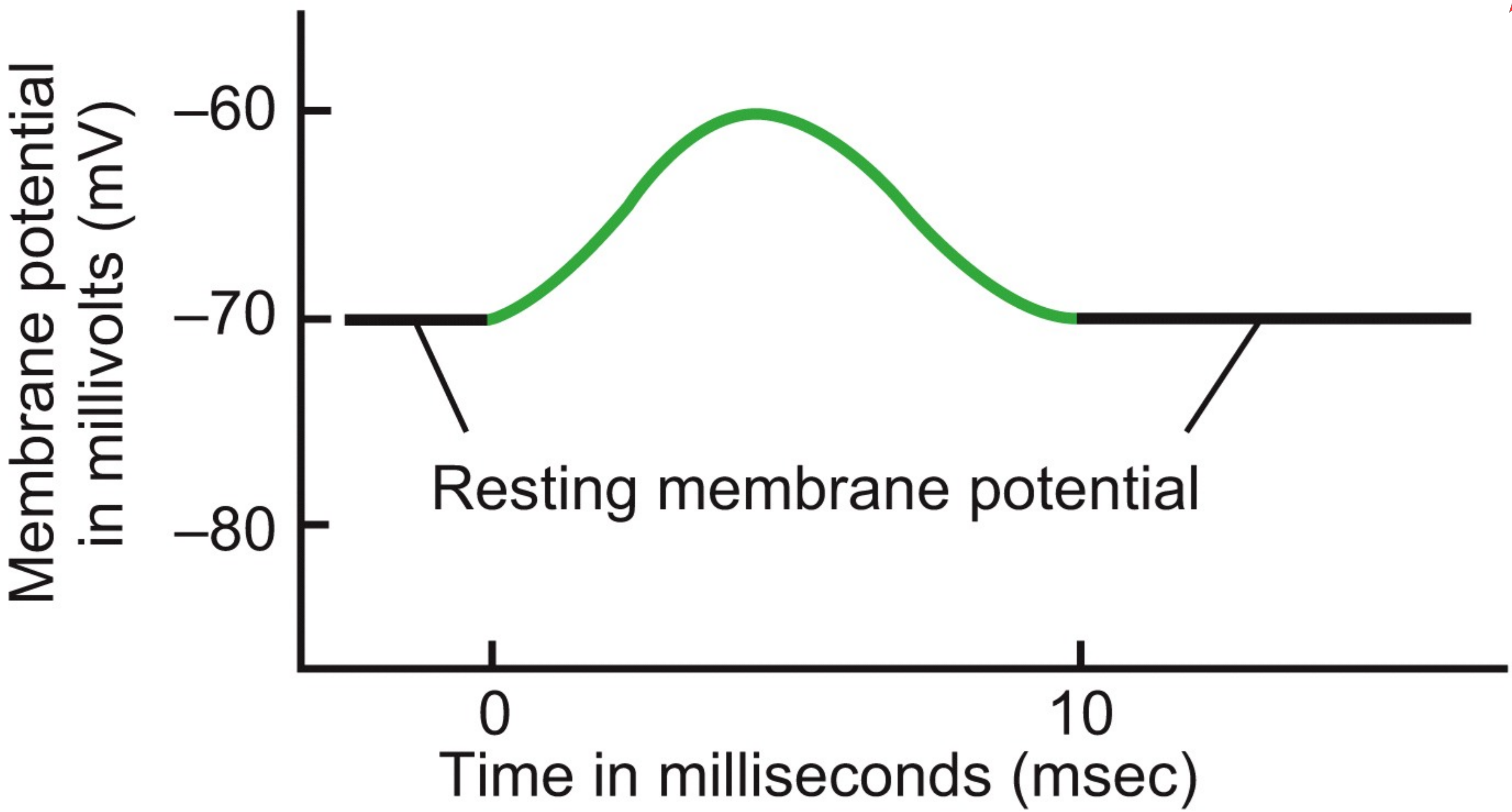


The sodium-potassium ATP pump's function is to maintain the resting membrane potential and to restore the potential if a positive or negative graded potential occurs.



(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 electrolyte distribution across membrane (this is an electro-chemical gradient)

–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^+) 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

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

–As potassium leaves cytoplasm becomes less negative

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 conceptulize!)

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

Factor Contributing to the Creation and Maintenance of Resting Membrane Potential

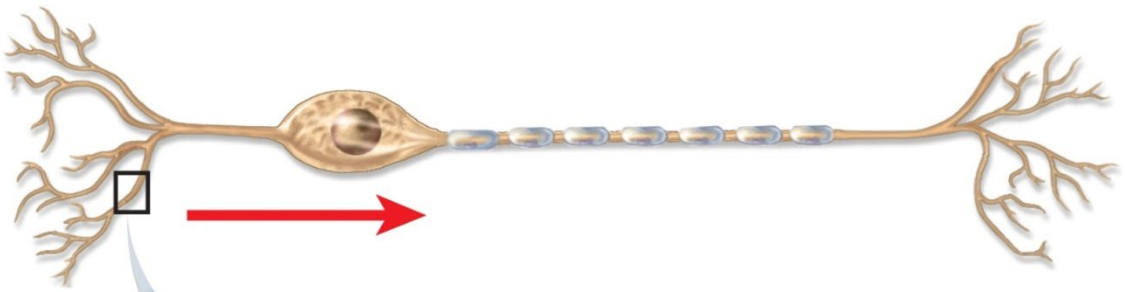
Tracing oxygen consumption, the brain accounts for about 20% of the body's energy consumption, despite representing 2 percent of its weight

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 or receptor 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 in to 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 ★

Local potentials behave differently than action potentials:

–Reversible

•when stimulation ceases flow of Na stops

•then K^+ diffusion out of cell // returns the cell to its normal resting potential

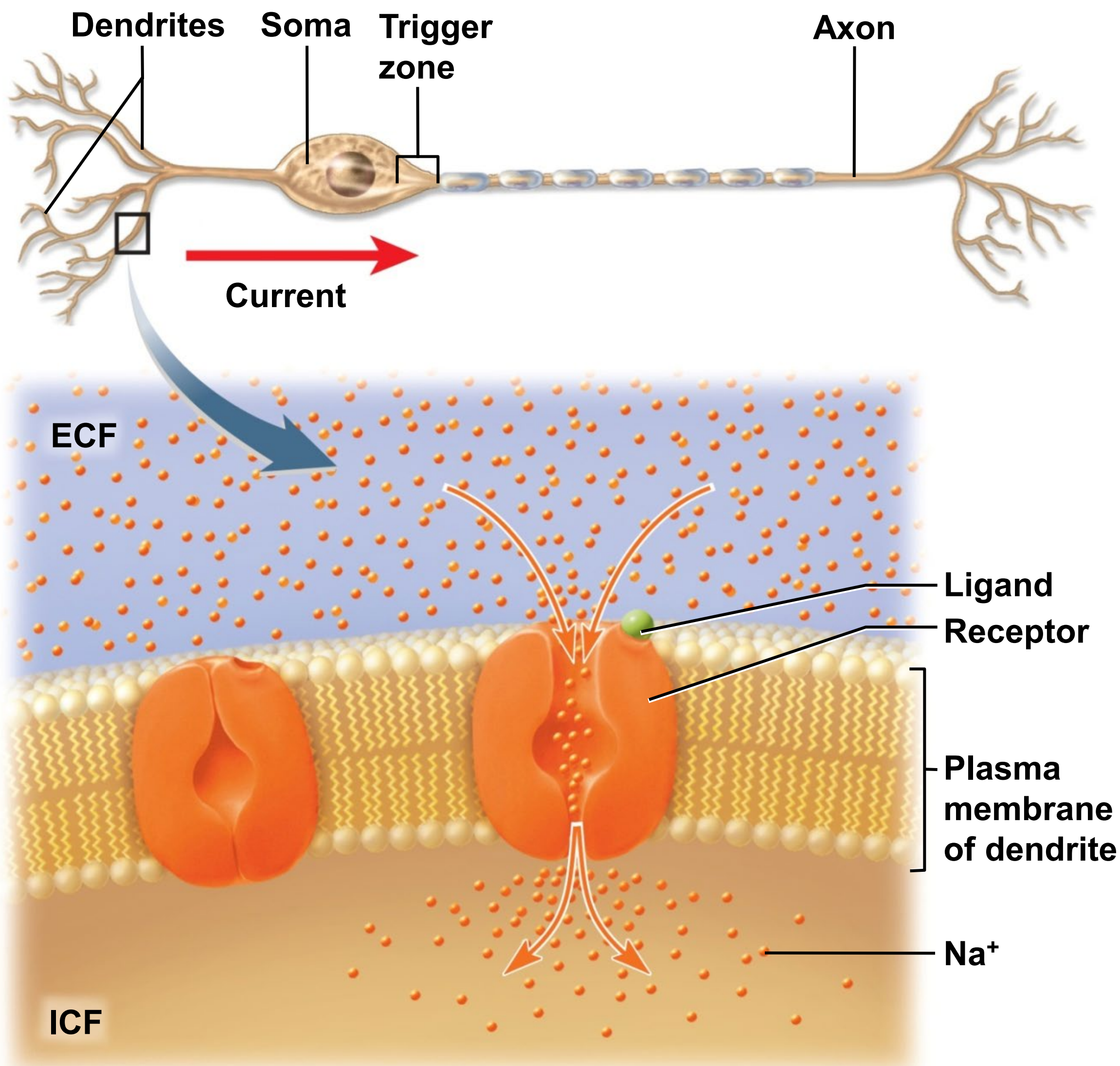
–A stimulus maybe either excitatory or **inhibitory**

•the neurotransmitter glycine make the membrane potential more negative (inhibitory)

•A hyperpolarize membrane // less likely to produce an action potential

•glutamate makes the membrane potential more positive (excitatory)

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

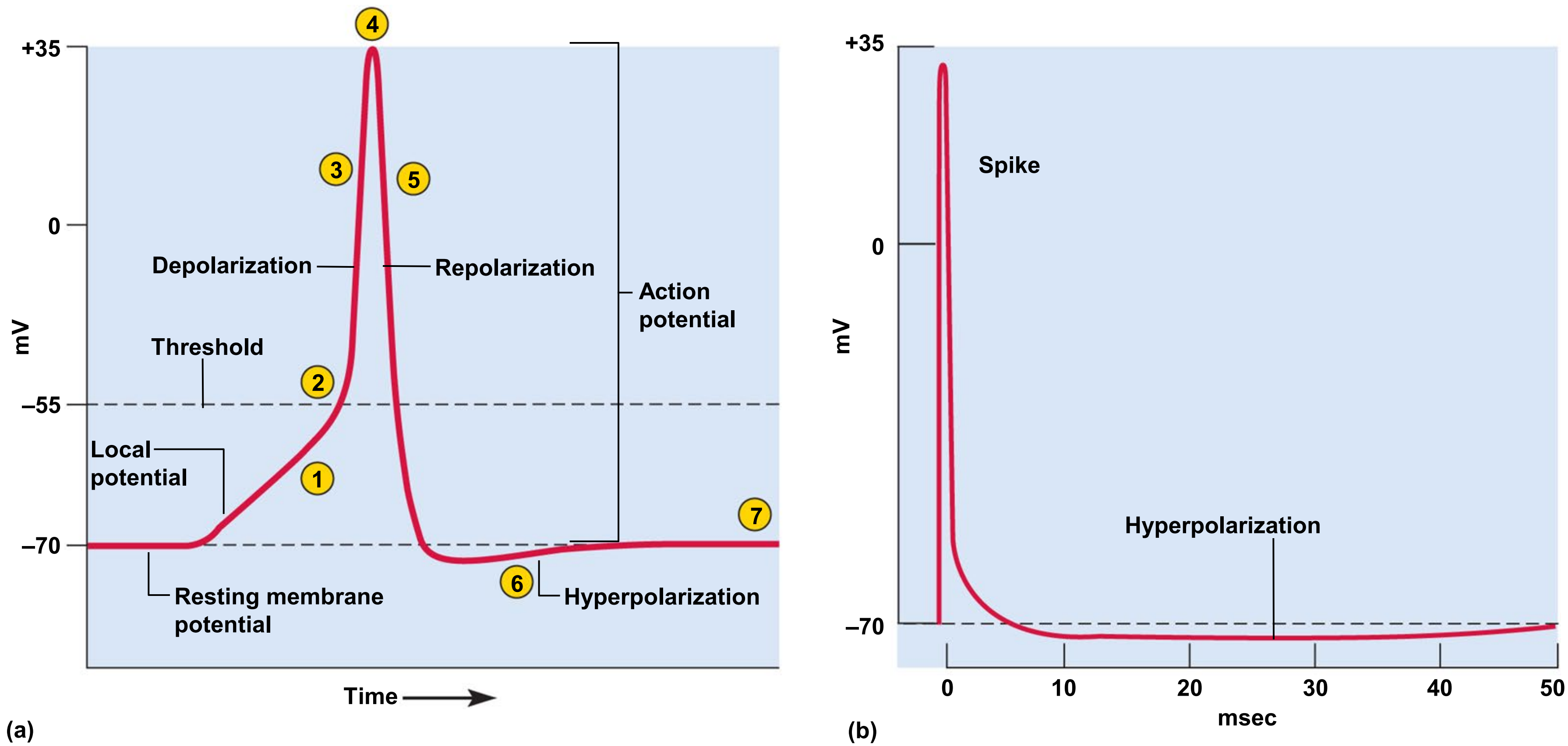
Action Potentials

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

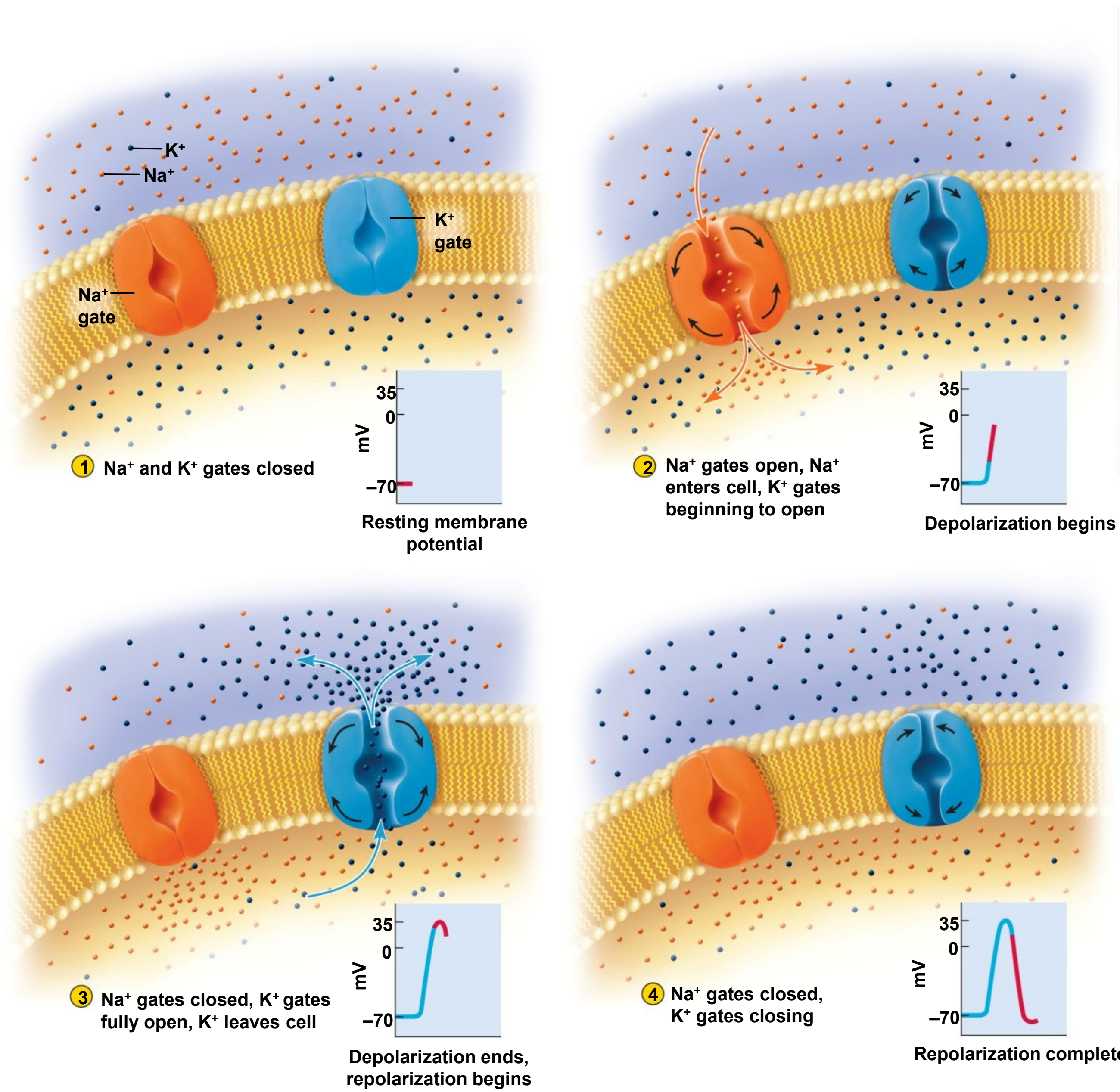
Action Potential

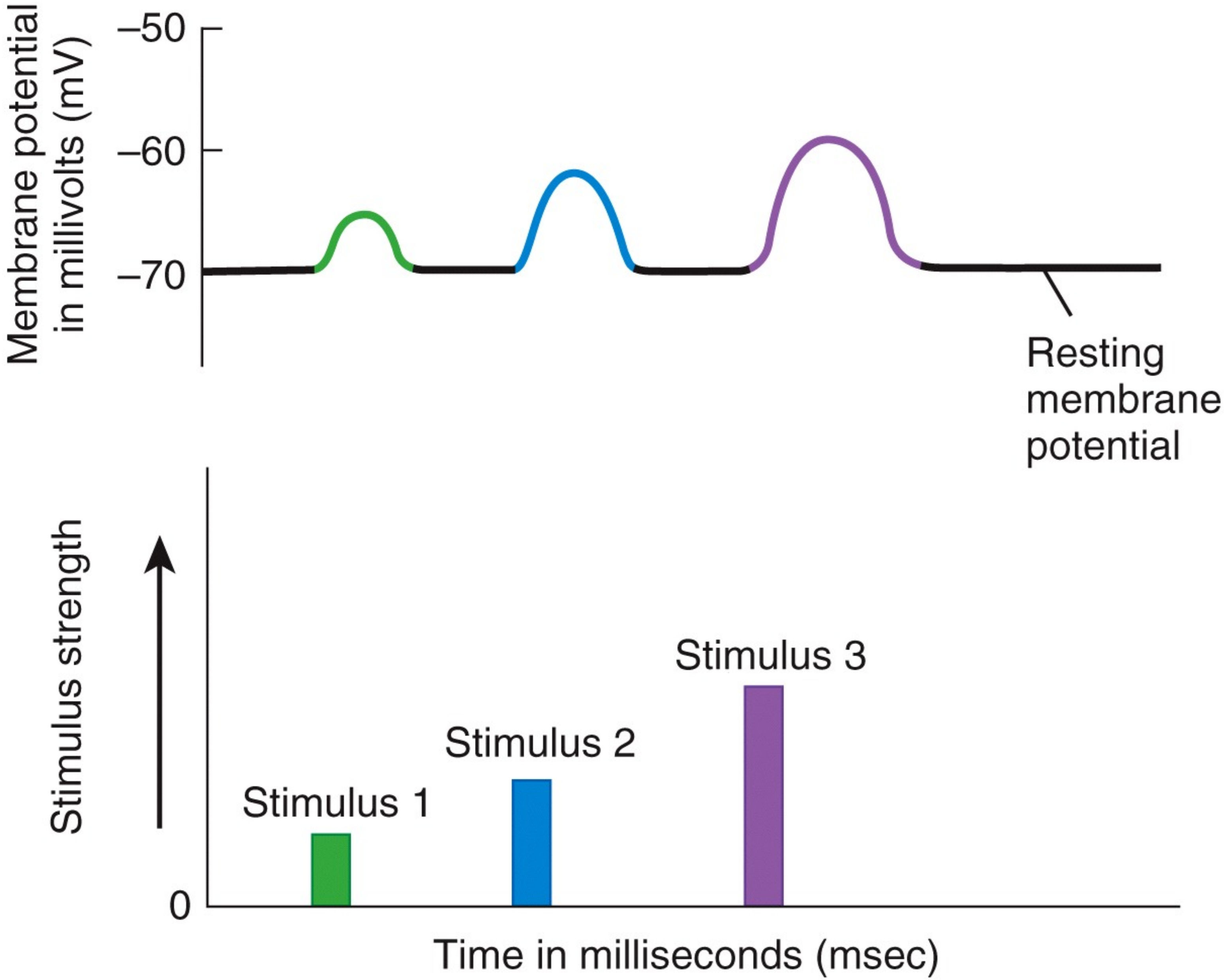


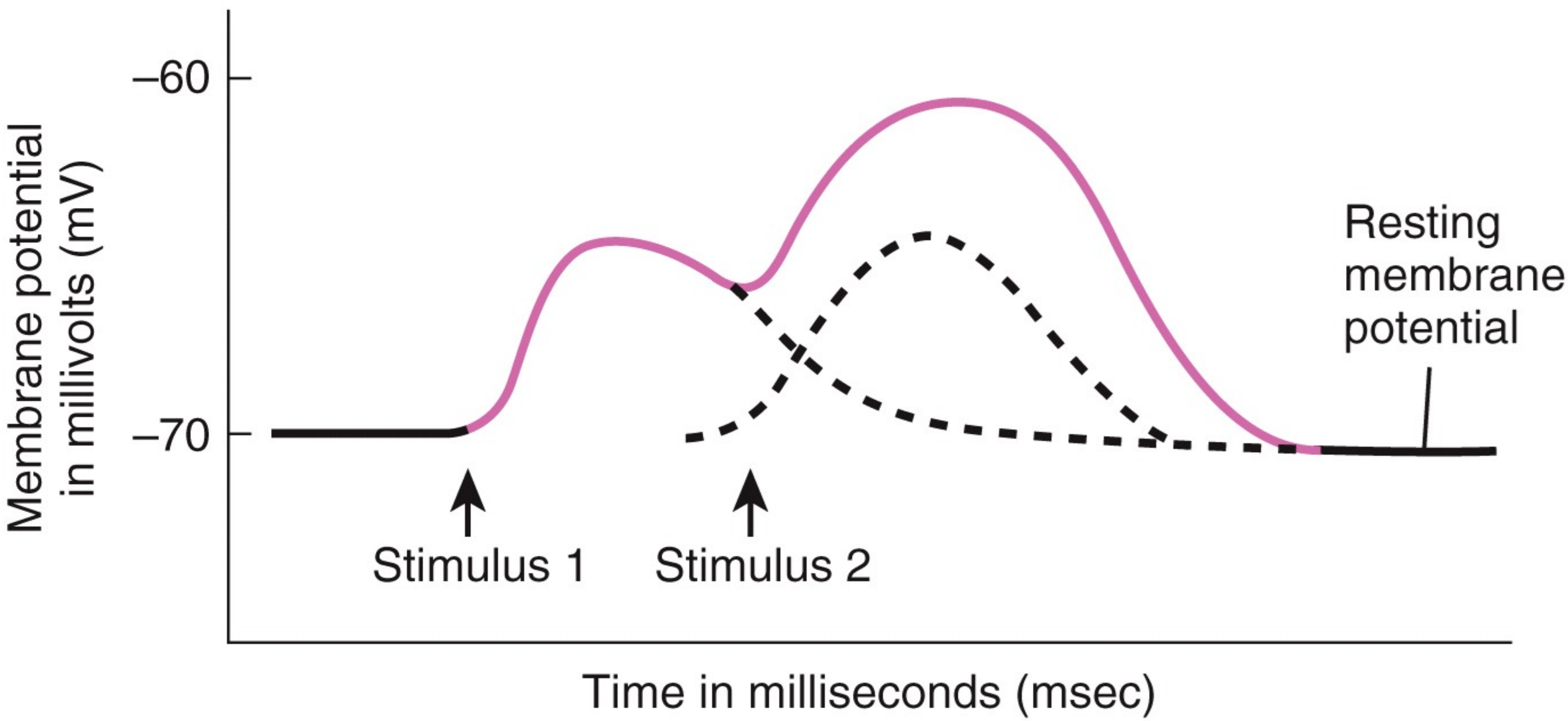
Action potential occurs so fast it is often referred to as a “spike”

There are four test questions here!

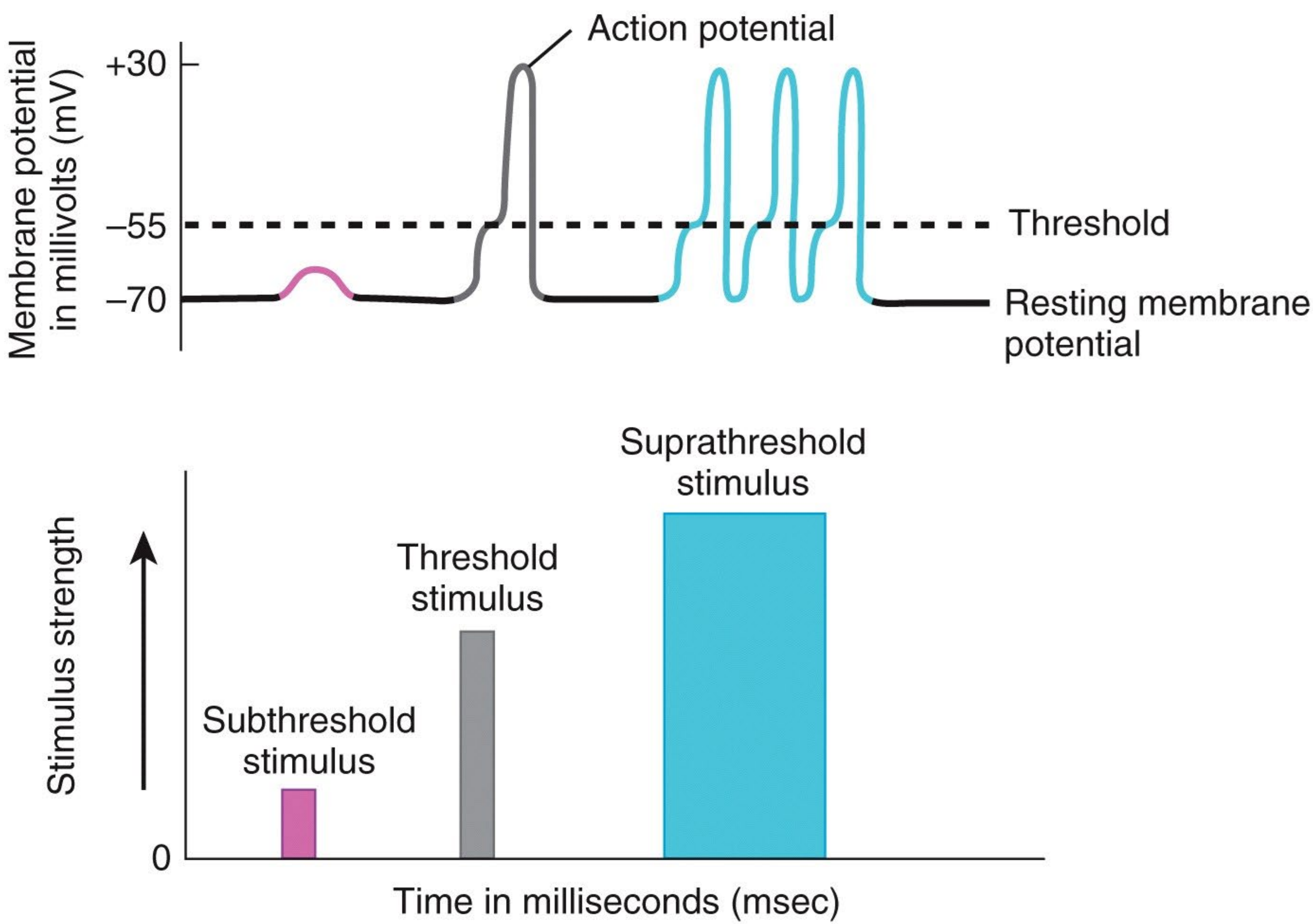
Sodium and Potassium Gates Function During Action Potential



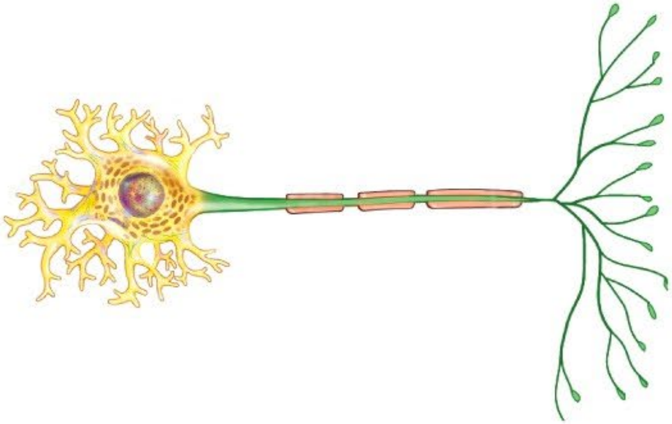

Membrane potential in millivolts (mV)
–50
–60
–70
Resting membrane potential
Stimulus strength
0
Stimulus 1
Stimulus 2
Stimulus 3
Time in milliseconds (msec)

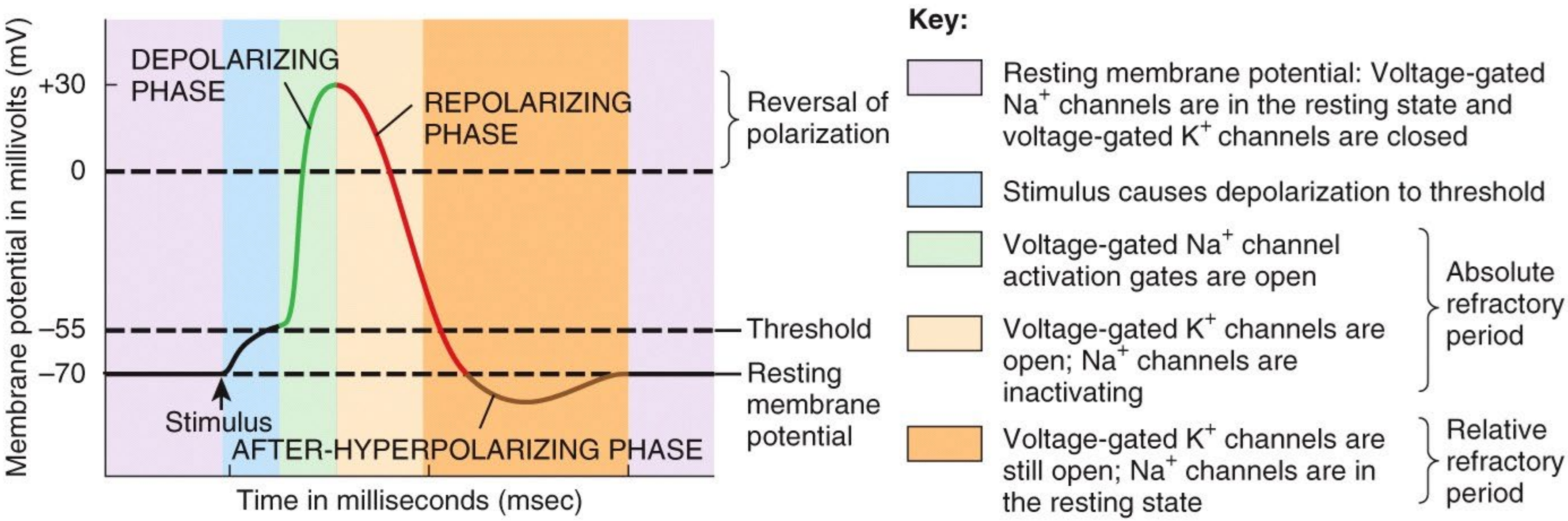


Membrane potential in millivolts (mV)
–60
–70
Resting membrane potential
Stimulus 1
Stimulus 2
Time in milliseconds (msec)

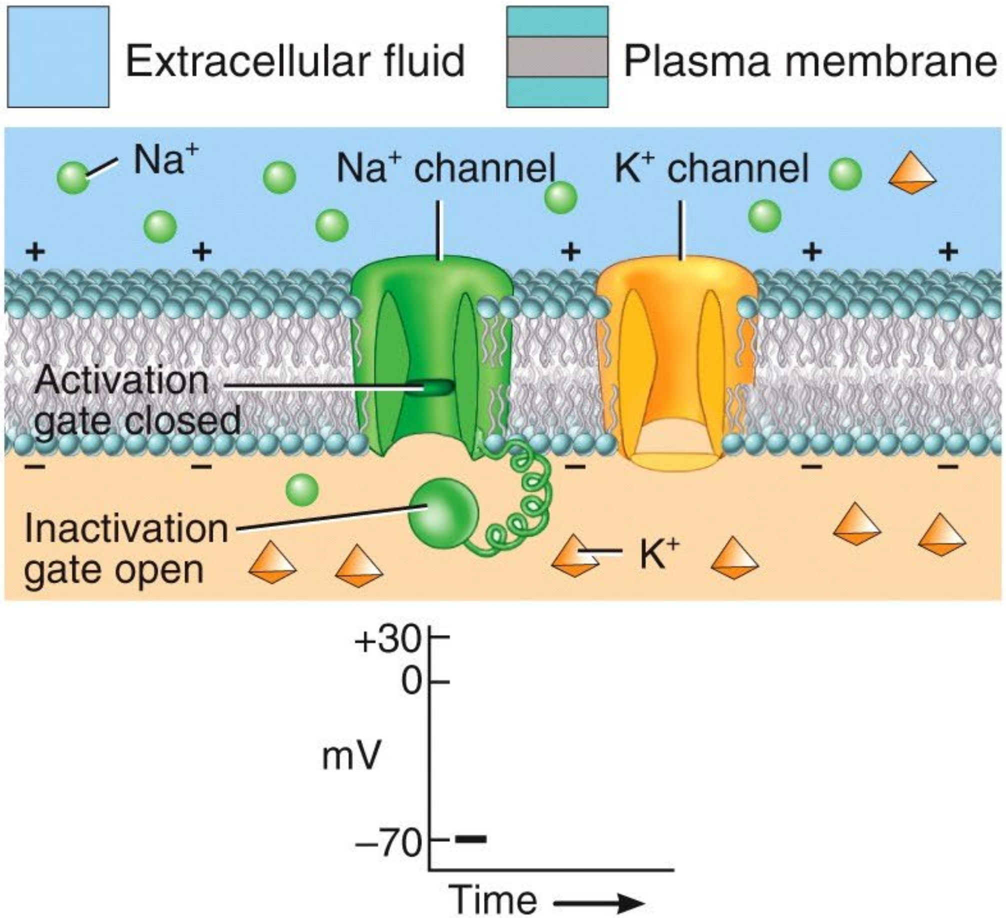


Action potential
Membrane potential in millivolts (mV)
+30
–55
–70
Threshold
Resting membrane potential
Suprathreshold stimulus
Threshold stimulus
Subthreshold stimulus
Stimulus strength
0
Time in milliseconds (msec)

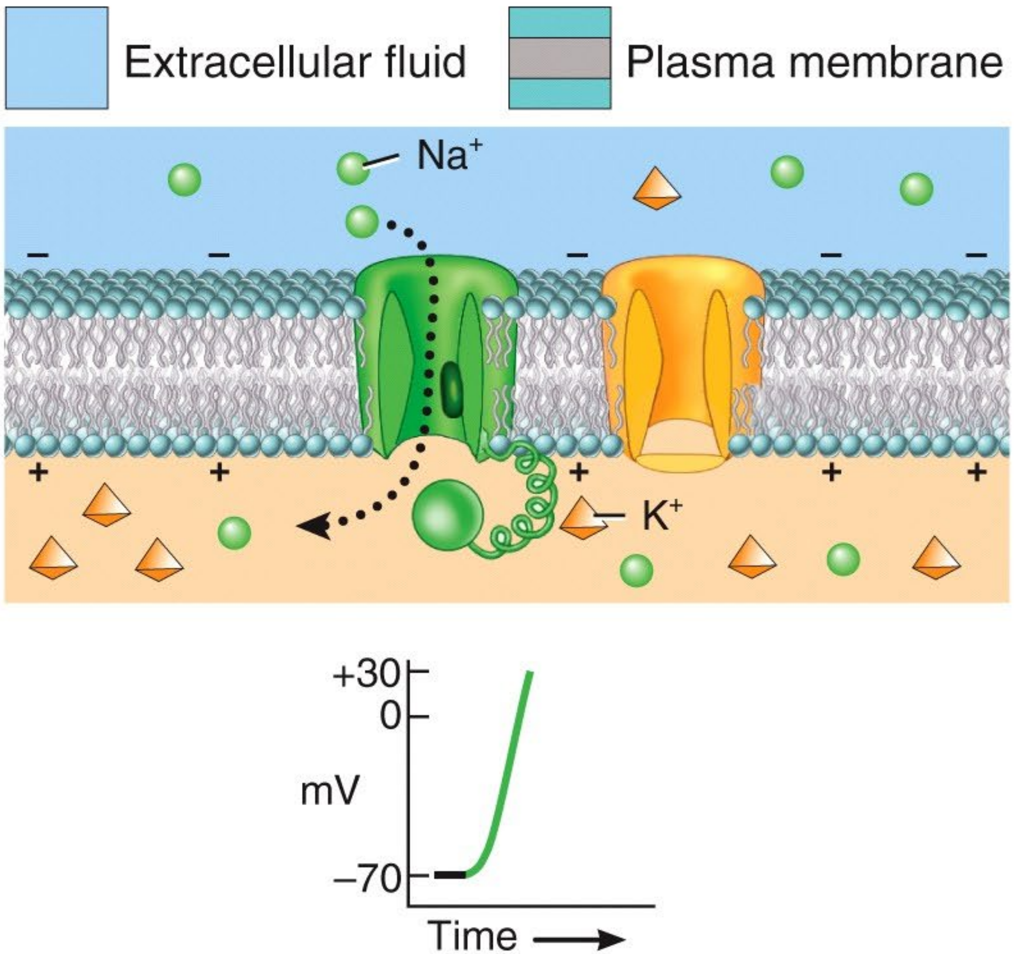




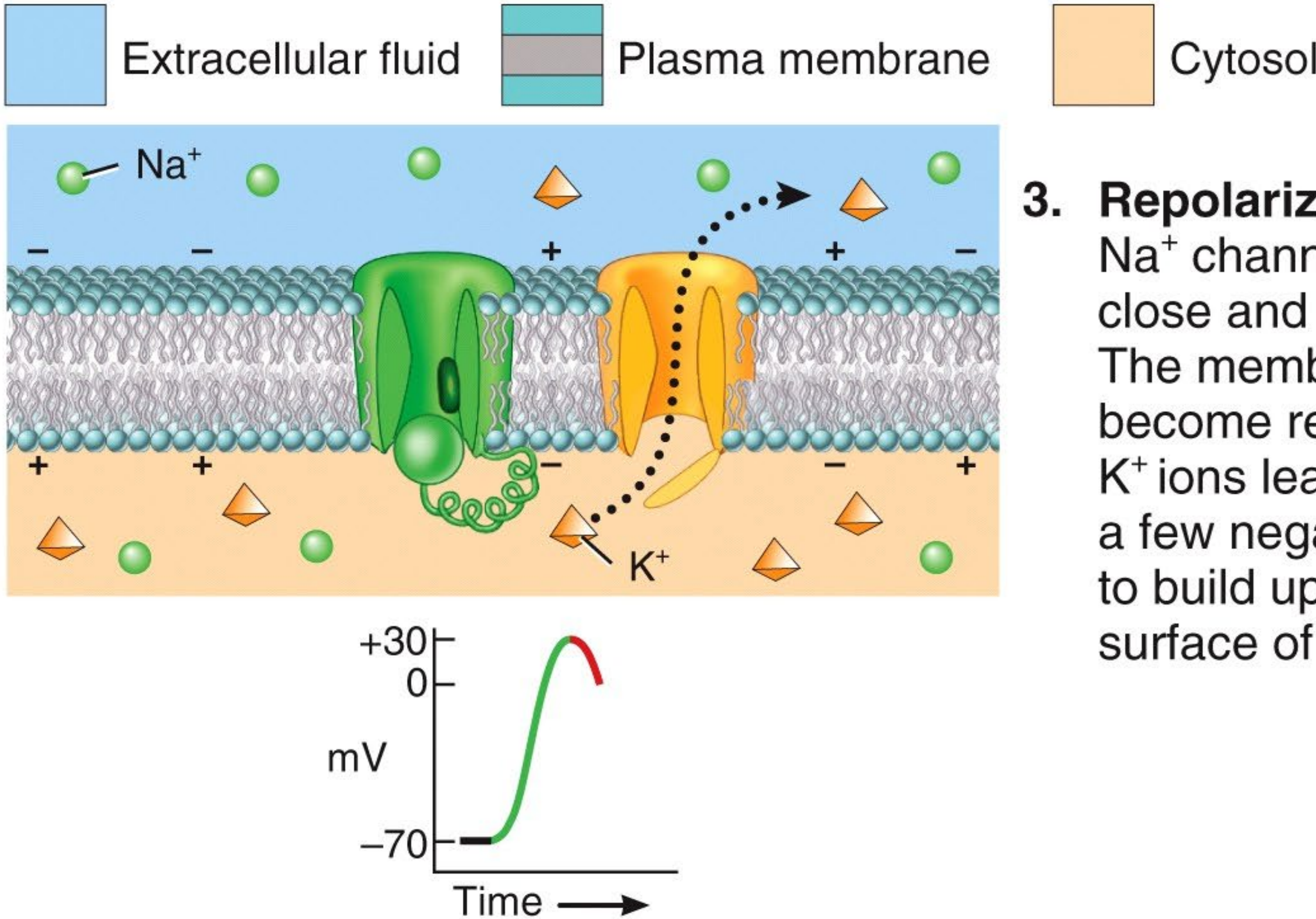
Four Phases: Resting – Depolarization – Repolarization - Hyperpolarizing



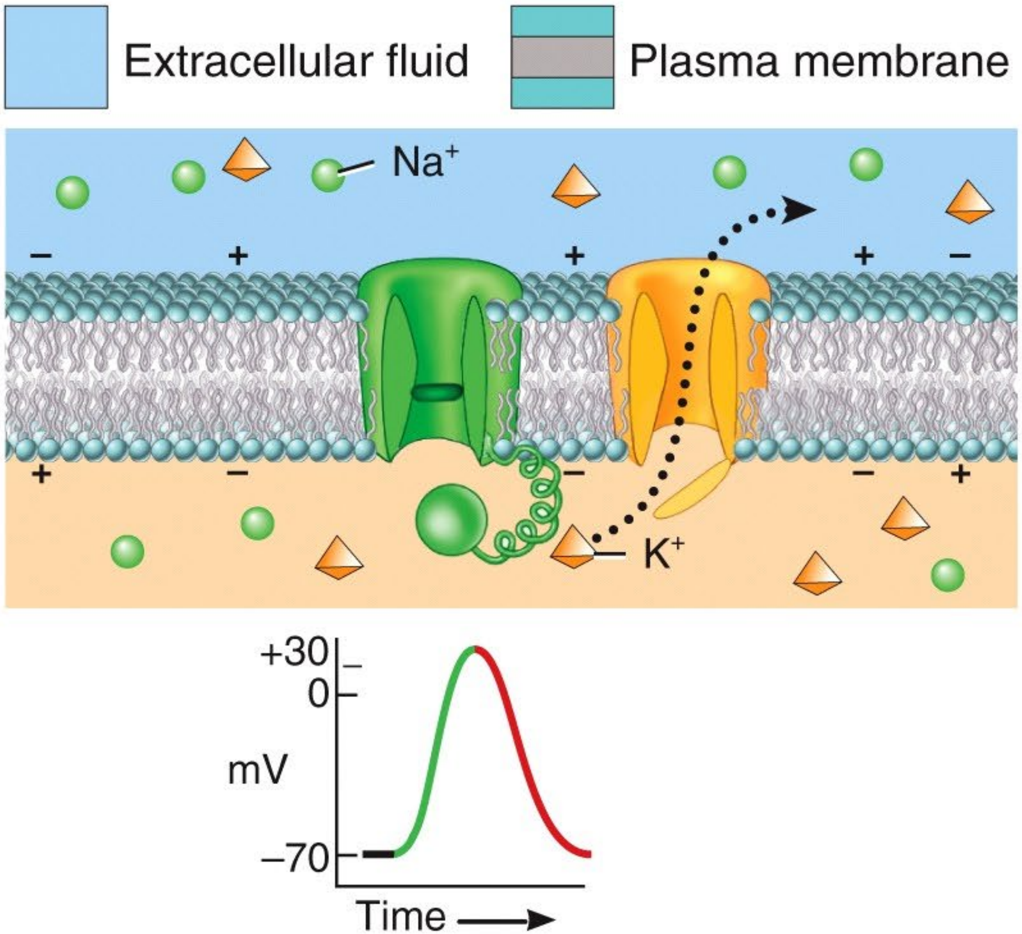
1. Resting state:
All voltage-gated Na^+ and K^+ channels are closed. The axon plasma membrane is at resting membrane potential: small buildup of negative charges along inside surface of membrane and an equal buildup of positive charges along outside surface of membrane.



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:

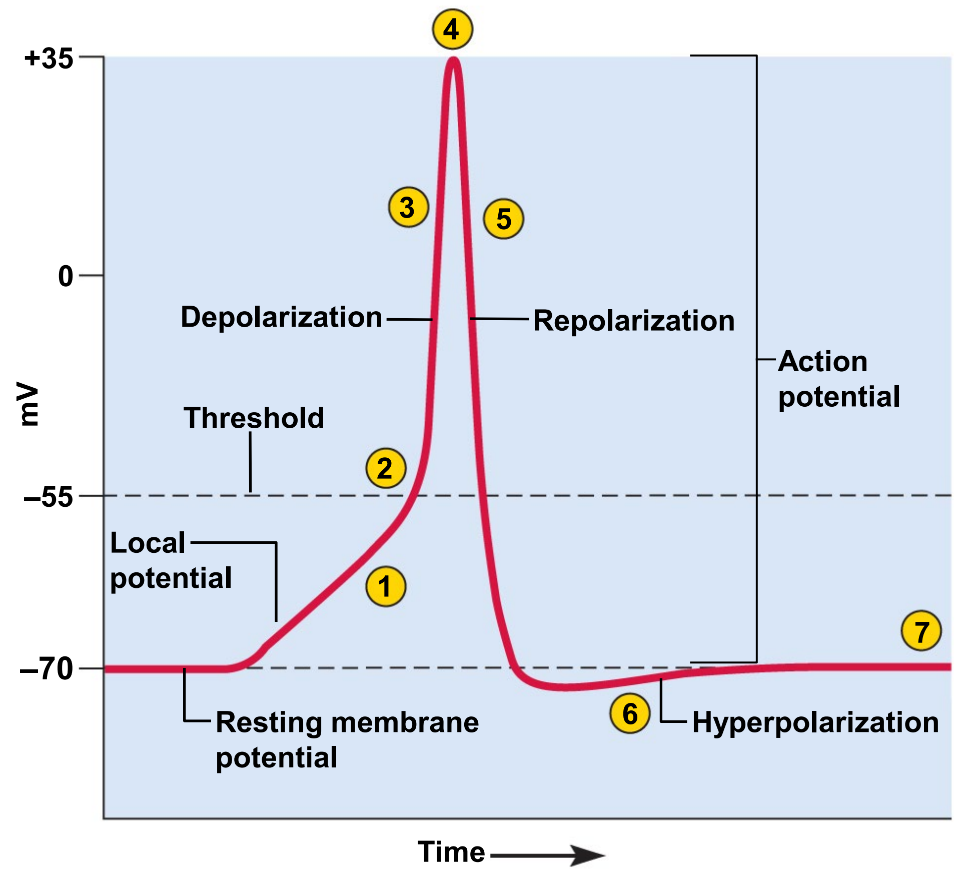
K^+ outflow continues. As more K^+ ions leave the neuron, more negative charges build up along inside surface of membrane. K^+ outflow eventually restores resting membrane potential. Na^+ channel activation gates close and inactivation gates open. Return to resting state when K^+ gates close.

Action Potentials

only a thin layer of the cytoplasm next to the cell membrane is affected /// very few ions are involved

action potential is often called a **spike**

called spike because AP happens so fast



Action Potential Characteristics

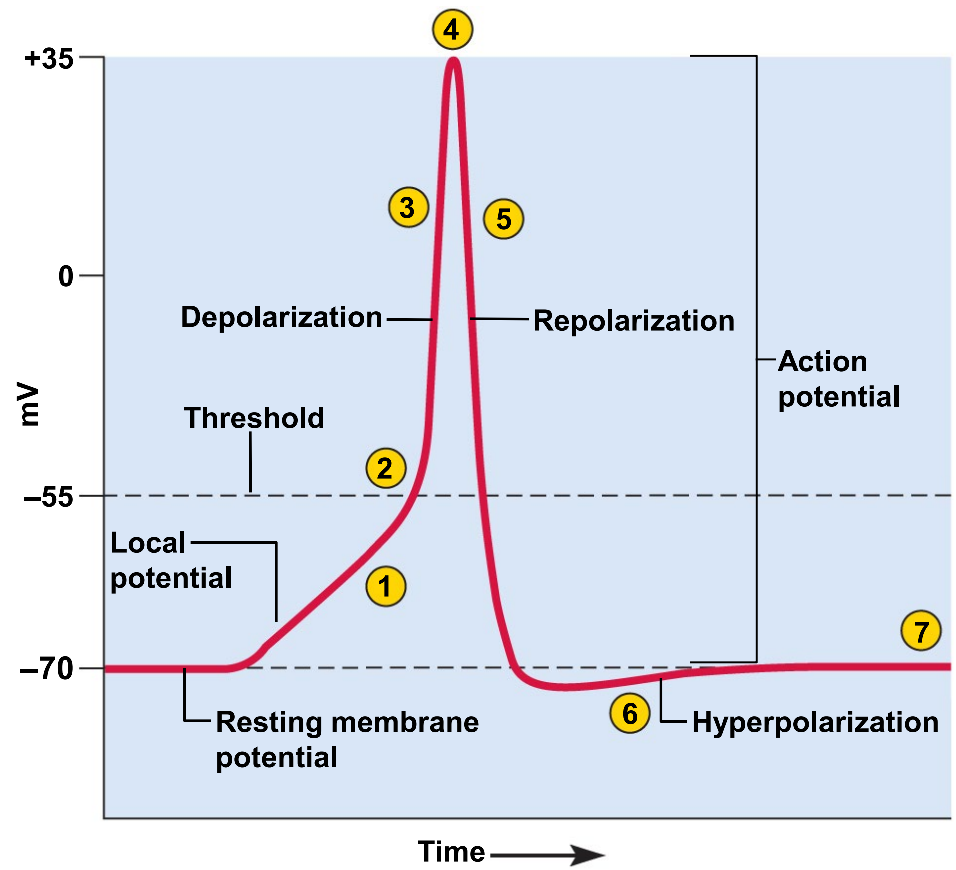
characteristics of action potential (event in axon) versus a local potential (event in dendrite/soma)

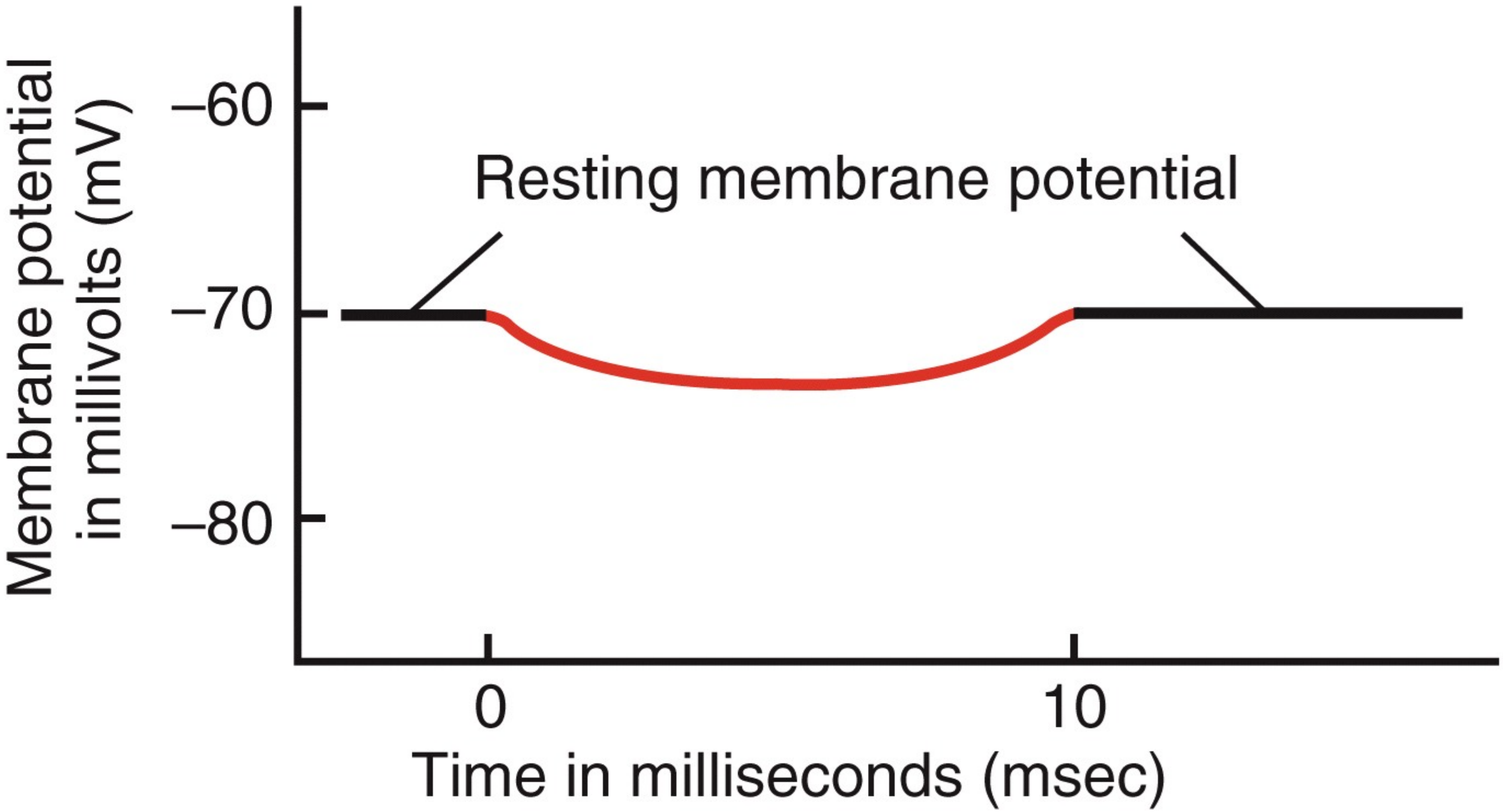
**all-or-none law // ** if threshold is reached, neuron fires at its maximum voltage

if threshold is not reached it does not fire

non-decremental - does not become weaker with distance

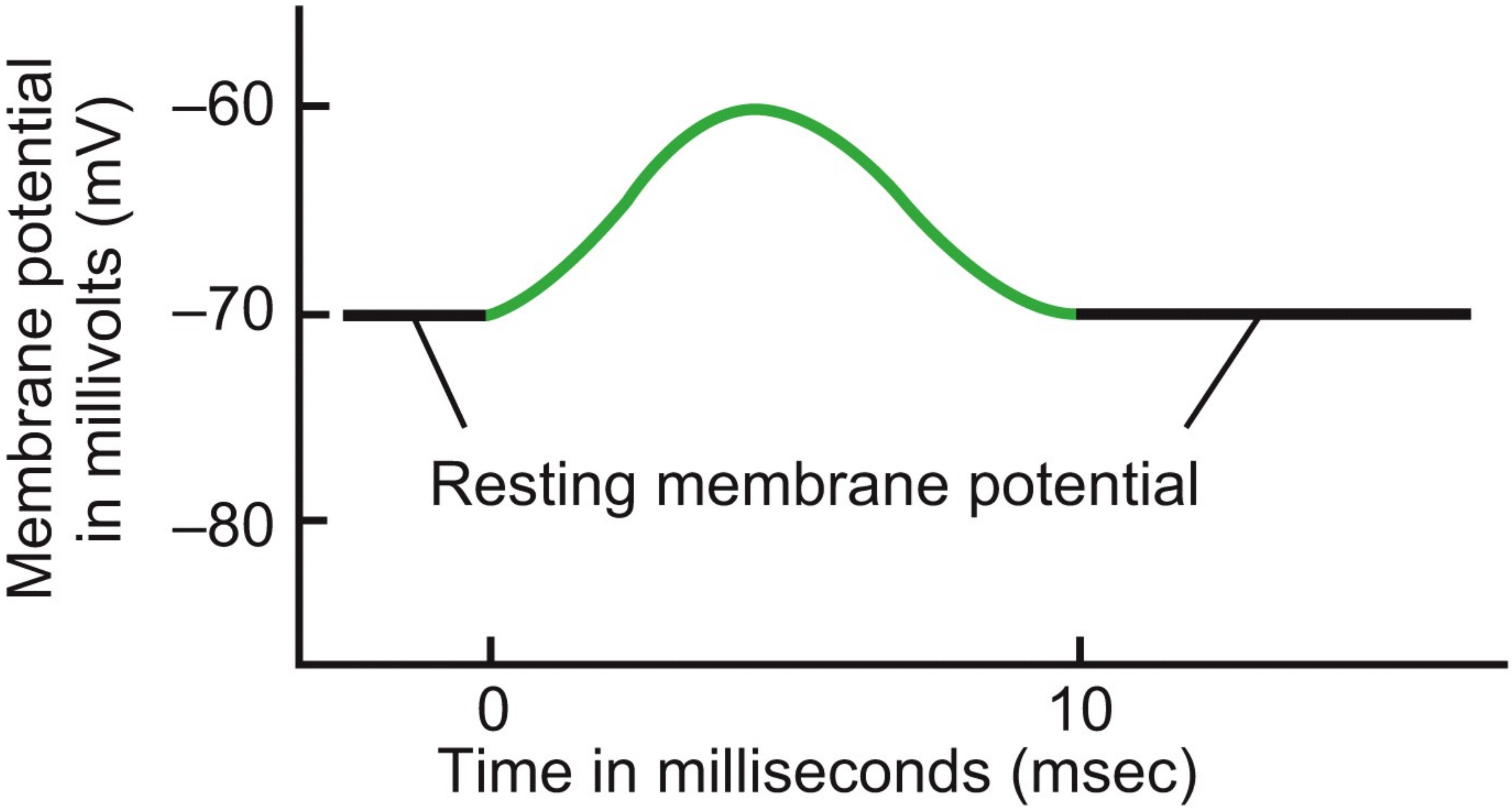
irreversible - once started goes to completion and can not be stopped





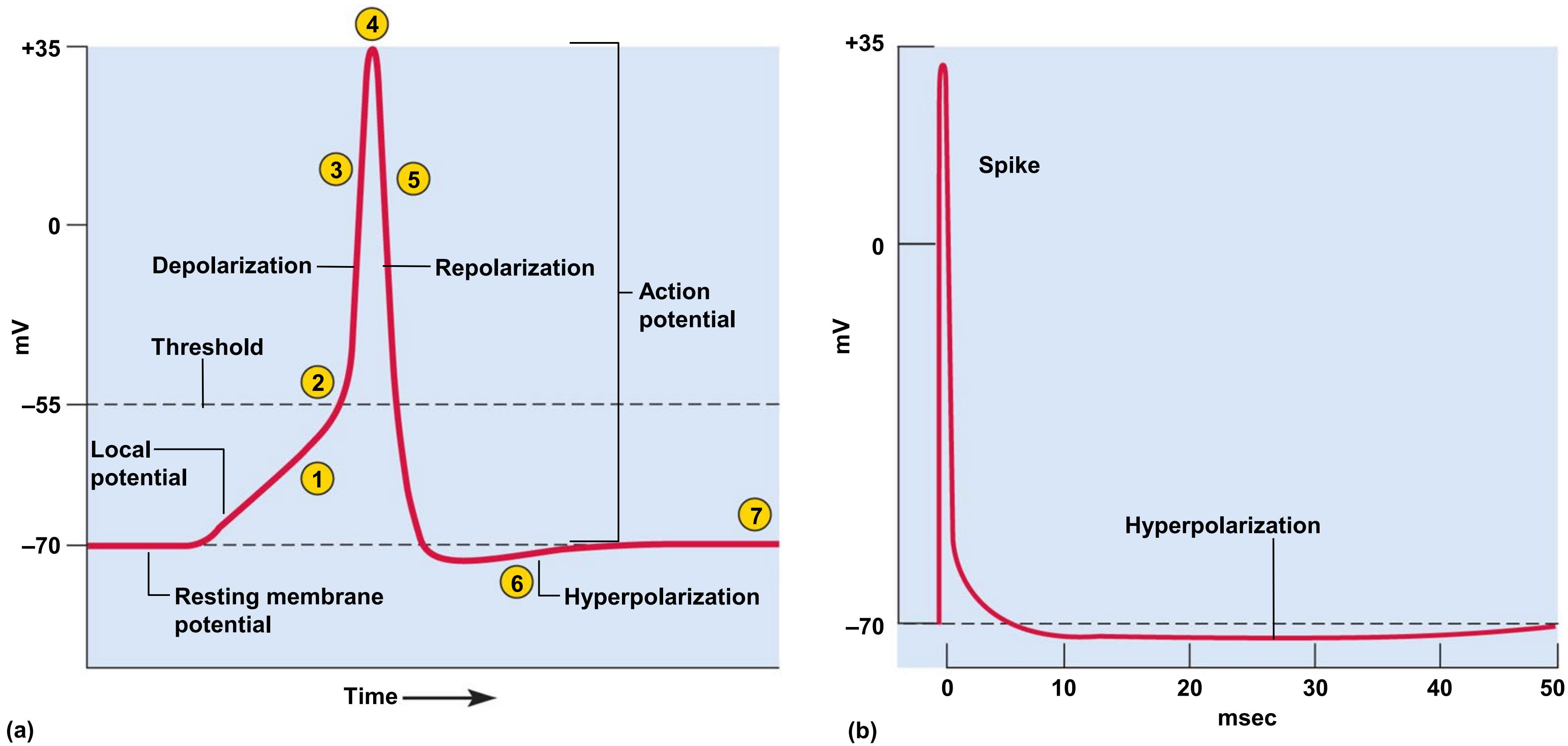
(a) Hyperpolarizing graded potential

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



(b) Depolarizing graded potential

Action Potential



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.

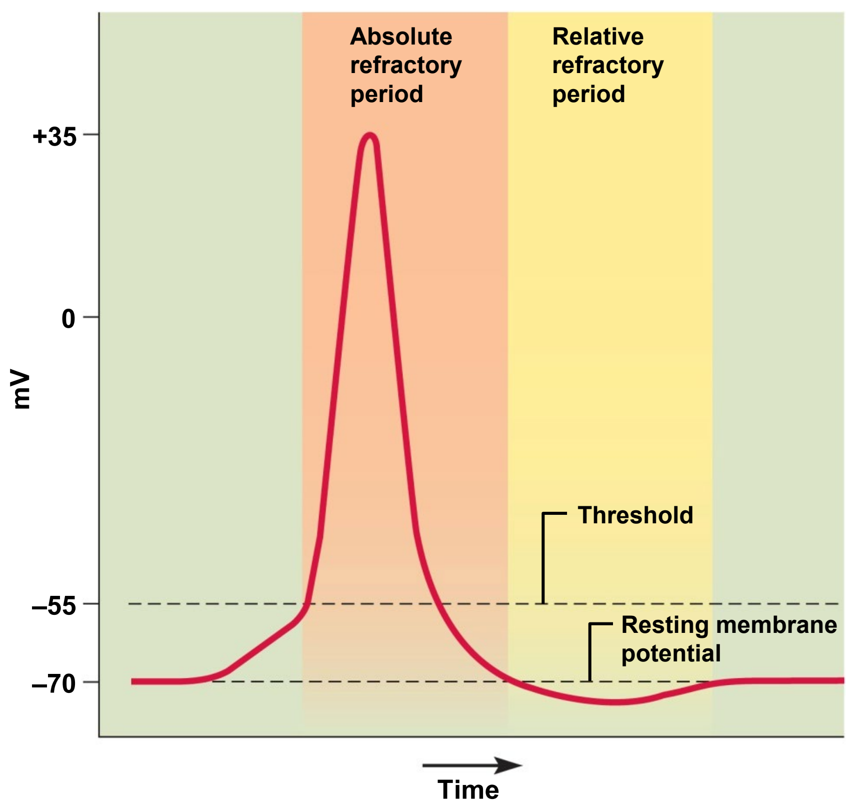
•two phases of the refractory period

Absolute refractory period

•no stimulus of any strength will trigger AP

•as long as Na^+ gates are open

•from action potential to RMP



The Refractory Period

Two phases of the refractory period

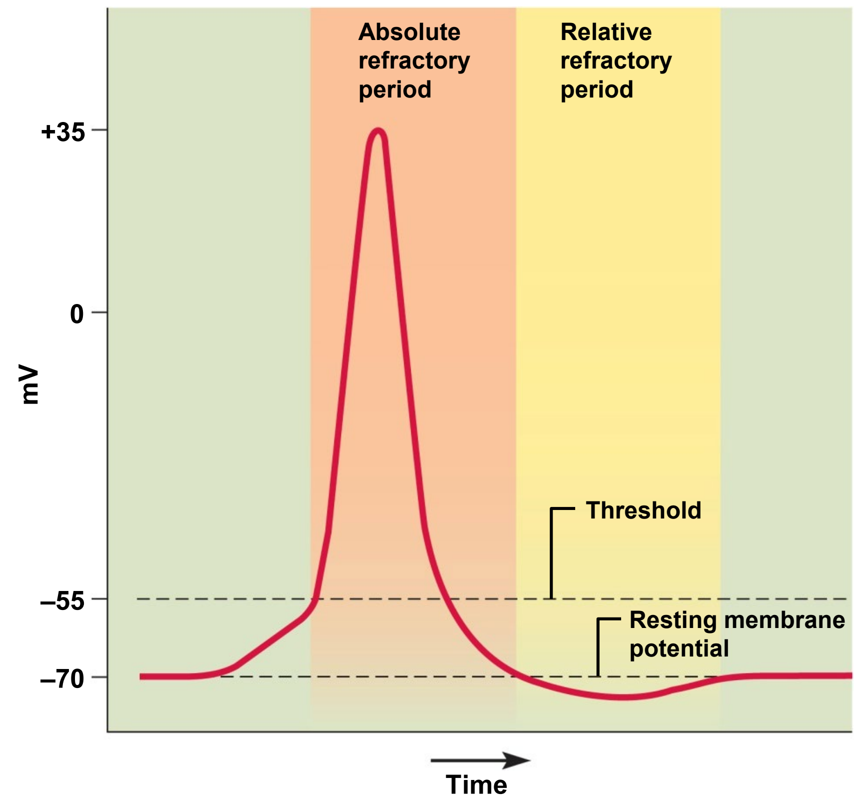
–relative refractory period

•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

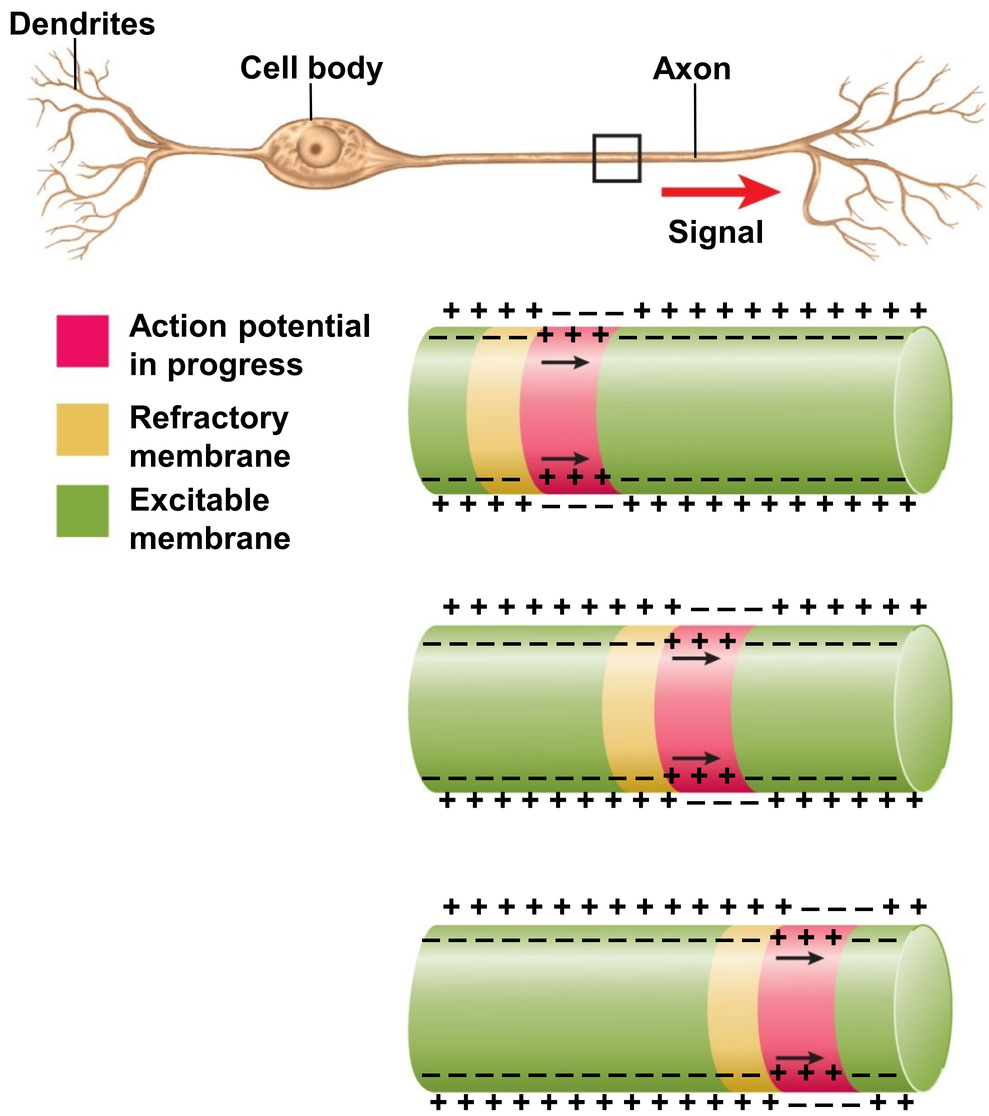


Signal Conduction in Un-myelinated Fibers

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



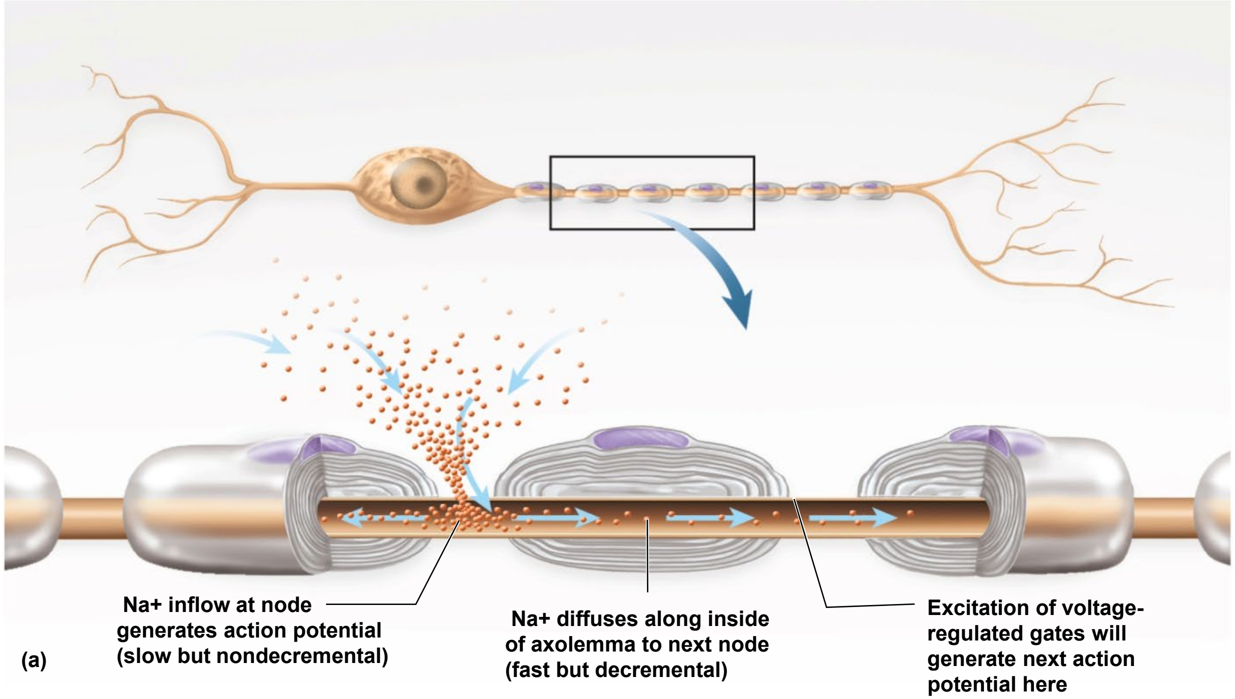
Saltatory Conduction in Myelinated Axons

•voltage-gated channels needed for AP

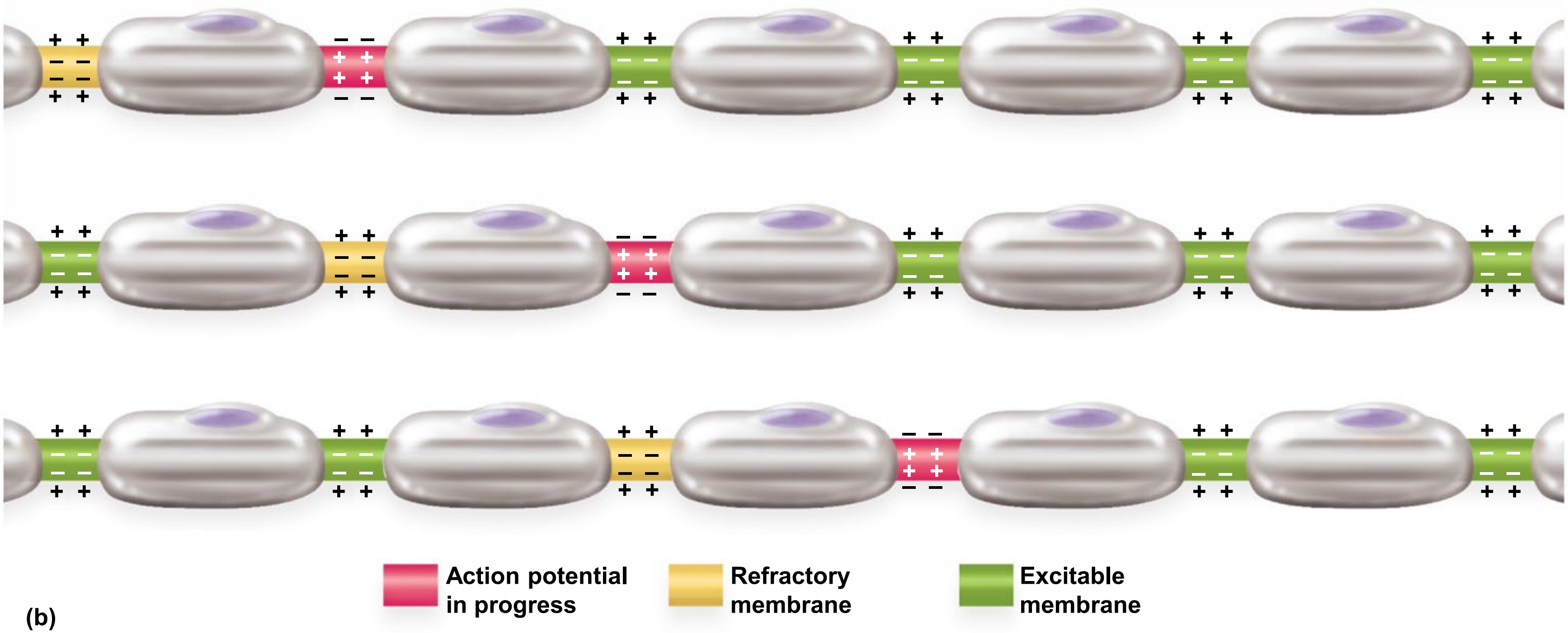
–fewer than 25 per μm^2 in myelin-covered regions (internodes)
–up to 12,000 per μm^2 in nodes of Ranvier

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

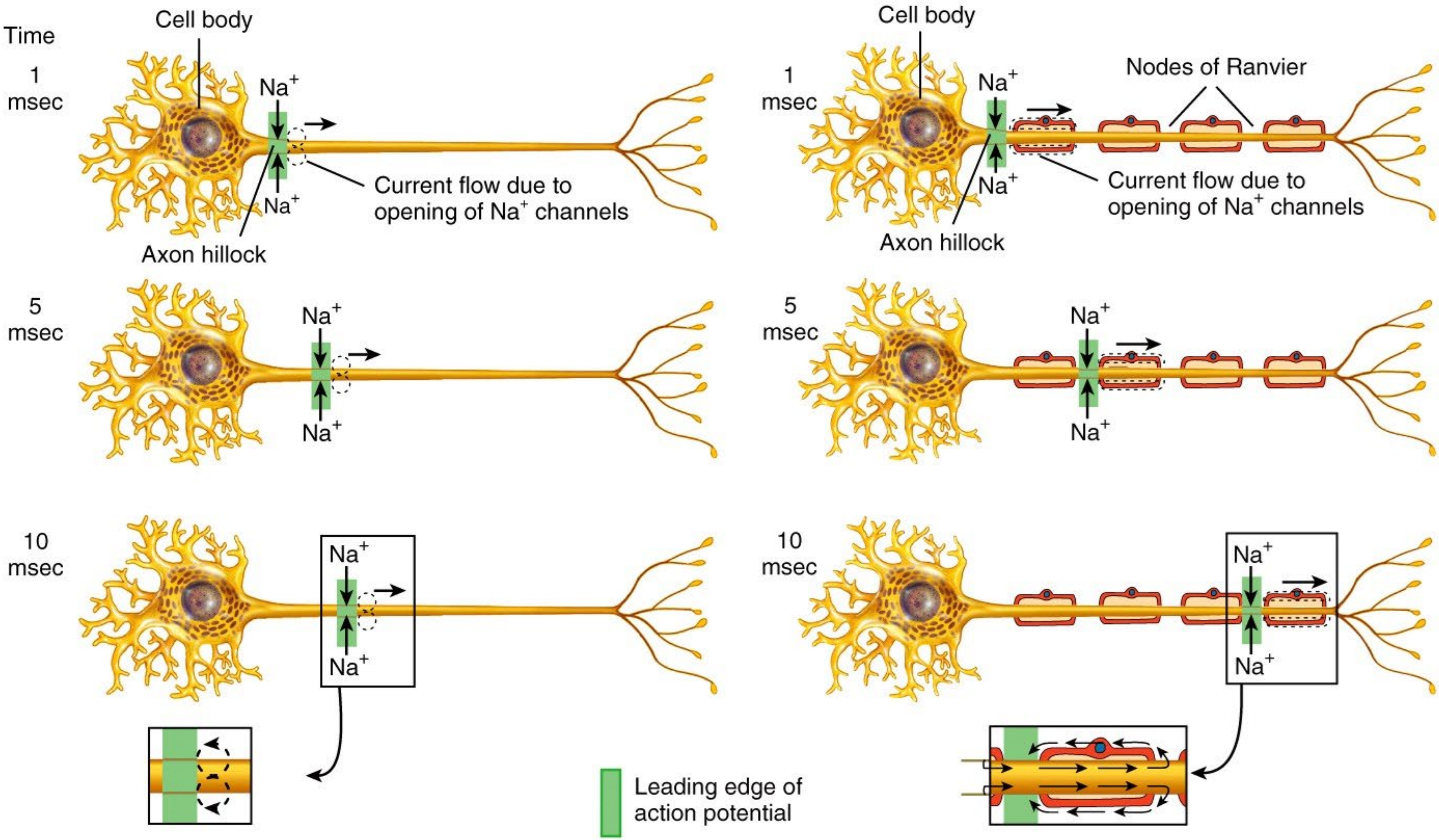
•saltatory conduction – the nerve signal seems to jump from node to node // faster than in unmyelinated axons



Saltatory Conduction

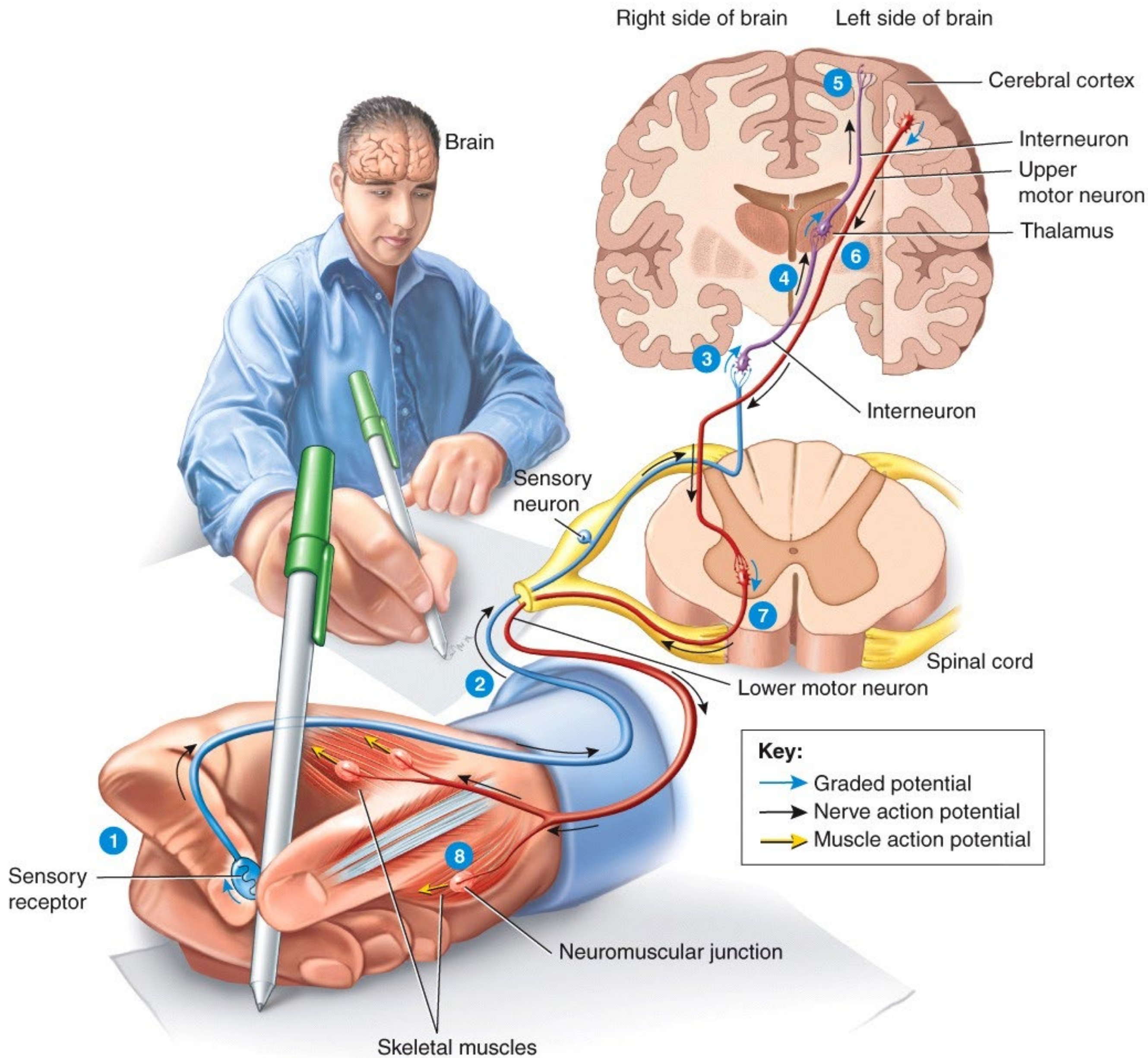


Faster than the conduction speed in an unmyelinated axons



(a) Continuous conduction

(b) Saltatory conduction


Right side of brain
Left side of brain
Cerebral cortex
Brain
Interneuron
Upper
motor neuron
Thalamus
Interneuron
Sensory
neuron
Spinal cord
Lower motor neuron
Key:
Graded potential
Nerve action potential
Muscle action potential
Sensory
receptor
Neuromuscular junction
Skeletal muscles
1
2
3
4
5
6
7
8