Physiology 1 for pharmacy students

Graded potential and action potential

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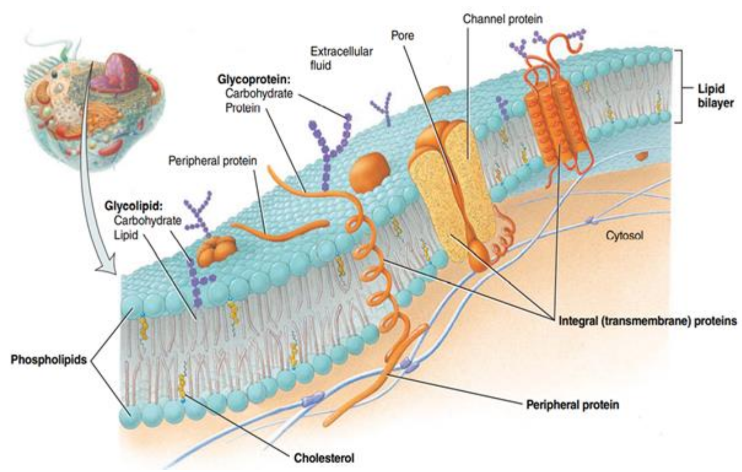


Polarization

- In neurons, the resting membrane potential ranges from −40 to −90 mV. A typical value is −70 mV. The minus sign indicates that the inside of the cell is negative relative to the outside.

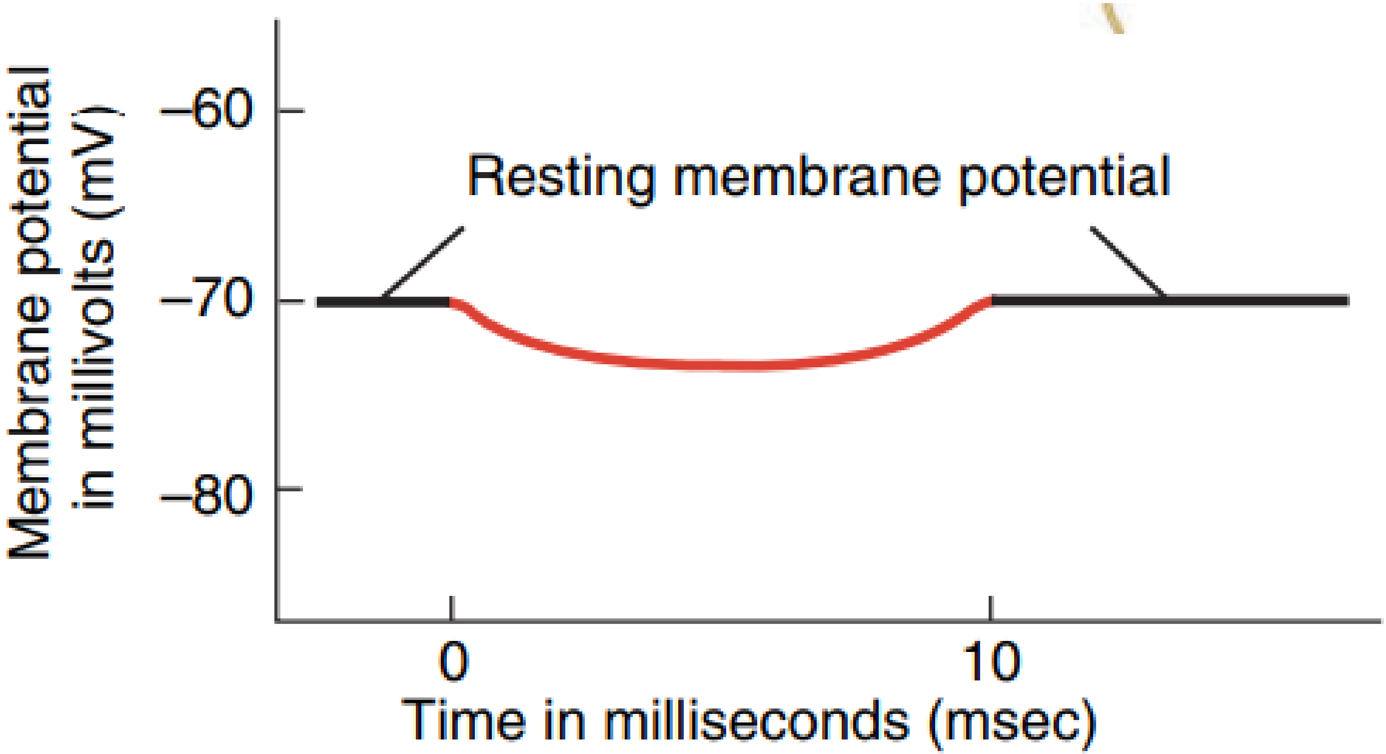
- A cell that exhibits a membrane potential is said to be **polarized.** Most body cells are polarized; the membrane potential varies from +5 mV to −100 mV in different types of cells.

Graded potential

- A small deviation from the resting membrane potential that makes the membrane either more polarized (inside more negative) or less polarized (inside less negative).

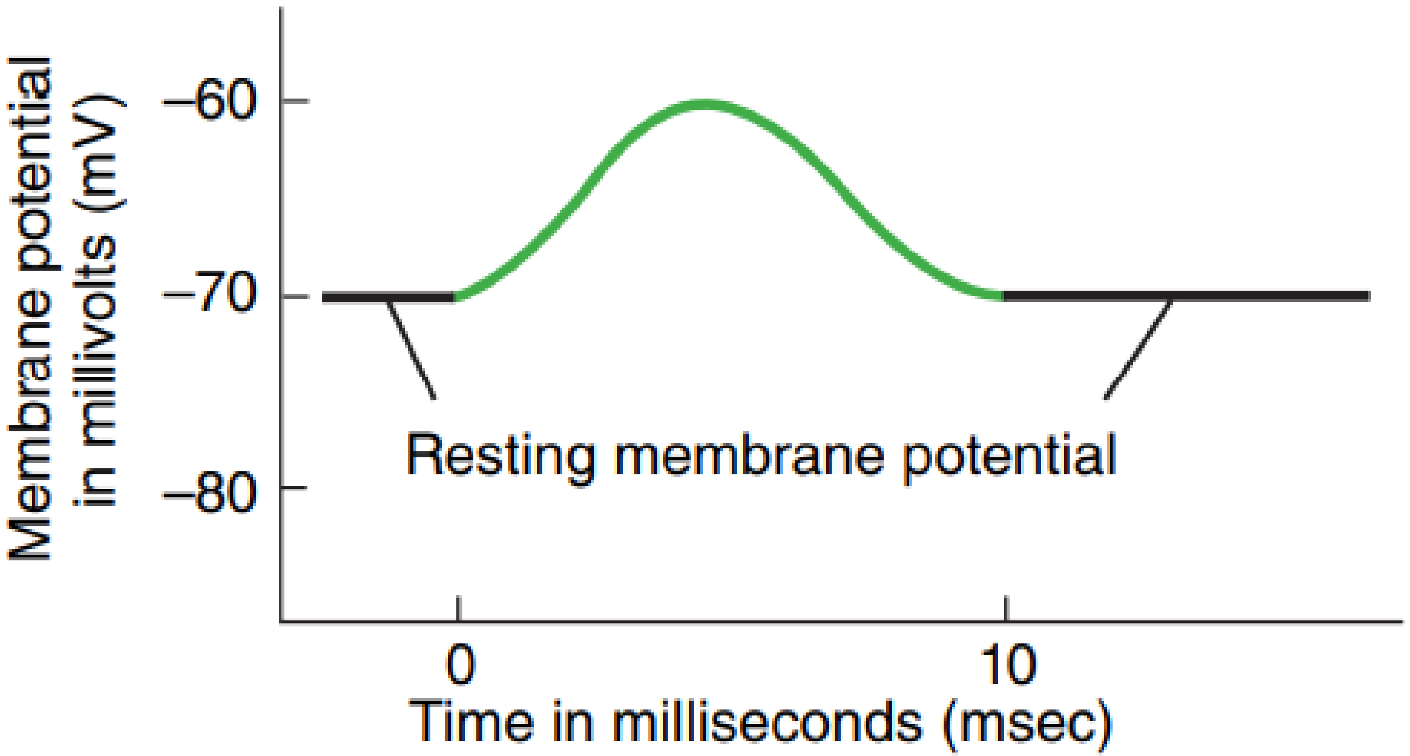
- When the response makes the membrane more polarized (inside more negative), it is termed a **hyperpolarizing** graded potential.
- When the response makes the membrane less polarized (inside less negative), it is termed a **depolarizing** graded potential.

Hyperpolarization



(a) Hyperpolarizing graded potential

Depolarization

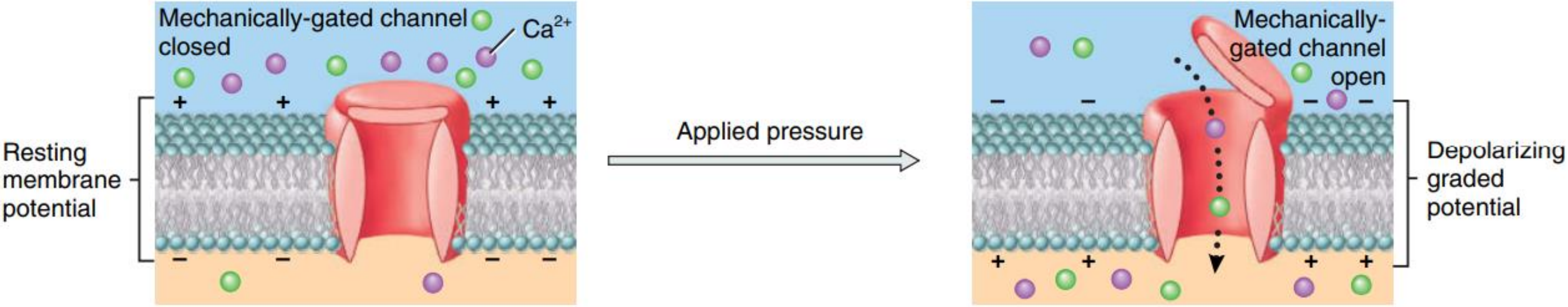


(b) Depolarizing graded potential

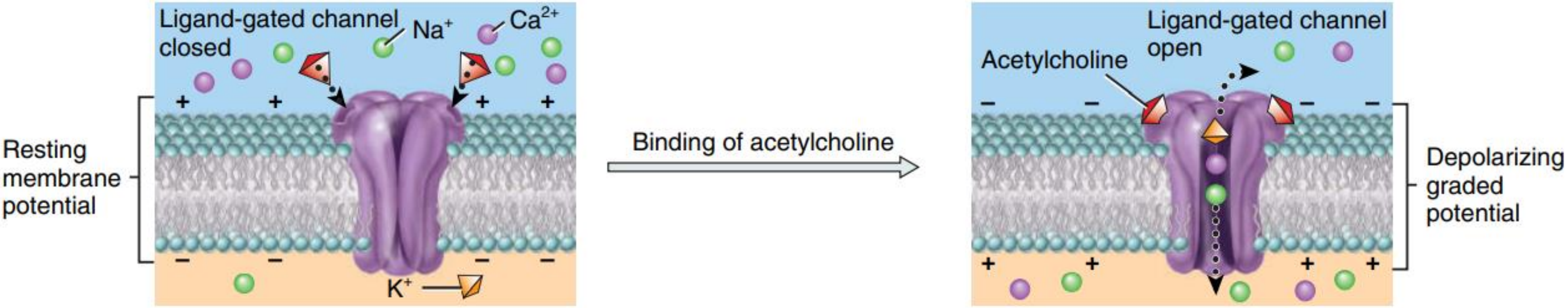
Graded potential

- A graded potential occurs when a stimulus causes **mechanically-gated or ligand-gated channels** to open or close in an excitable cell’s plasma membrane.

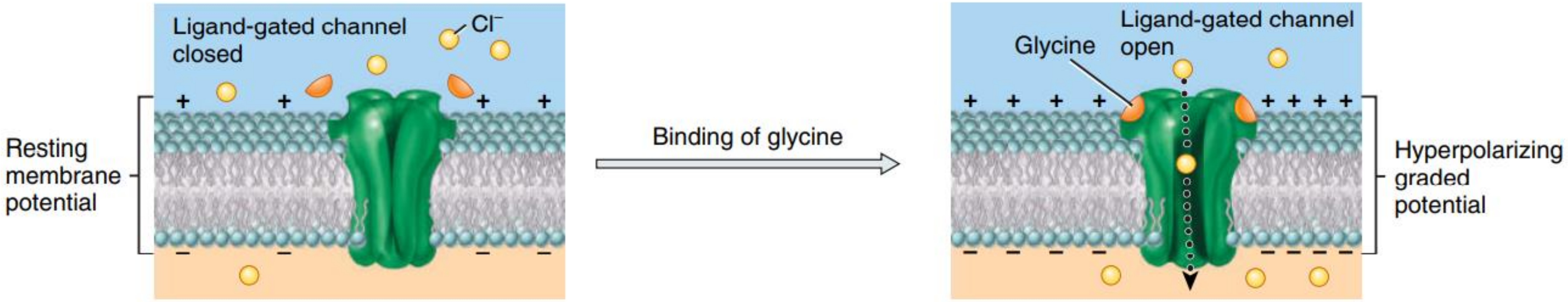
- To say that these electrical signals are graded means that they **vary in amplitude** (size), depending on the strength of the stimulus.



(a) Depolarizing graded potential caused by pressure, a mechanical stimulus



(b) Depolarizing graded potential caused by the neurotransmitter acetylcholine, a ligand stimulus

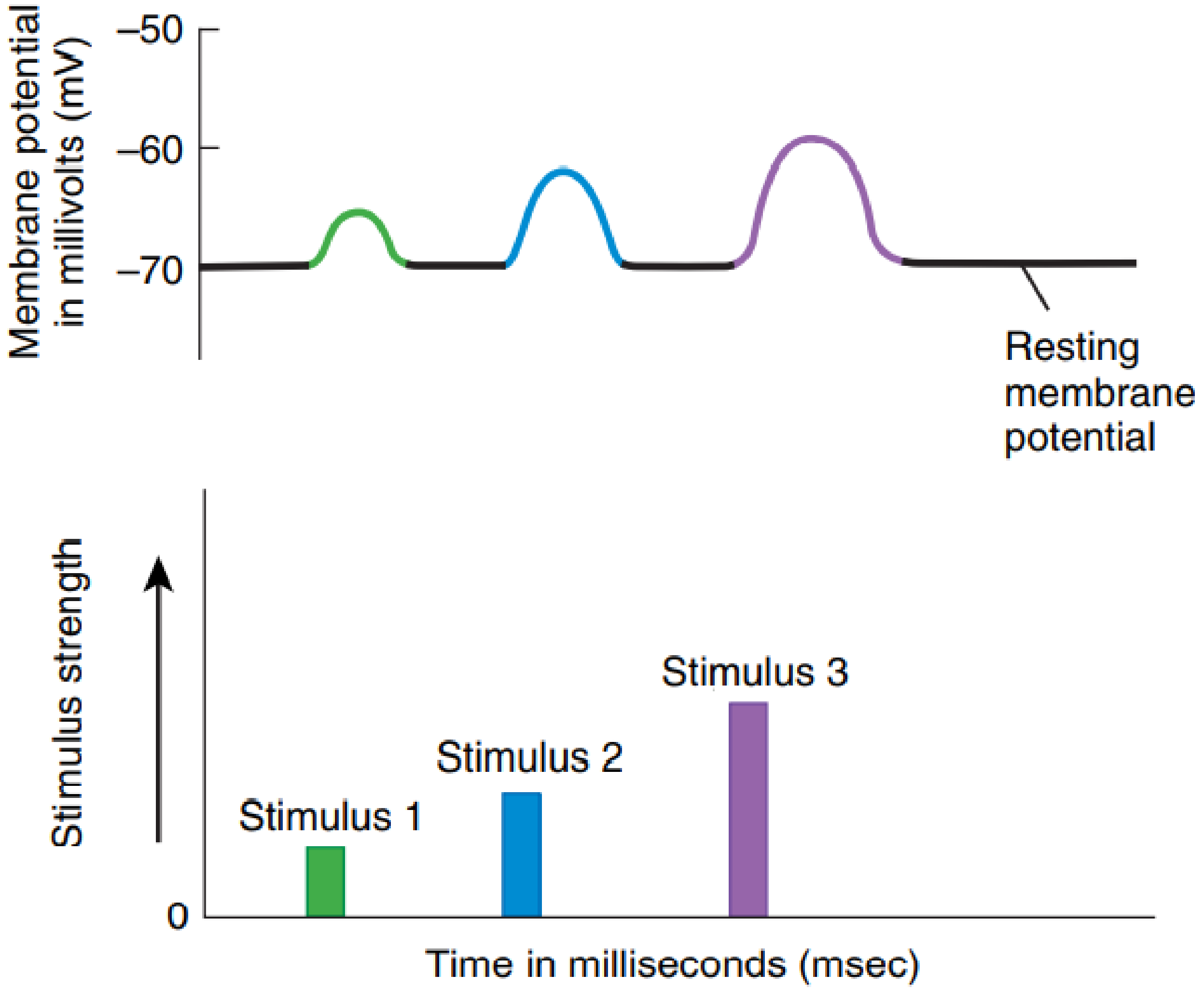


(c) Hyperpolarizing graded potential caused by the neurotransmitter glycine, a ligand stimulus

Graded potential

- They are larger or smaller depending on <u>how many </u>ligand-gated or mechanically-gated <u>channels have opened</u> (or closed) and <u>how long </u>each remains <u>open</u>.

The amplitude of a graded potential depends on the stimulus strength. The greater the stimulus strength, the larger the amplitude of the graded potential.



Graded potential

- The opening or closing of these ion channels alters the flow of specific ions across the membrane producing a **flow of current that is localized**, which means that it spreads to adjacent regions along the plasma membrane in either direction from the stimulus source for a **short distance** and then gradually dies out as the charges are lost across the membrane through leak channels.

Graded potential

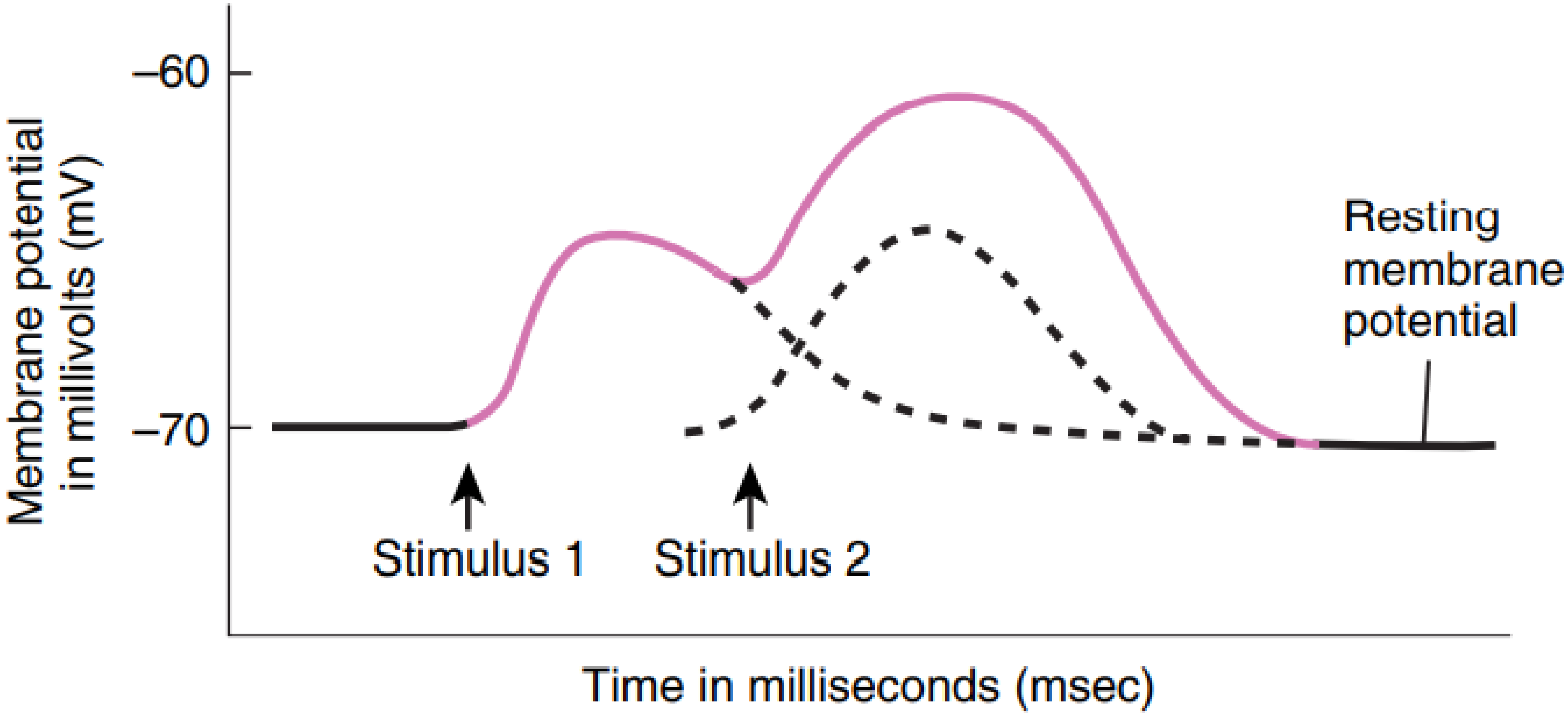
- This mode of travel by which graded potentials die out as they spread along the membrane is known as **decremental conduction**. Because they die out within a few millimeters of their point of origin, graded potentials are **useful for short-distance communication only**.

Graded potential

- Although an individual graded potential undergoes decremental conduction, it can become stronger and last longer by summating with other graded potentials.

- **Summation** is the process by which graded potentials add together.

Summation occurs when two or more graded potentials add together to become larger in amplitude.



Graded potential

- If two depolarizing graded potentials summate, the net result is a larger depolarizing graded potential.

- If two hyperpolarizing graded potentials summate, the net result is a larger hyperpolarizing graded potential.

- If two equal but opposite graded potentials summate (one depolarizing and the other hyperpolarizing), then they cancel each other out and the overall graded potential disappears.

Graded potential

- Graded potentials have different names depending on which type of stimulus causes them and where they occur.

- For example, when a graded potential occurs in sensory receptors are called receptor potential.

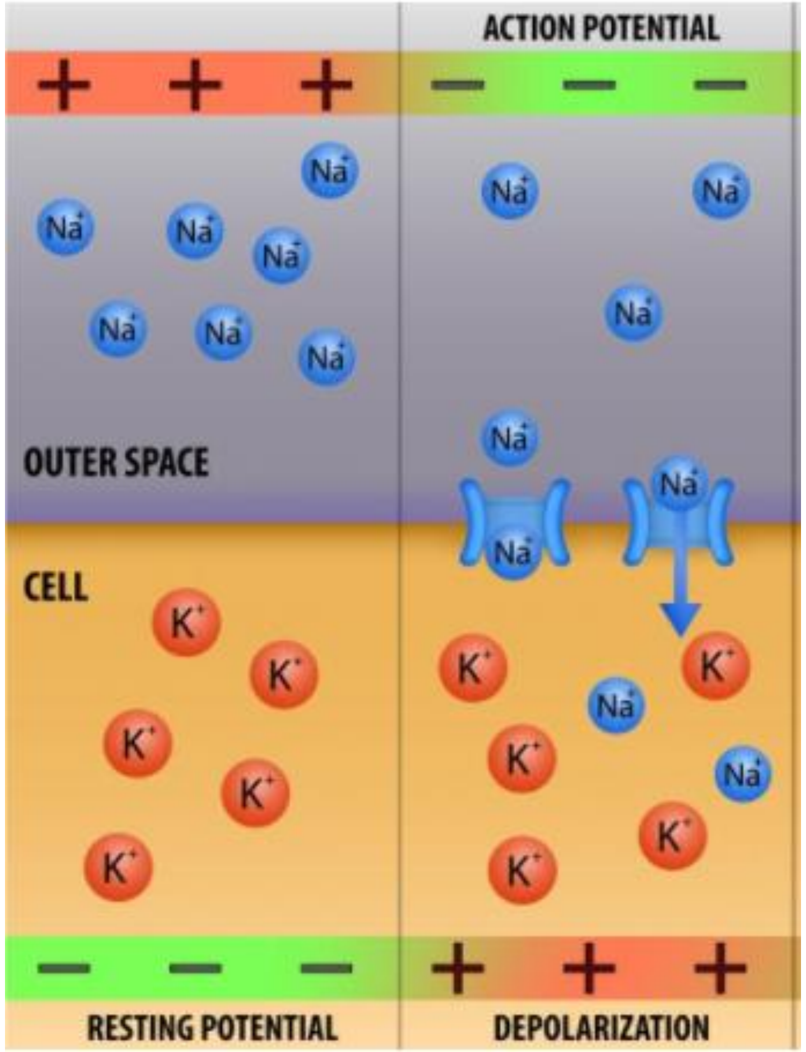
Action potential

- A sequence of rapidly occurring events that decrease and reverse the membrane potential and then eventually restore it to the resting state.

- An action potential has two main phases: a depolarizing phase and a repolarizing phase.

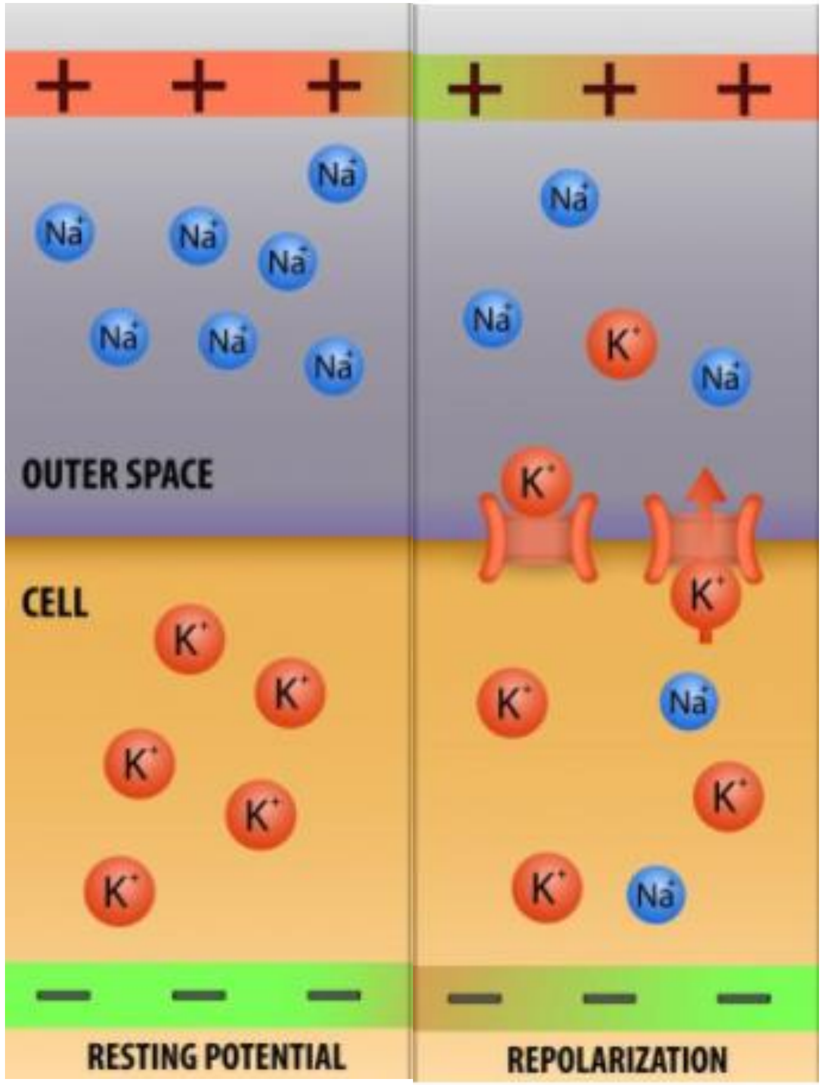
Phases of action potential

- During the **depolarizing phase**, the negative membrane potential becomes less negative, reaches zero, and then becomes positive.



Phases of action potential

- During the **repolarizing phase**, the membrane potential is restored to the resting state.



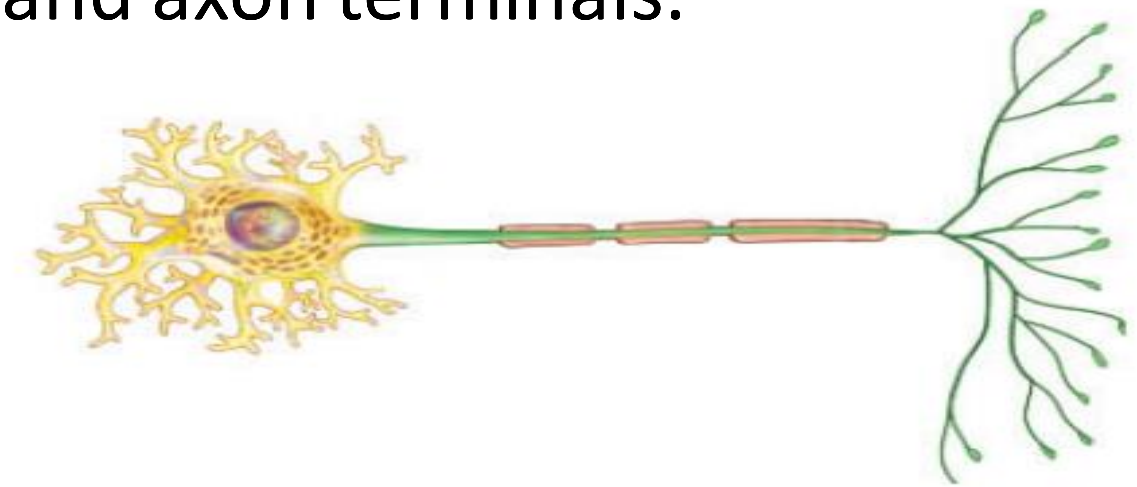
Phases of action potential

- Following the repolarizing phase there **may be an after-hyperpolarizing phase**, during which the membrane potential temporarily becomes more negative than the resting level.

Voltage-gated channels

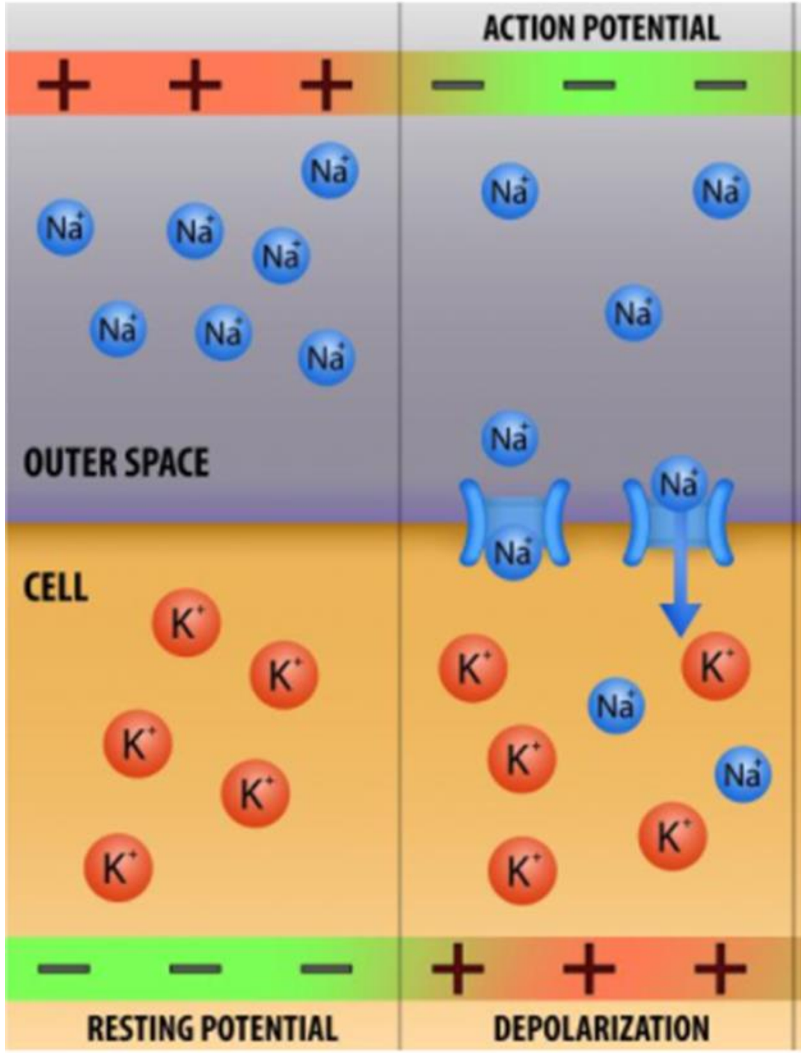
- Two types of voltage-gated channels open and then close during an action potential.

- These channels are present mainly in the axon plasma membrane and axon terminals.



Voltage-gated channels

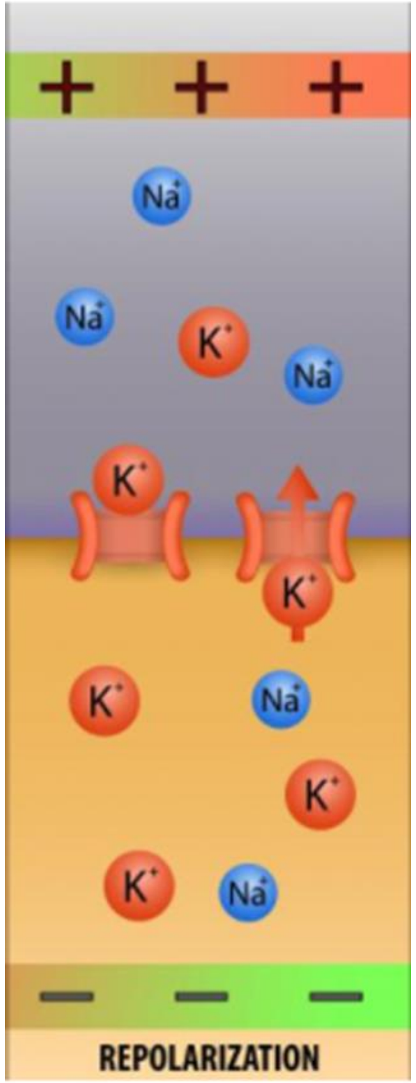
- The first channels that open, the voltage-gated Na+ channels, allow Na+ to rush into the cell, which causes the depolarizing phase.



Voltage-gated channels

- Then voltage-gated K+ channels open, allowing K+ to flow out, which produces the repolarizing phase.

- The after-hyperpolarizing phase occurs when the voltage-gated K+ channels remain open after the repolarizing phase ends.



Threshold

- An action potential occurs in the membrane when depolarization reaches a certain level termed the threshold.

- Different excitable cells have different thresholds for generation of an action potential, but the threshold in a particular cell usually is constant.

Threshold

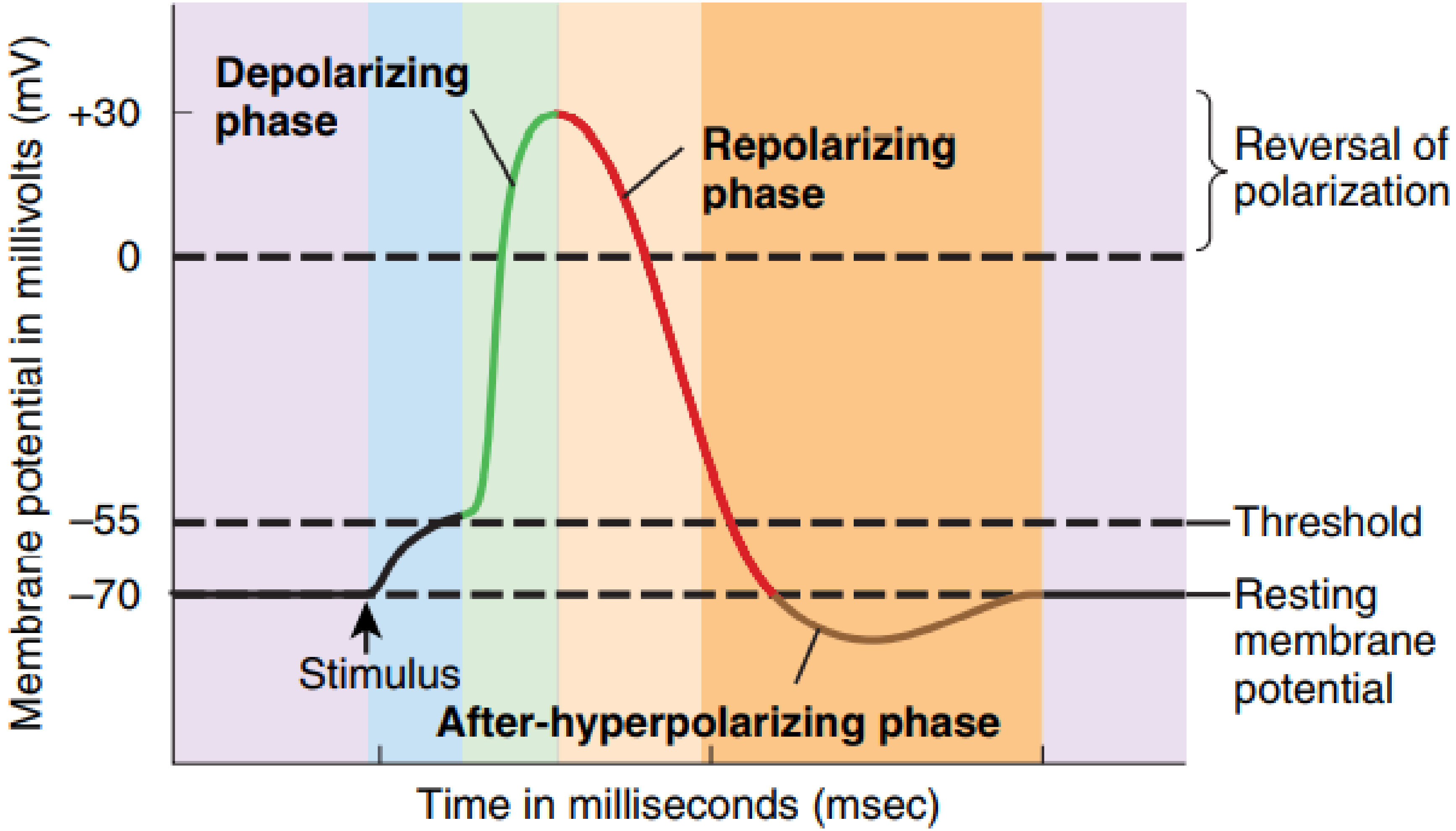
- The generation of an action potential depends on whether a particular stimulus is able to bring the membrane potential to threshold.

- An action potential will not occur in response to a subthreshold stimulus, a weak depolarization that cannot bring the membrane potential to threshold.

Threshold

- An action potential either occurs completely or it does not occur at all. This characteristic of an action potential is known as the **all-or-none principle**.

Threshold



Depolarizing phase
Repolarizing phase
Reversal of polarization
+30
0
–55
–70
Threshold
Resting membrane potential
Stimulus
After-hyperpolarizing phase
Membrane potential in millivolts (mV)
Time in milliseconds (msec)

Threshold

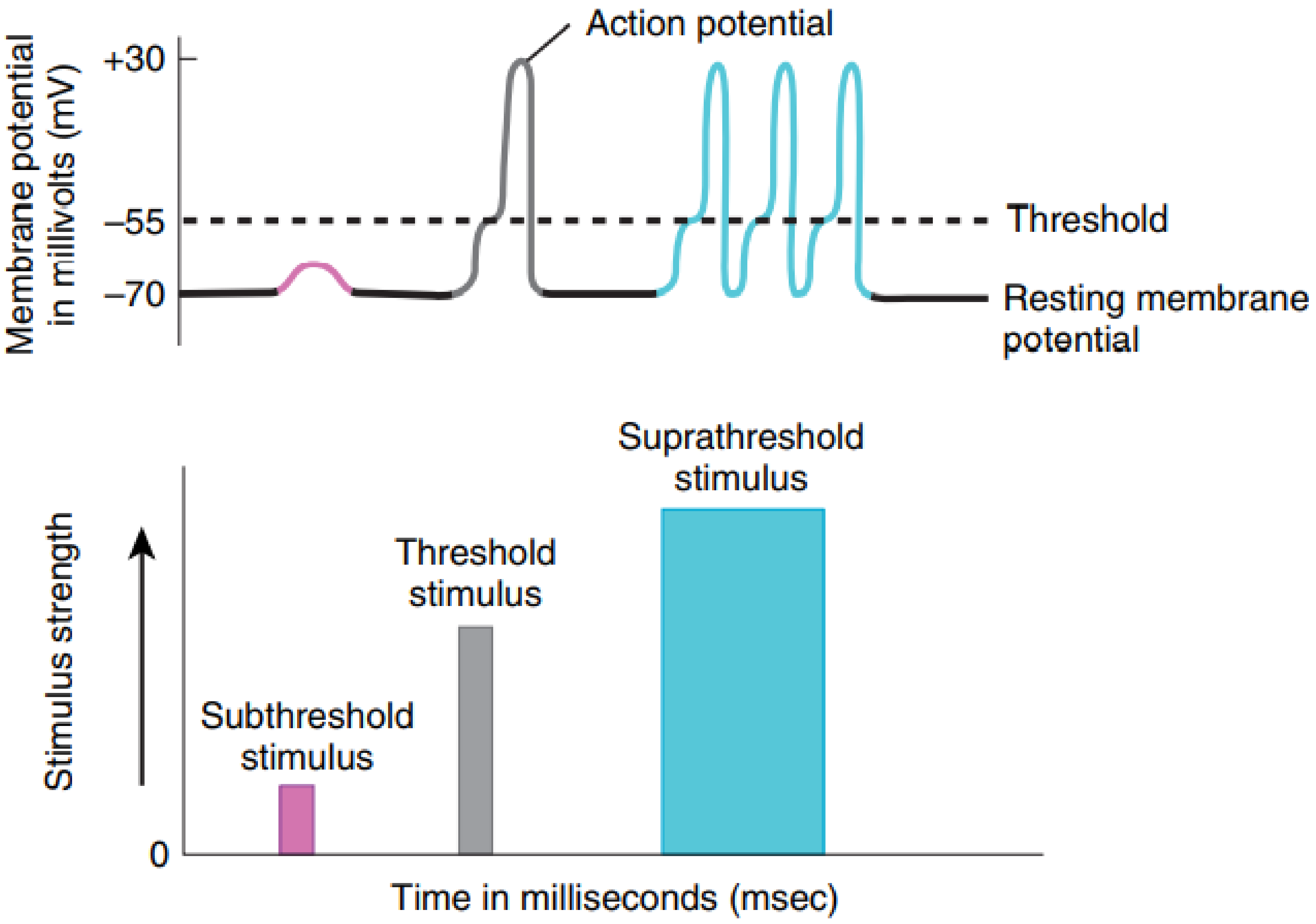
- Several action potentials will form in response to a **suprathreshold stimulus**, a stimulus that is strong enough to depolarize the membrane above threshold.

- Each of the action potentials caused by a suprathreshold stimulus has <u>the same amplitude</u> (size) as an action potential caused by a threshold stimulus.

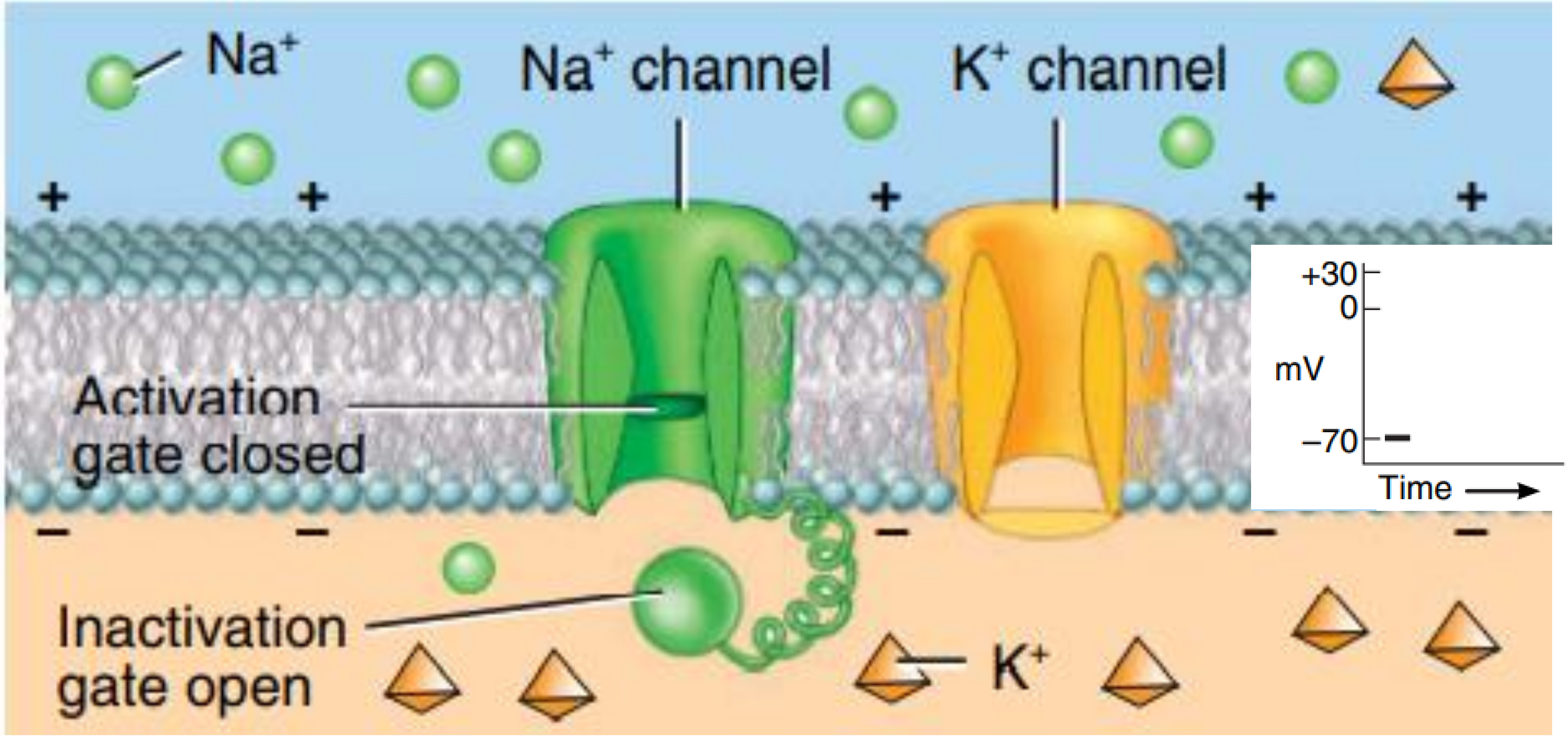
Threshold

- Once an action potential is generated, the amplitude of an action potential is always the same and does not depend on stimulus intensity.

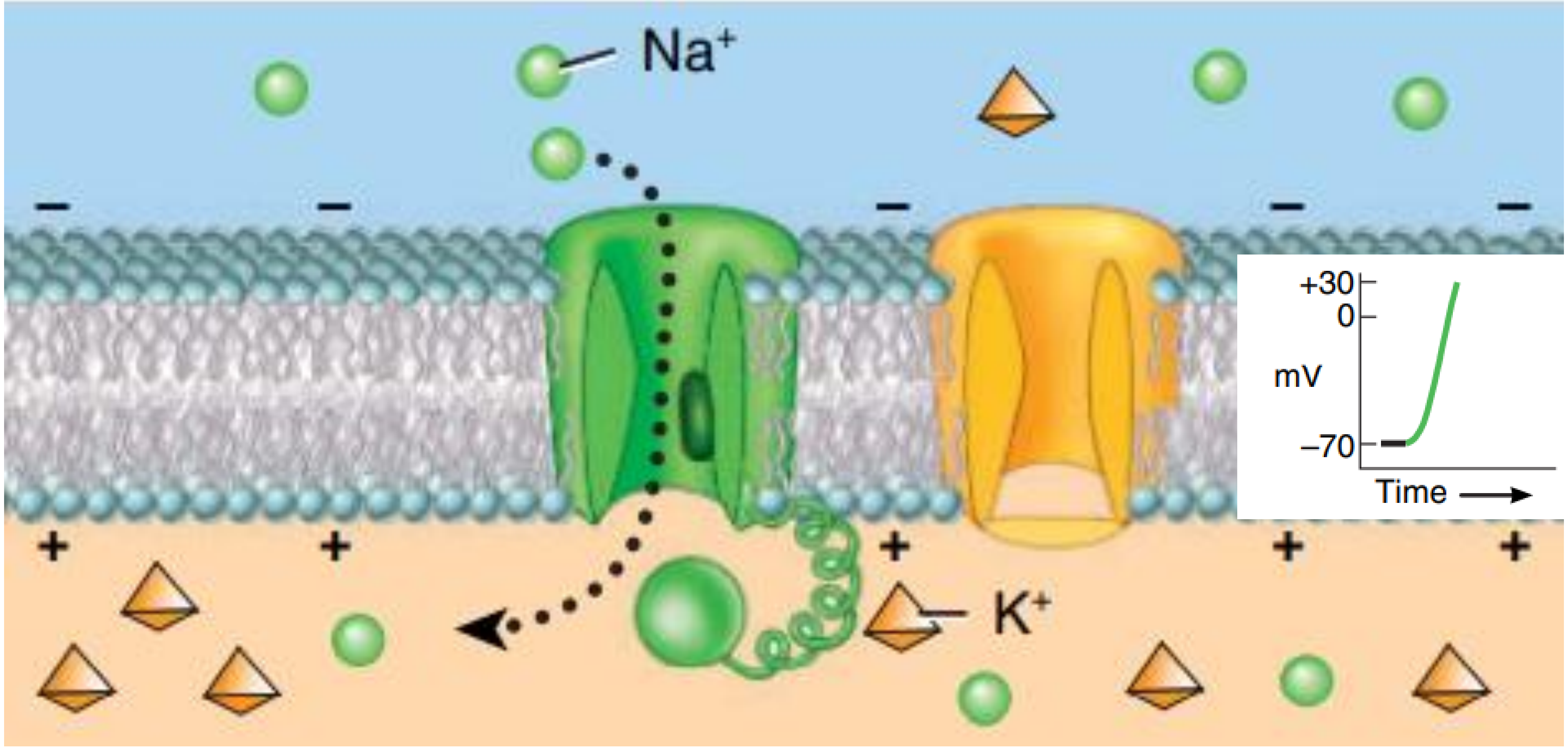
- The greater the stimulus strength above threshold, the <u>greater the frequency</u> of the action potentials until a maximum frequency is reached.


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)

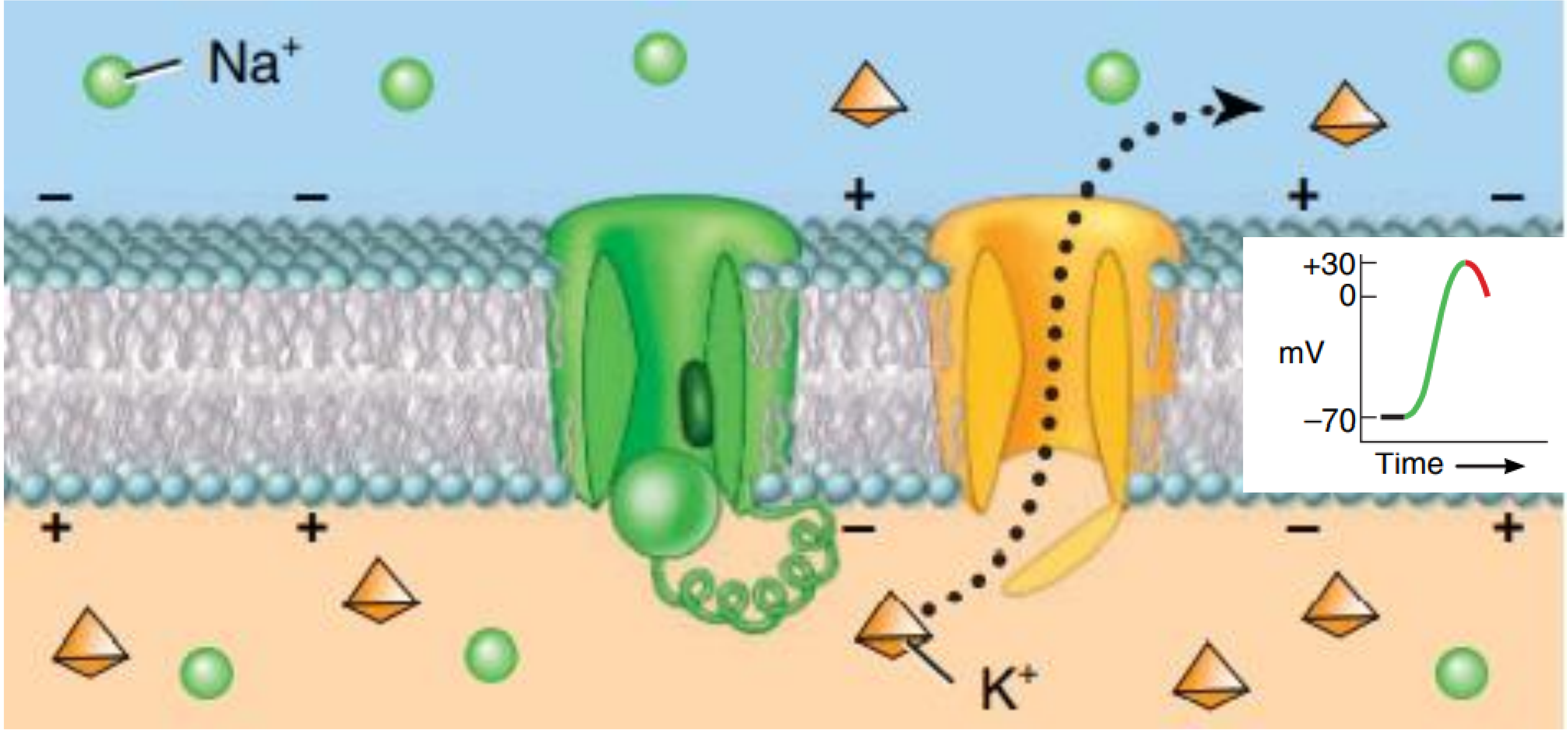
Resting state



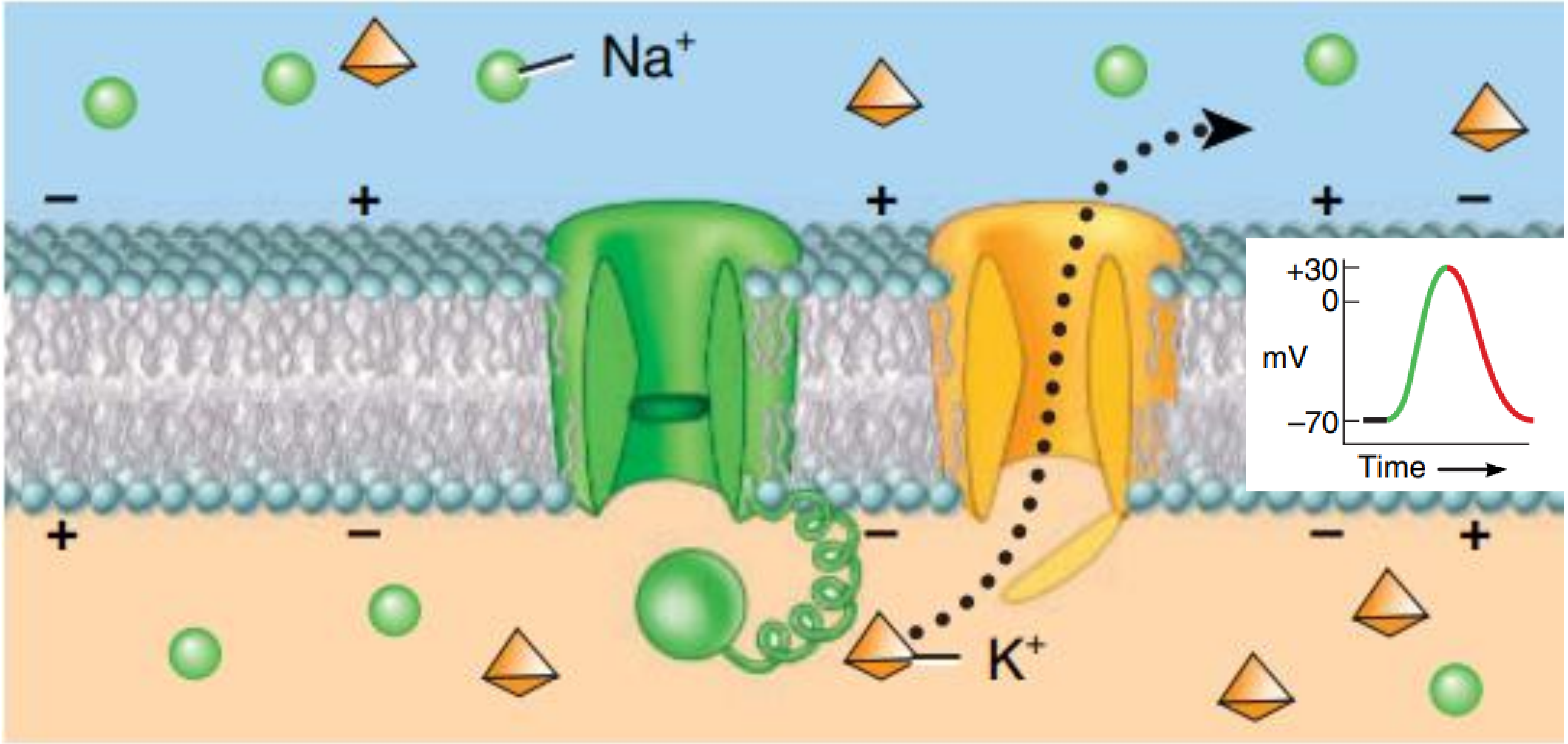
Depolarization phase



Repolarization phase-1



Repolarization phase-2



Refractory period

- The period of time after an action potential begins during which an excitable cell cannot generate another action potential in response to a normal threshold stimulus is called the **refractory period**.

- In contrast to action potentials, graded potentials do not exhibit a refractory period.

Absolute refractory period

- During the absolute refractory period, even a very strong stimulus cannot initiate a second action potential.

- This period coincides with the period of Na+ channel activation and inactivation.

- Inactivated Na+ channels cannot reopen; they first must return to the resting state.

Relative refractory period

- The relative refractory period is the period of time during which a second action potential can be initiated, but only by a larger-than normal stimulus.

- It coincides with the period when the voltage-gated K+ channels are still open after inactivated Na+ channels have returned to their resting state.

Propagation of action potential

- In contrast to the graded potential, an **action potential is not decremental** (it does not die out).

- Instead, an action potential keeps its strength as it spreads along the membrane. This mode of conduction is called **propagation**.

Types of propagation

1- **Continuous conduction**, which involves step-by-step depolarization and repolarization of each adjacent segment of the plasma membrane.

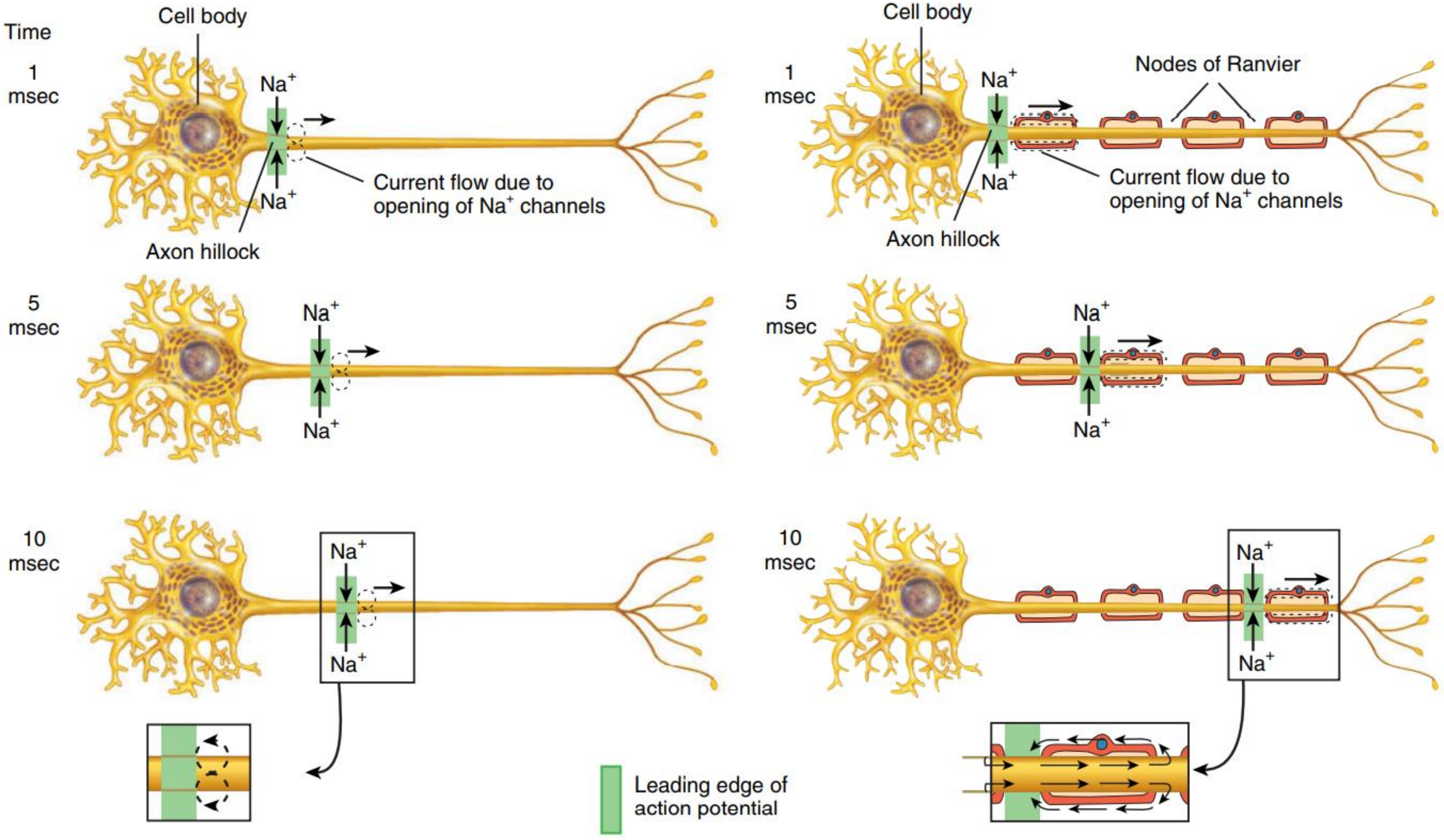
The action potential propagates only a relatively short distance in a few milliseconds.

Continuous conduction occurs in unmyelinated axons and in muscle fibers.

Types of propagation

2- **Saltatory conduction**, a special mode of action potential propagation that occurs along myelinated axons.

It occurs because of the uneven distribution of voltage-gated channels. Few voltage-gated channels are present in regions where a myelin sheath covers the axolemma. By contrast, at the nodes of Ranvier, the axolemma has many voltage-gated channels. Hence, current carried by Na+ and K+ flows across the membrane mainly at the nodes.



(a) Continuous conduction

(b) Saltatory conduction

Factors affecting the speed of propagation

- 1. **Amount of myelination**. Action potentials propagate faster along myelinated axons than along unmyelinated axons.

- 2. **Axon diameter**. Larger diameter axons propagate action potentials faster due to their larger surface areas.

- 3. **Temperature**. Axons propagate action potentials at lower speeds when cooled.

Comparison between graded potential and action potential

CHARACTERISTIC	GRADED POTENTIALS	ACTION POTENTIALS
Origin	Arise mainly in dendrites and cell body.	Arise at trigger zones and propagate along axon.
Types of channels	Ligand-gated or mechanically-gated ion channels.	Voltage-gated channels for Na^+ and K^+.
Conduction	Decremental (not propagated); permit communication over short distances.	Propagate and thus permit communication over longer distances.
Amplitude (size)	Depending on strength of stimulus, varies from less than 1 mV to more than 50 mV.	All or none; typically about 100 mV.
Duration	Typically longer, ranging from several milliseconds to several minutes.	Shorter, ranging from 0.5 to 2 msec.
Polarity	May be hyperpolarizing (inhibitory to generation of action potential) or depolarizing (excitatory to generation of action potential).	Always consist of depolarizing phase followed by repolarizing phase and return to resting membrane potential.
Refractory period	Not present; summation can occur.	Present; summation cannot occur.

Thank you