

ACTION POTENTIAL

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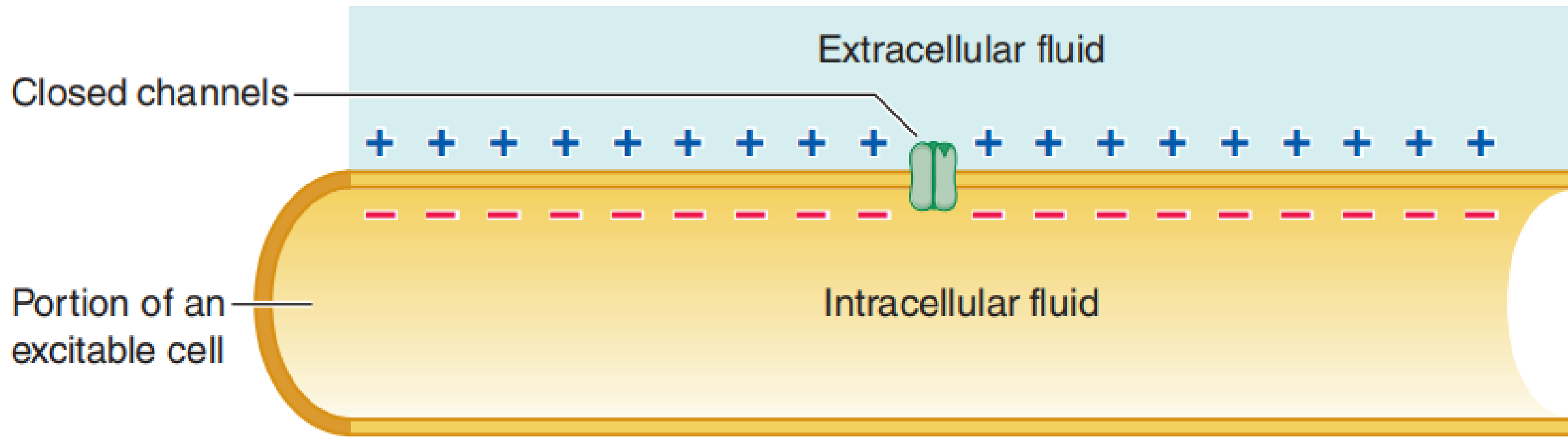
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TERMS

TERMS

- Several terms used to describe changes in potential.
- Charges are separated across the plasma membrane, so the membrane has **potential**.
- Any time membrane potential is **other than 0 millivolts** (mV), in either the positive or the negative direction, the membrane is in a state of **polarization**.
- At resting potential, the membrane is **polarized at -70 mV in a typical neuron**.



(a) Entire membrane at resting potential

TERMS

- **1. Depolarization:**
- The membrane **becomes less polarized**; the **inside becomes less negative** than at resting potential, with the potential moving **closer to 0 mV** (for example, a change from -70 to -60 mV); **fewer charges are separated than at resting potential**.
- This term also refers to the **inside even becoming positive** as it does during an **action potential**.

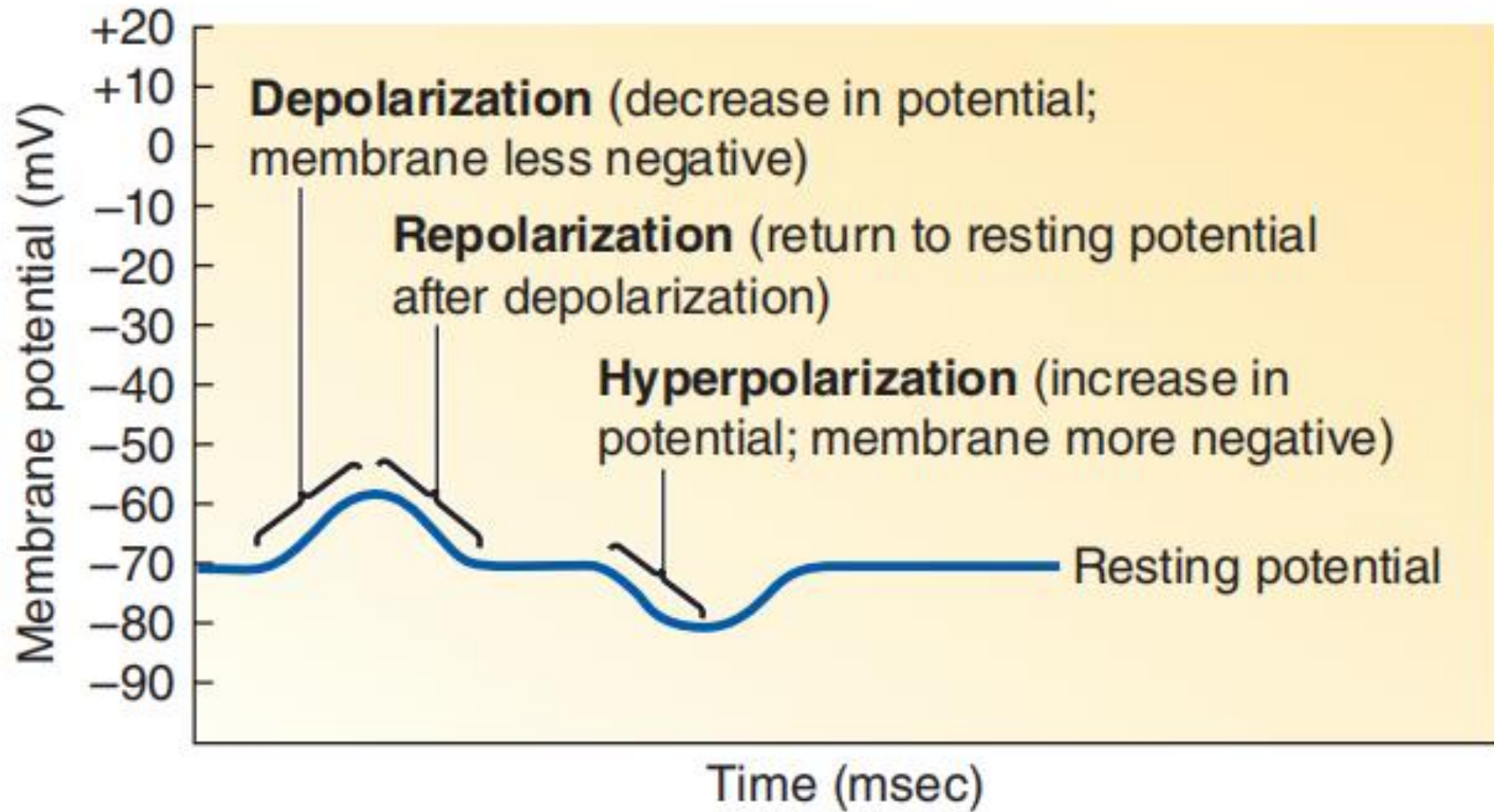


Figure 4-1 Types of changes in membrane potential.

TERMS

- **2. Repolarization:**
- The membrane returns to resting potential after having been depolarized.

TERMS

- **3. Hyperpolarization:**
- The membrane becomes **more polarized**; the **inside becomes more negative** than at resting potential, with the potential moving even farther from 0 mV (for instance, a change from -70 to -80 mV); more charges are separated than at resting potential.

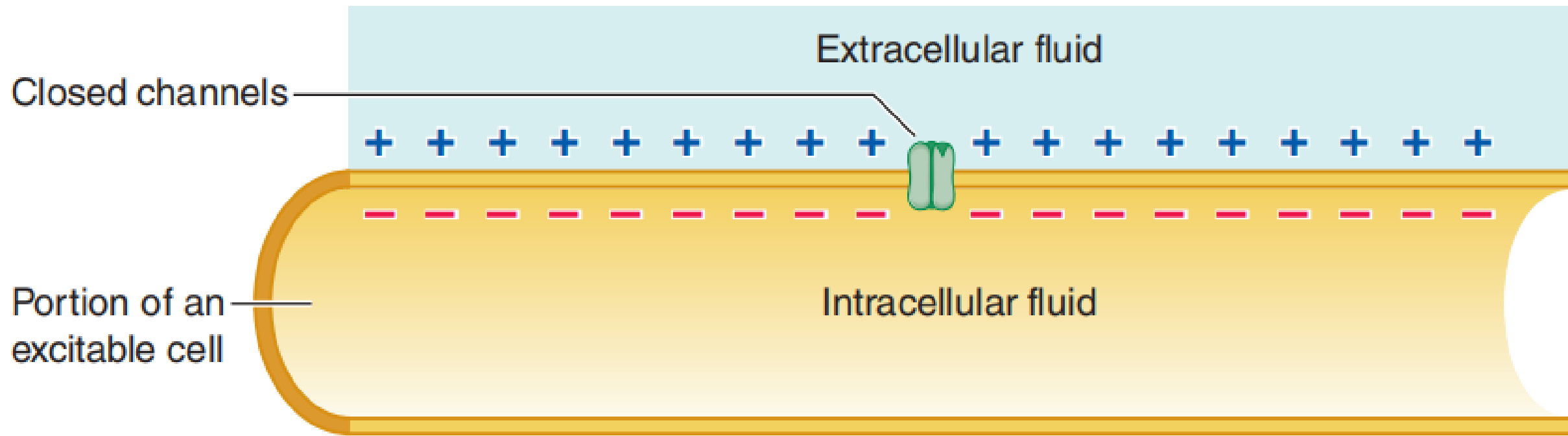
- **Changes in membrane potential** are brought about by **changes in ion movement across the membrane.**
- For example, if the **net inward flow of positively charged ions increases** compared to the resting state (such as more **Na⁺** moves in), the membrane **depolarizes** (becomes less negative inside).
- By contrast, if the net **outward flow of positively charged ions increases** compared to the resting state (such as more **K⁺** moves out), the membrane **hyperpolarizes** (becomes more negative inside).

- Changes in ion movement are brought about by **changes in membrane permeability** in response to **triggering events (stimulus)**.
- There are four kinds of **gated channels**, depending on the factor that causes the channel to change shape:
 1. **Voltage-gated channels**
 2. **Chemically gated channels**
 3. **Mechanically gated channels**
 4. **Thermally gated channels**

GRADED POTENTIALS

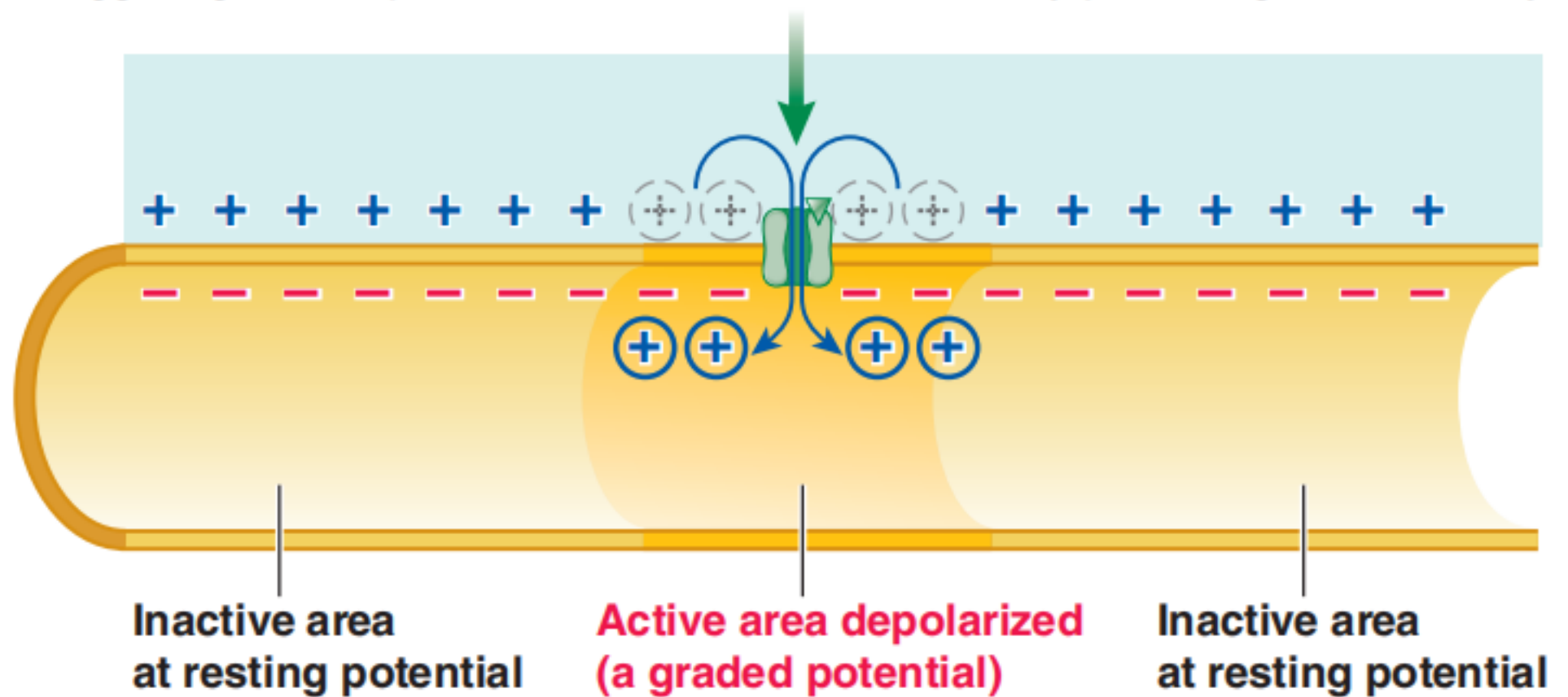
GRADED POTENTIALS

- Graded potentials are **local changes in membrane potential** that occur in **varying grades** or degrees of magnitude or strength.



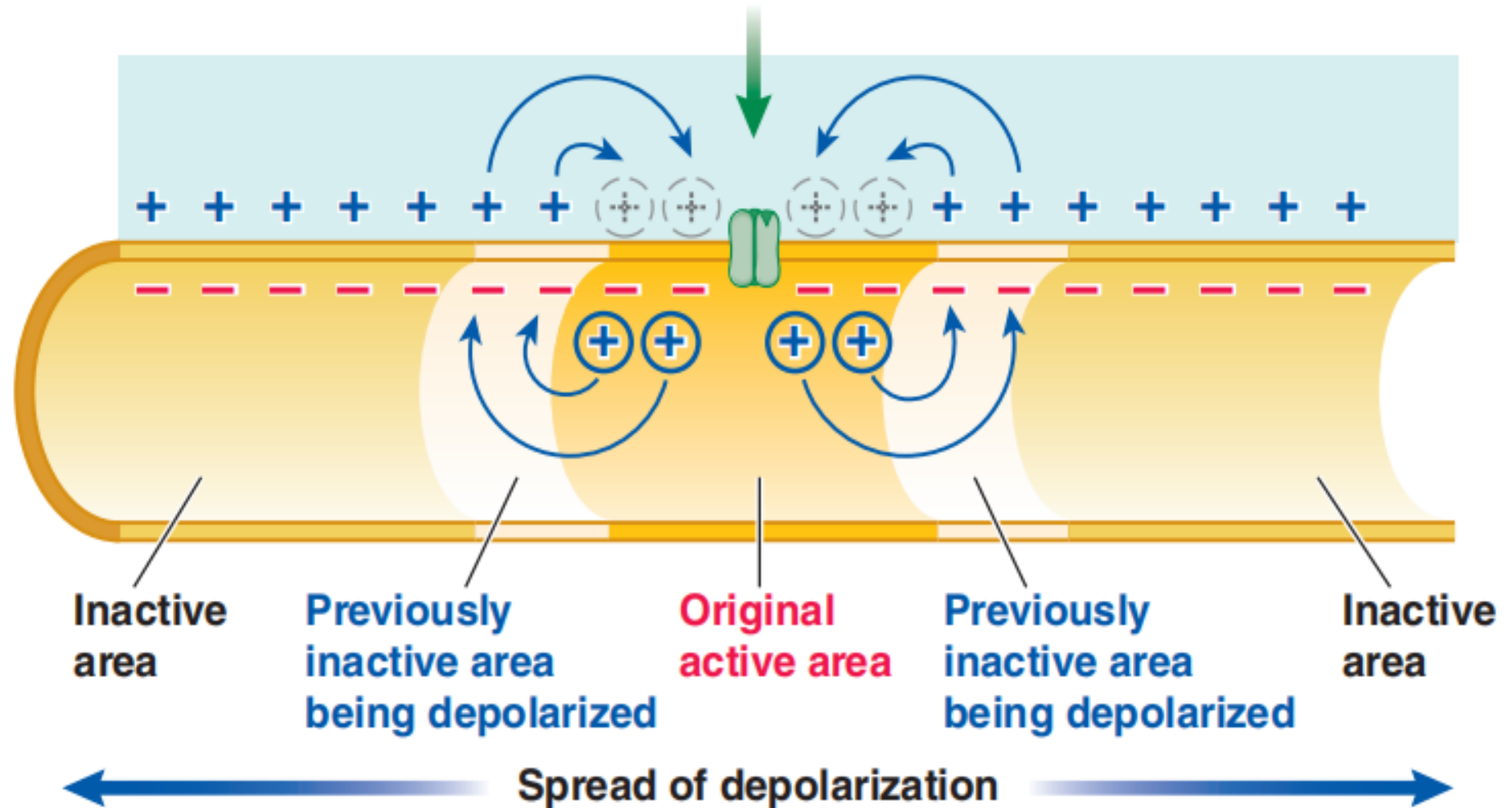
(a) Entire membrane at resting potential

Triggering event opens ion channels, most commonly permitting net Na^+ entry

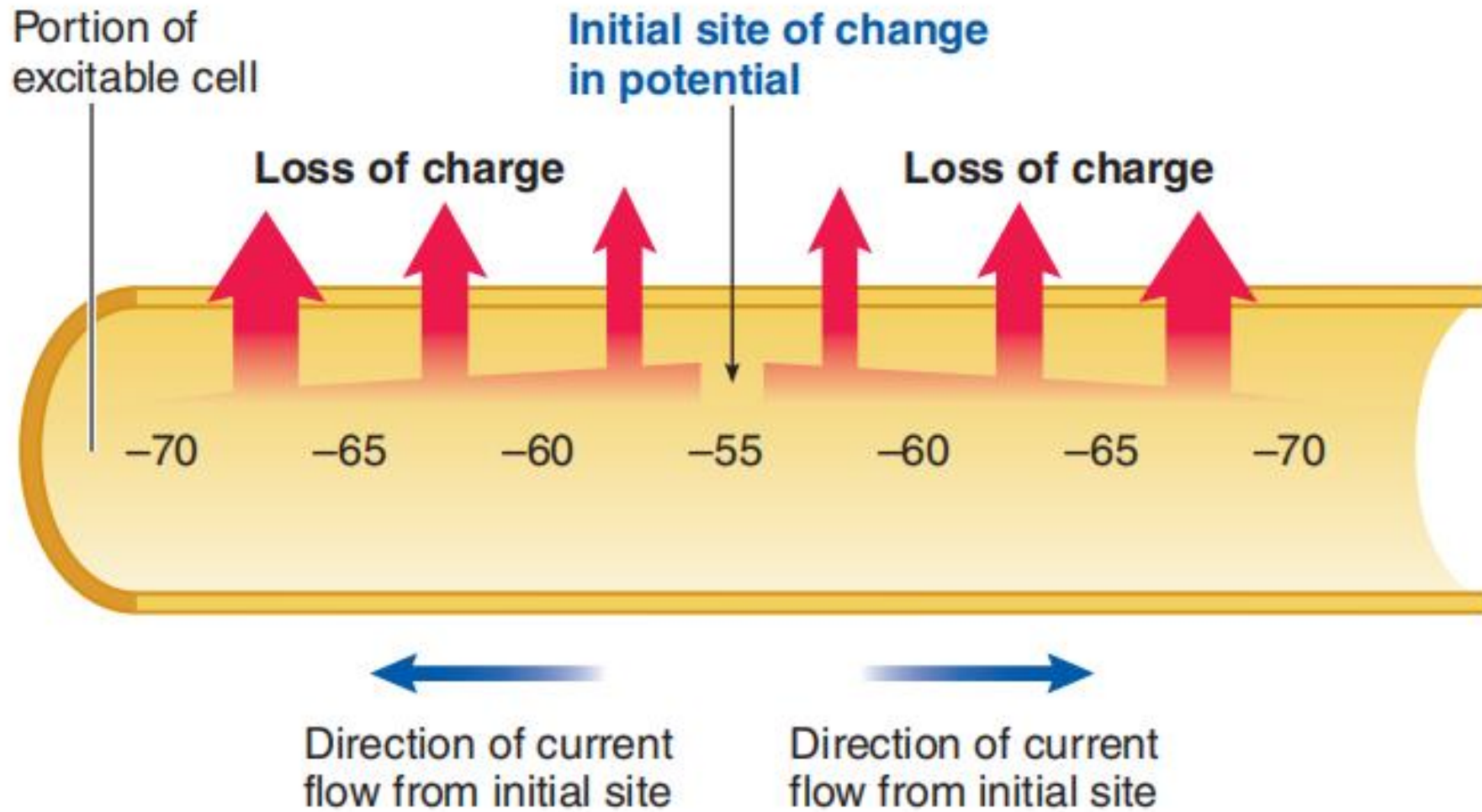


(b) Inward movement of Na^+ depolarizes membrane, producing a graded potential

Current flows between the active and adjacent inactive areas



(c) Depolarization spreads by local current flow to adjacent inactive areas, away from point of origin



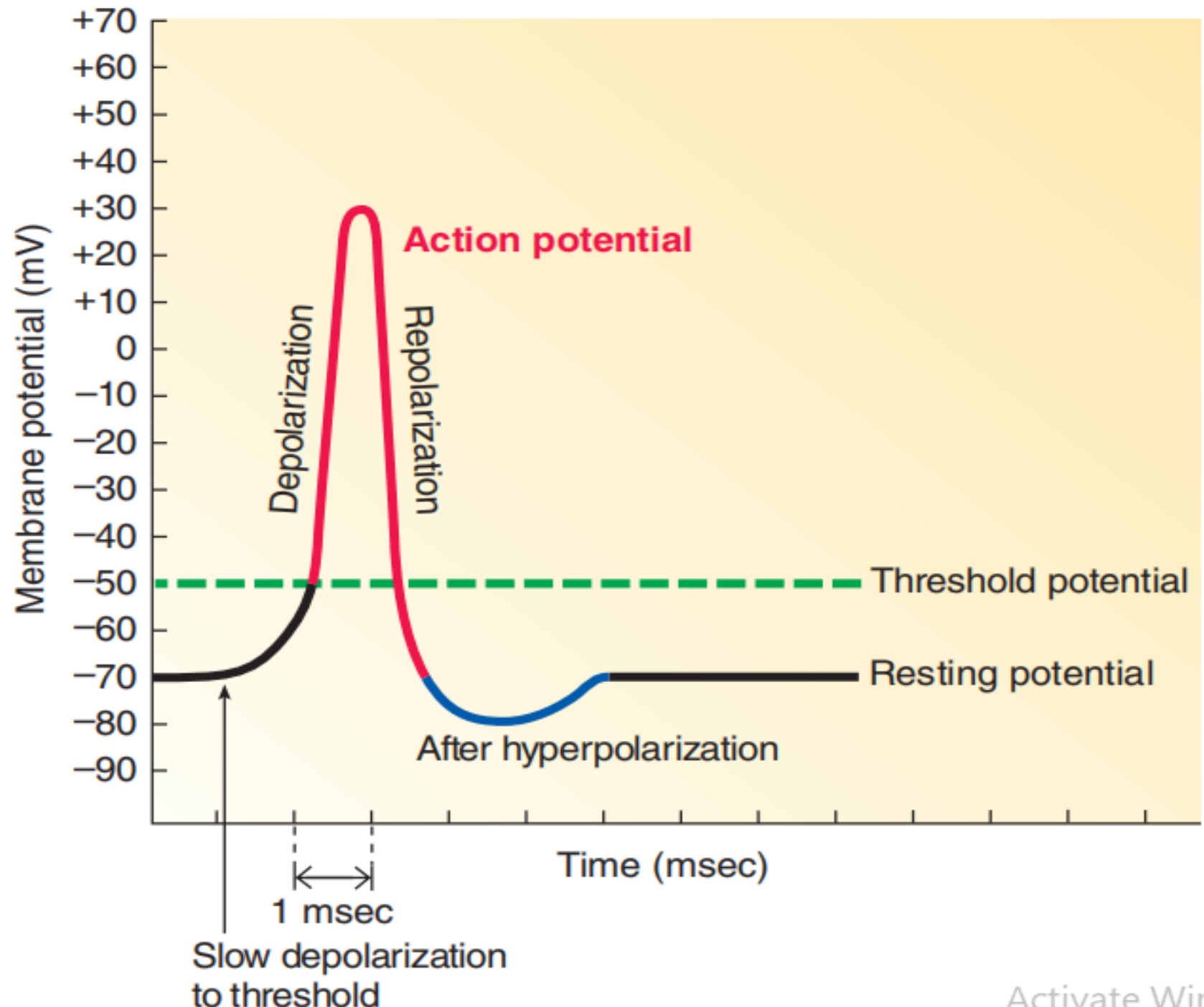
* Numbers refer to the local potential in mV at various points along the membrane.

(a) Current loss across the membrane

ACTION POTENTIALS

ACTION POTENTIALS

- Action potentials are **brief, rapid, large (100-mV) changes in membrane potential** during which the potential actually reverses so that the **inside of the excitable cell transiently becomes more positive than the outside.**
- Action potentials take place as a result of the triggered opening and subsequent closing of two specific types of channels:
voltage-gated Na⁺ channels and voltage-gated K⁺ channels.



ACTION POTENTIALS

- **1. Depolarization** from the resting potential of -70 mV proceeds slowly until it reaches a critical level known as **threshold potential**, typically between -50 and -55 mV.
- **2. At threshold potential**, an **explosive depolarization** takes place.
 - Peak potential is usually **+30 to +40 mV**.
- **3. Just as rapidly**, the membrane **repolarizes**, dropping back to resting potential.
- **4. Often**, the forces that repolarize the membrane push the potential too far, causing a brief after **hyperpolarization**.

ACTION POTENTIALS

- The action potential is the **entire rapid change in potential from threshold to peak and then back to resting.**
- If the initial triggered depolarization does not reach threshold potential, no action potential takes place.

MARKED CHANGES IN MEMBRANE PERMEABILITY
AND ION MOVEMENT LEAD TO AN ACTION POTENTIAL

- Action potentials take place as a result of the triggered opening and subsequent closing of two specific types of channels:
 - **voltage-gated Na⁺ channels and**
 - **voltage-gated K⁺ channels.**

- Unlike most membrane proteins, which remain stable despite fluctuations in membrane potential, **voltage-gated channel proteins are especially sensitive to voltage changes.**

VOLTAGE-GATED Na⁺ CHANNEL

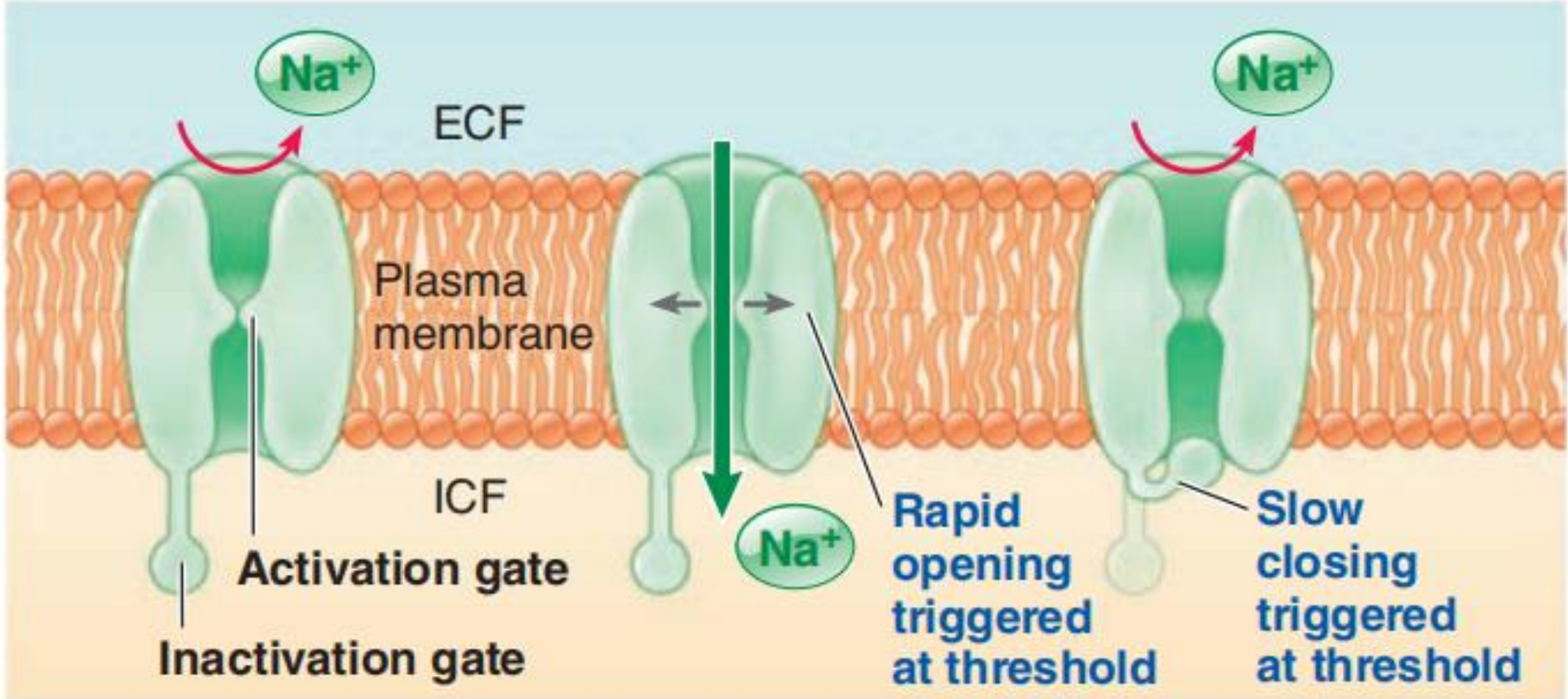
VOLTAGE-GATED Na⁺ CHANNEL

- The voltage-gated Na⁺ channel has **two gates**:
 - ❖ **1. Activation gate**
 - ❖ **2. Inactivation gate**
- **Both gates** must be **open** to permit **passage** of Na⁺ through the channel, and **closure of either gate prevents** passage.

VOLTAGE-GATED Na⁺ CHANNEL

- This voltage-gated Na⁺ channel can exist in three conformations:
 - (1) **closed but capable of opening:**
 - ❖ (activation gate closed, inactivation gate open).
 - (2) **open, or activated:**
 - ❖ (both gates open).
 - (3) **closed and not capable of opening, or inactivated:**
 - ❖ (activation gate open, inactivation gate closed).

VOLTAGE-GATED SODIUM CHANNEL



(a) Closed but capable of opening

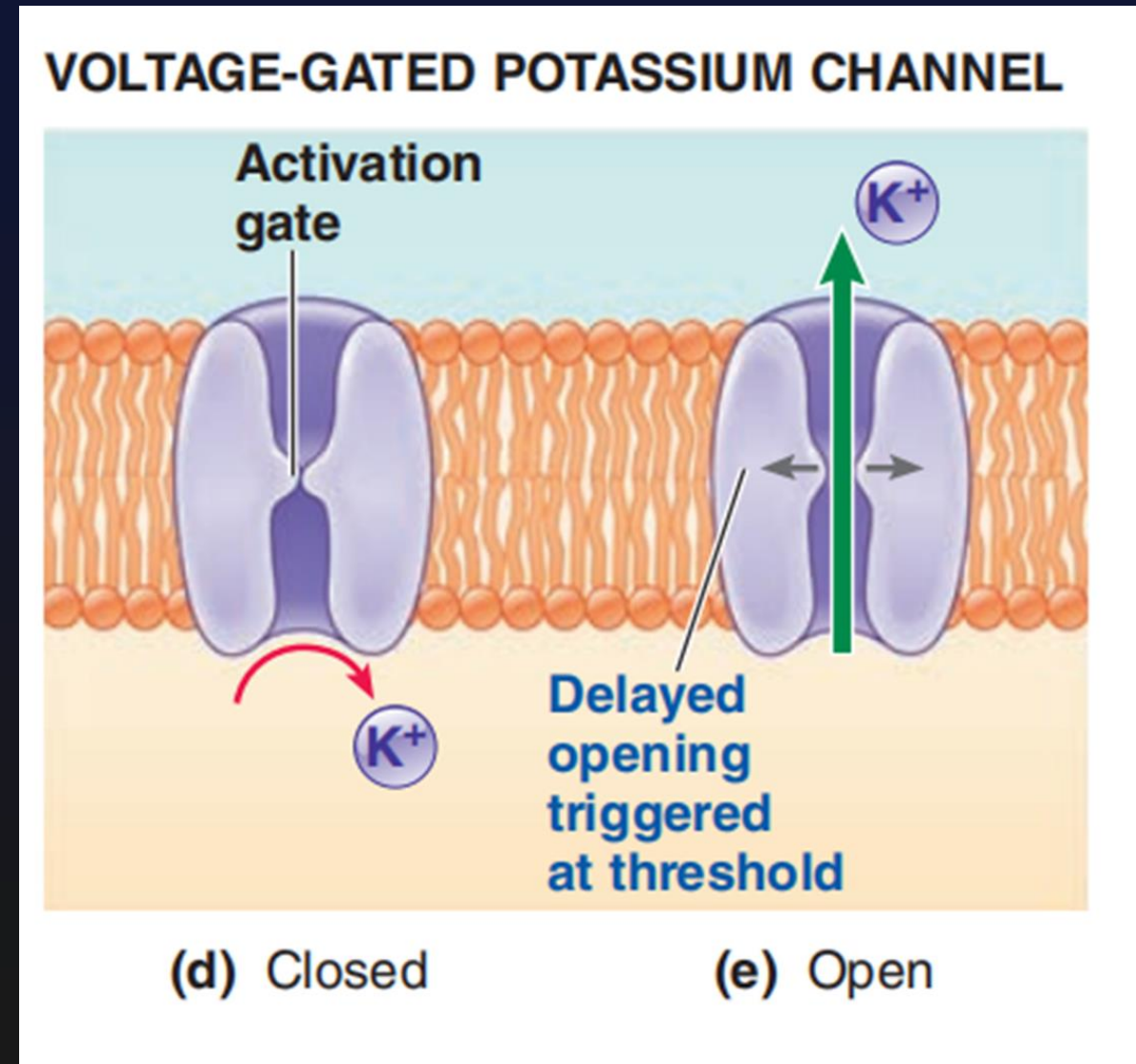
(b) Open (activated)

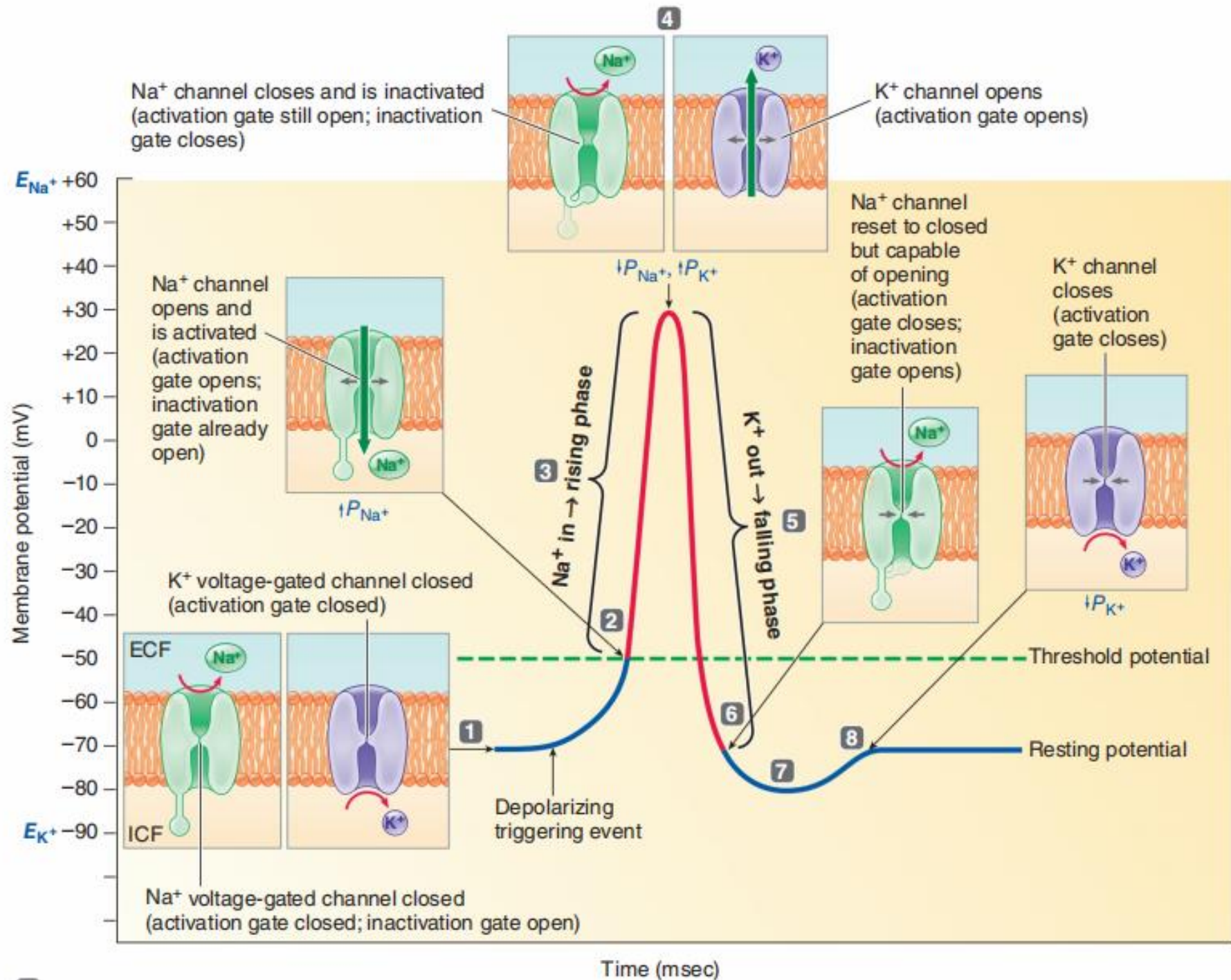
(c) Closed and not capable of opening (inactivated)

VOLTAGE-GATED K⁺ CHANNEL

VOLTAGE-GATED K⁺ CHANNEL

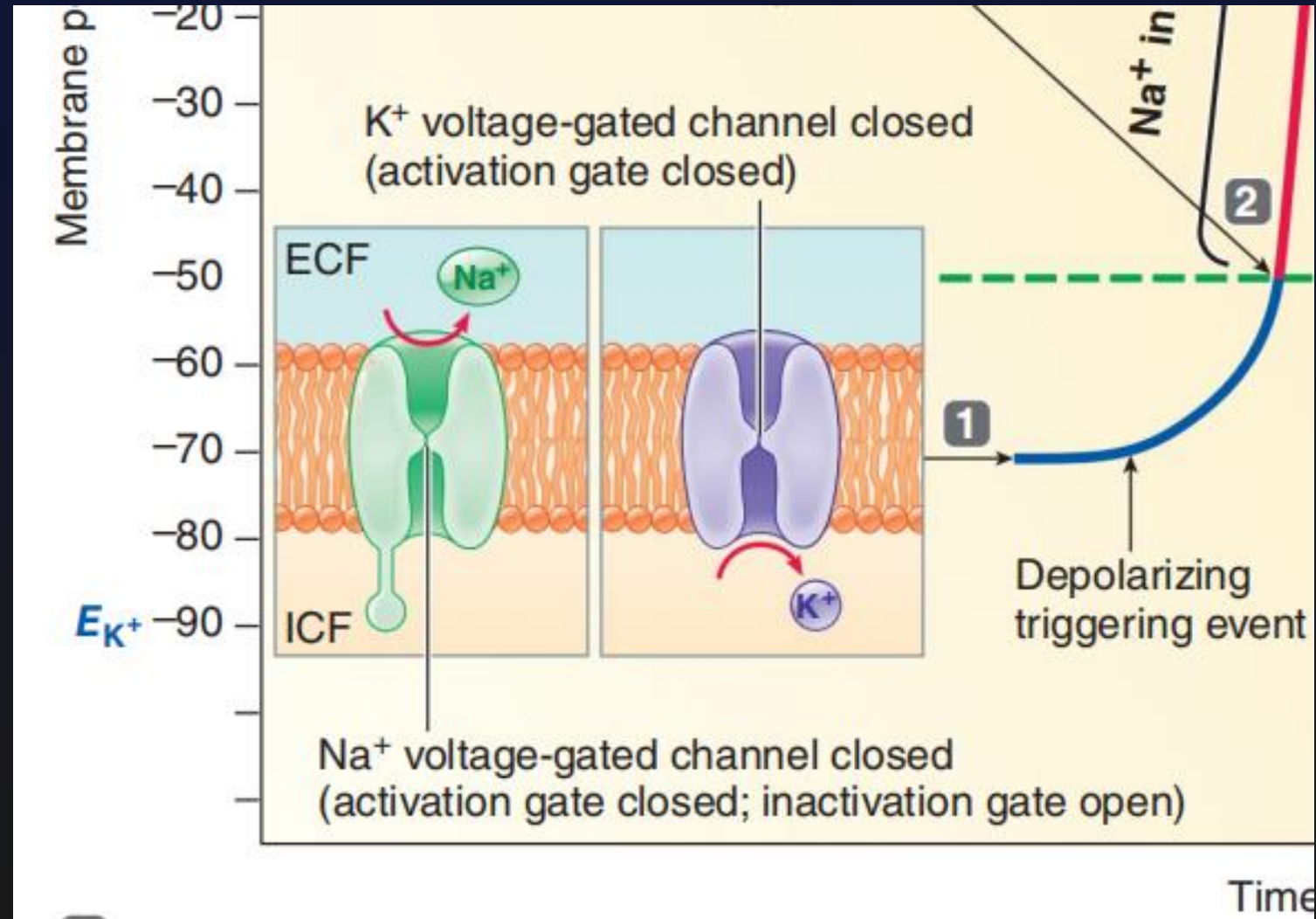
- The voltage-gated K⁺ channel is simpler.
- It has only an **activation gate**, which can be either closed or open.





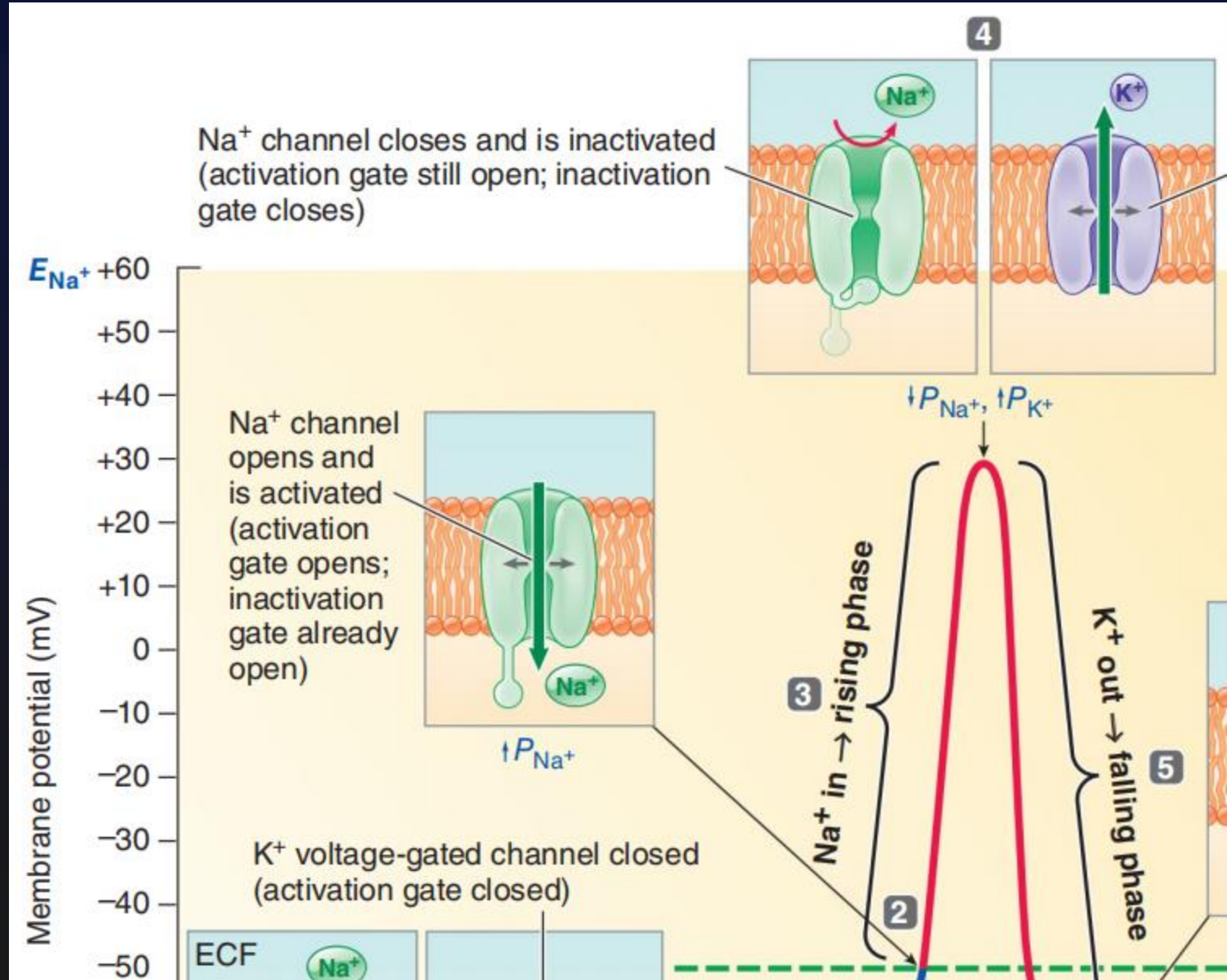
ACTION POTENTIAL

1. **Resting potential:** all voltage-gated channels closed.
2. **At threshold,** Na⁺ activation gate opens.



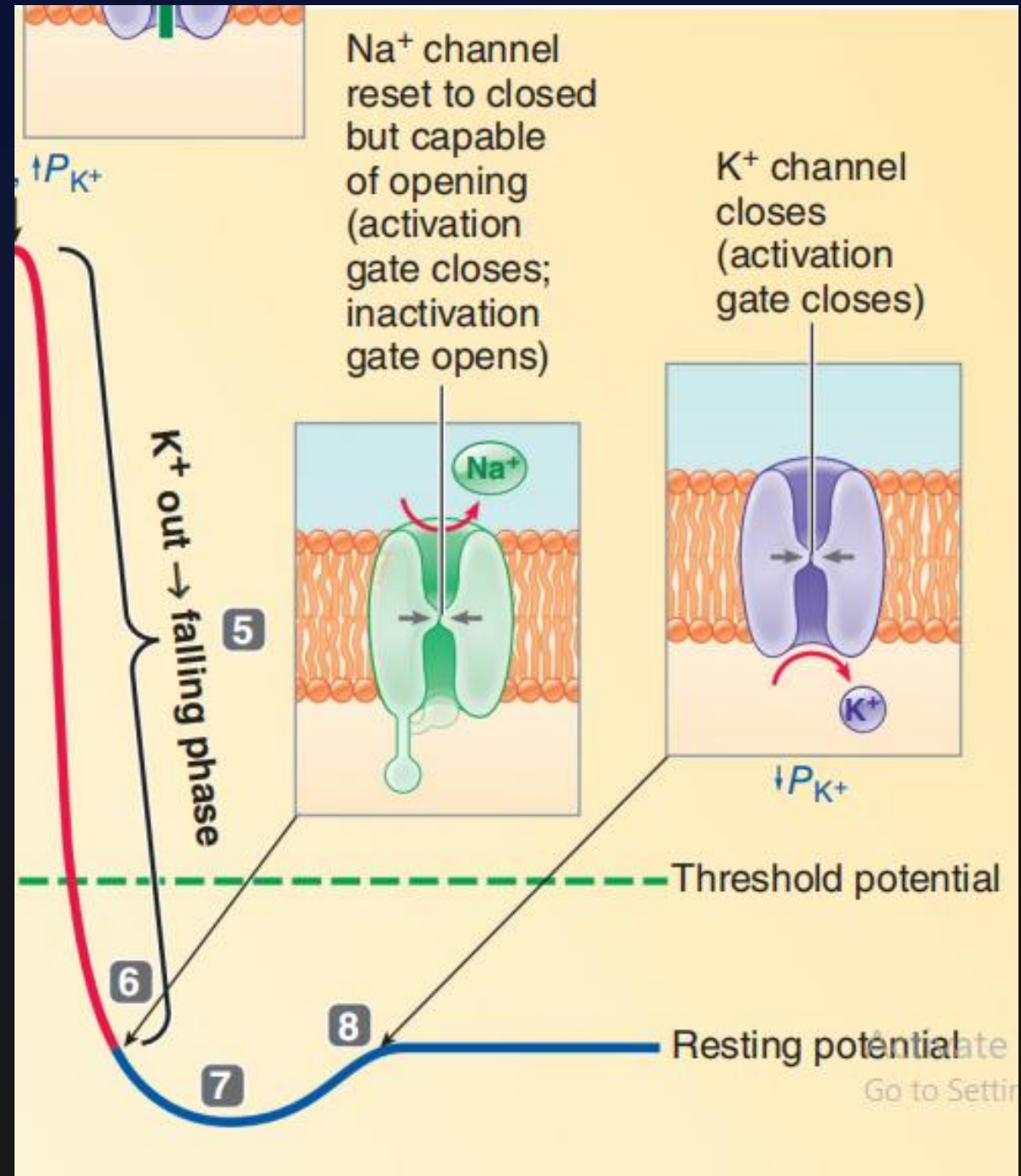
ACTION POTENTIAL

3. Na^+ enters cell, causing explosive depolarization to +30 mV, which generates rising phase of action potential.
4. At peak of action potential, Na^+ inactivation gate closes, ending net movement of Na^+ into cell. At the same time, K^+ activation gate opens.



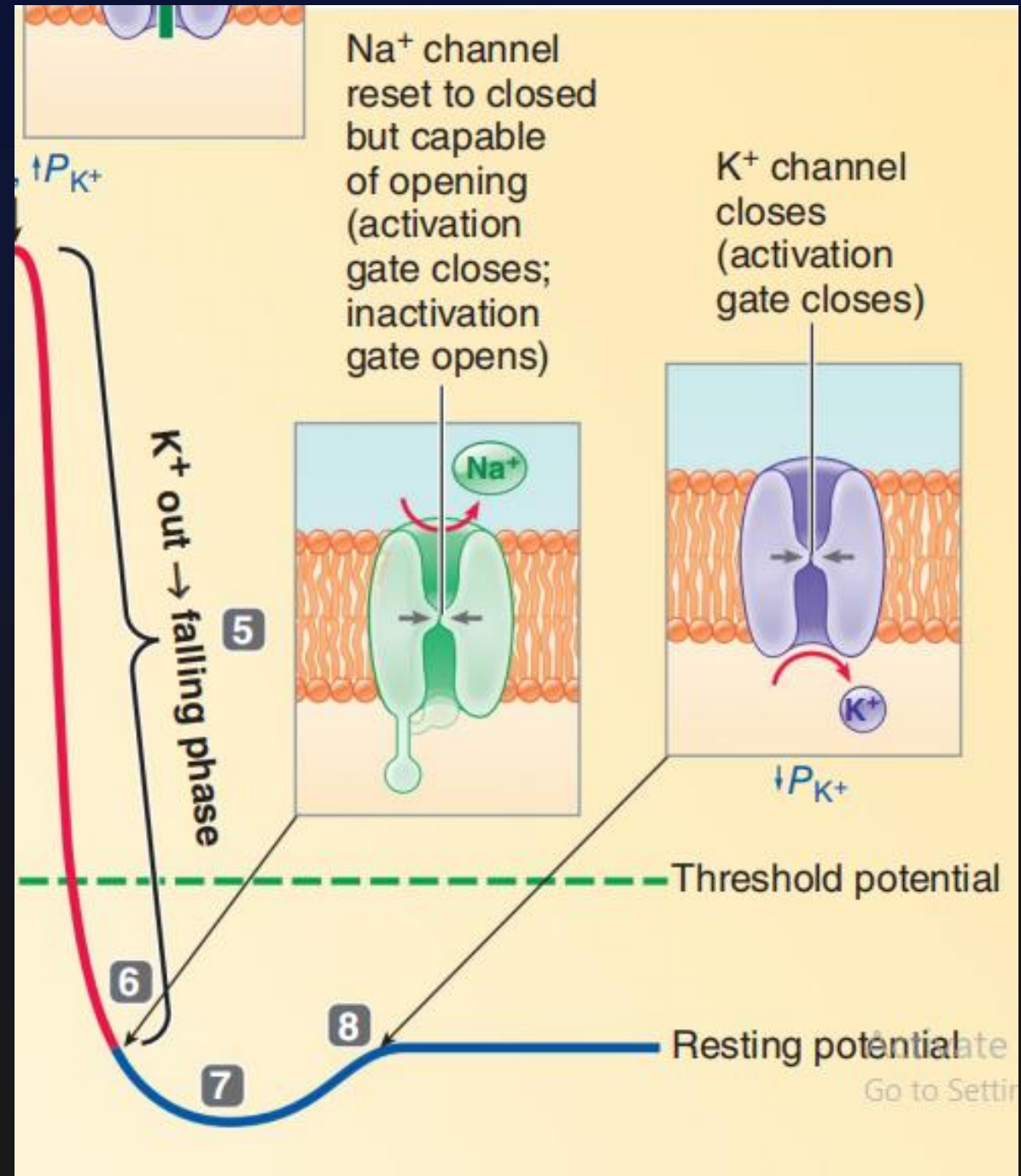
ACTION POTENTIAL

5. K^+ leaves cell, causing its repolarization to resting potential, which generates falling phase of action potential.
6. On return to **resting potential**, **Na^+ activation gate closes and inactivation gate opens**, resetting channel to respond to another depolarizing triggering event.



ACTION POTENTIAL

- Further outward movement of K^+ through still-open K^+ channel briefly hyperpolarizes membrane, which generates after **hyperpolarization**.
- K^+ activation gate closes**, and membrane returns to resting potential.



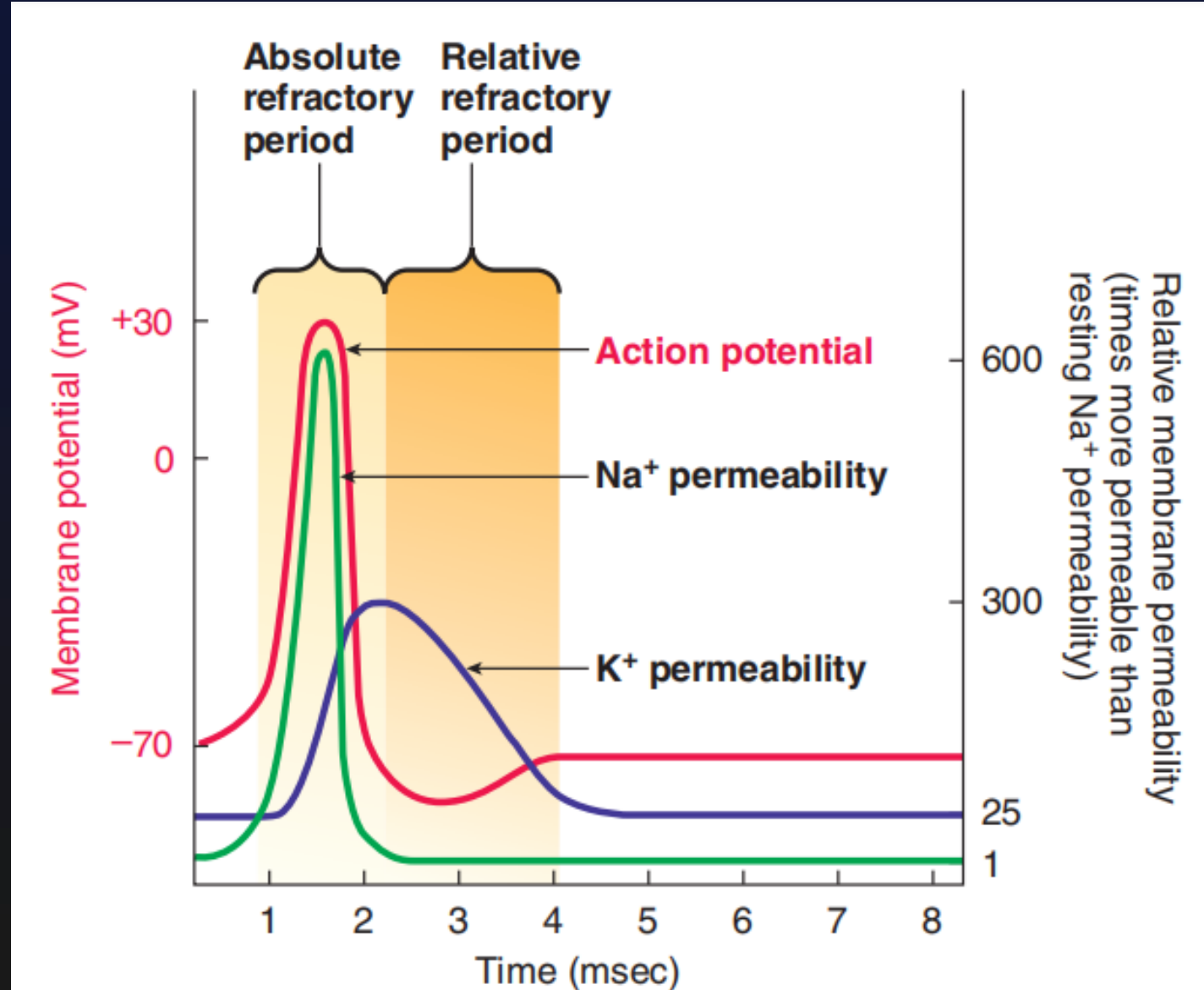
THE REFRACTORY PERIOD

THE REFRACTORY PERIOD

- The refractory period is the time during which **a second action potential cannot or is difficult to initiate** in a region that has just fired.
- The refractory period has two components:
 - 1. Absolute refractory period
 - 2. Relative refractory period

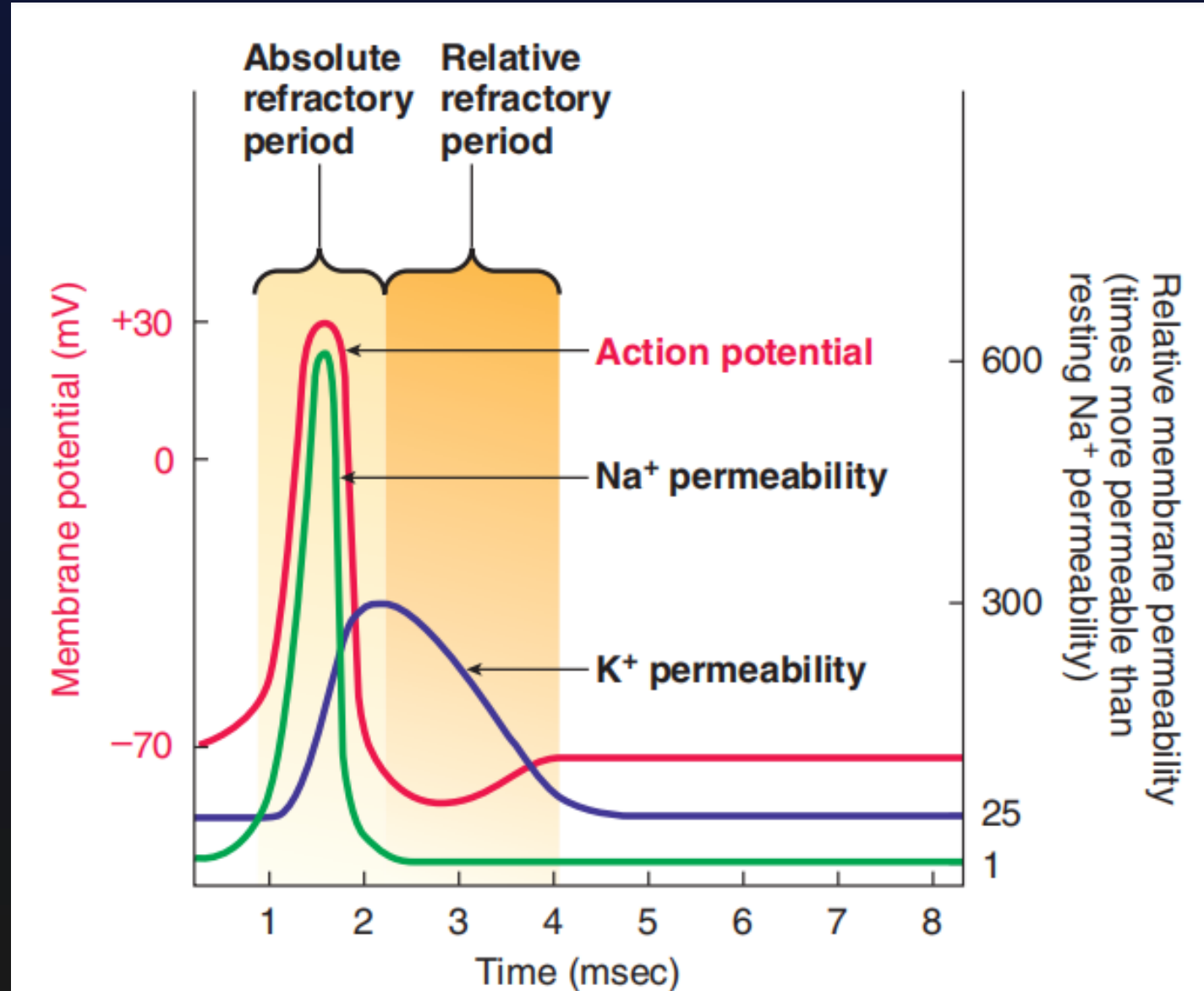
ABSOLUTE REFRACTORY PERIOD

- The absolute refractory period is the time during which **no new action potential can be generated, no matter** how strong the stimulus is.



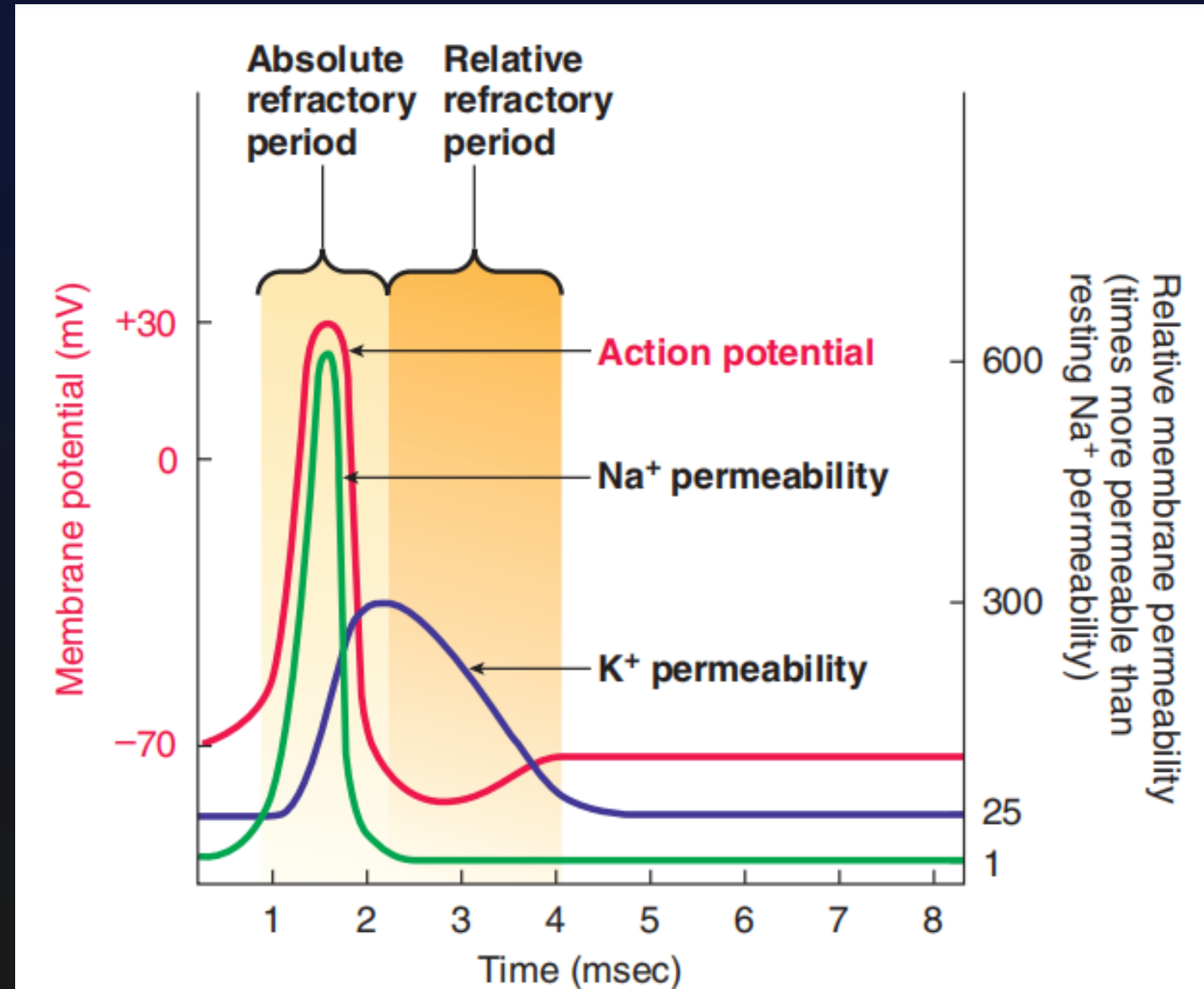
ABSOLUTE REFRACTORY PERIOD

- ❑ Cause:
- ❑ Once the voltage-gated Na⁺ channels are triggered to open at threshold, they **cannot open again** in response to another depolarizing triggering event, no matter how strong, **until they reset to their “closed and capable of opening” conformation when resting potential is restored.**



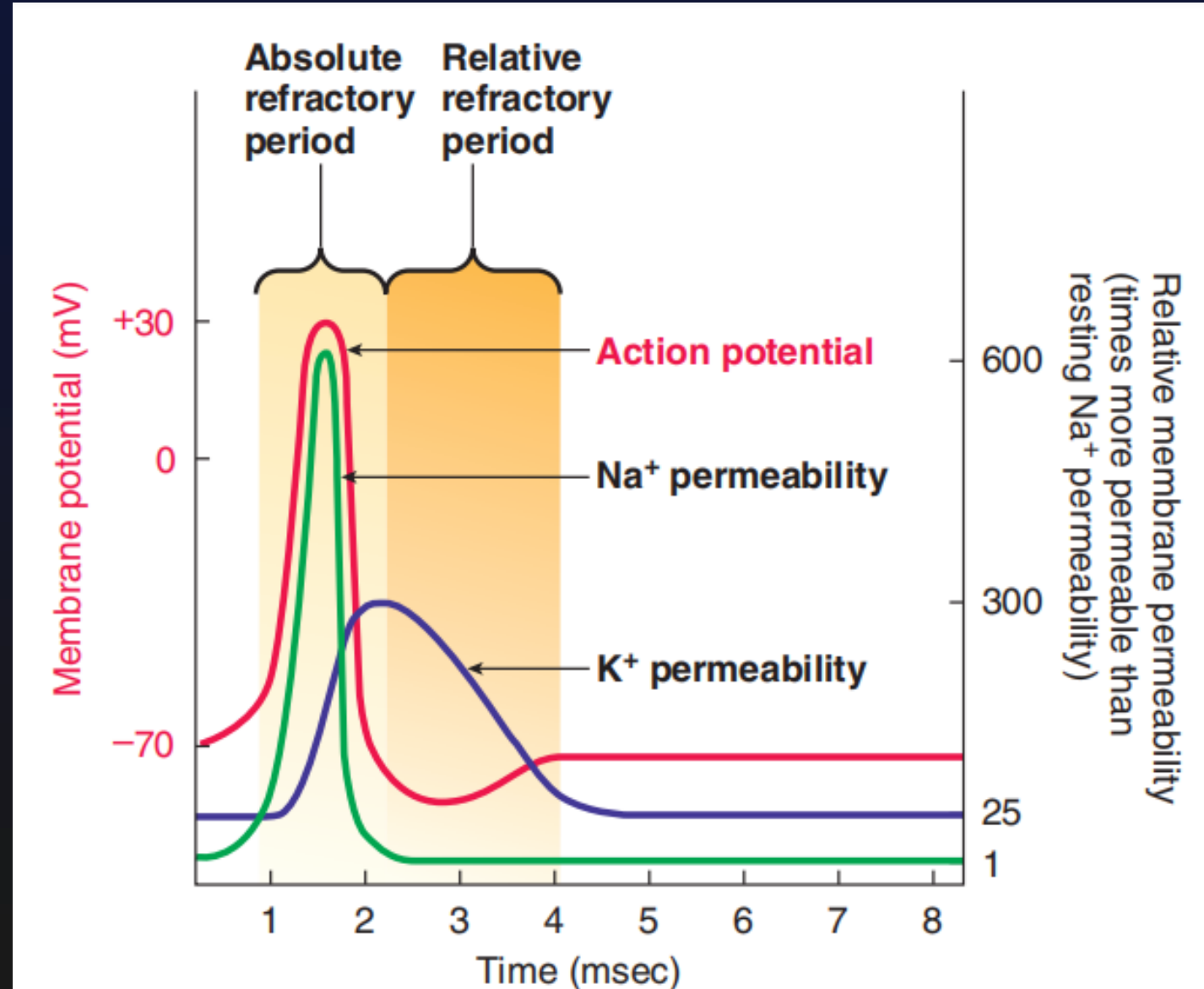
RELATIVE REFRACTORY PERIOD

- Relative refractory period, during which a second action potential can be produced only by a triggering event considerably stronger than usual.



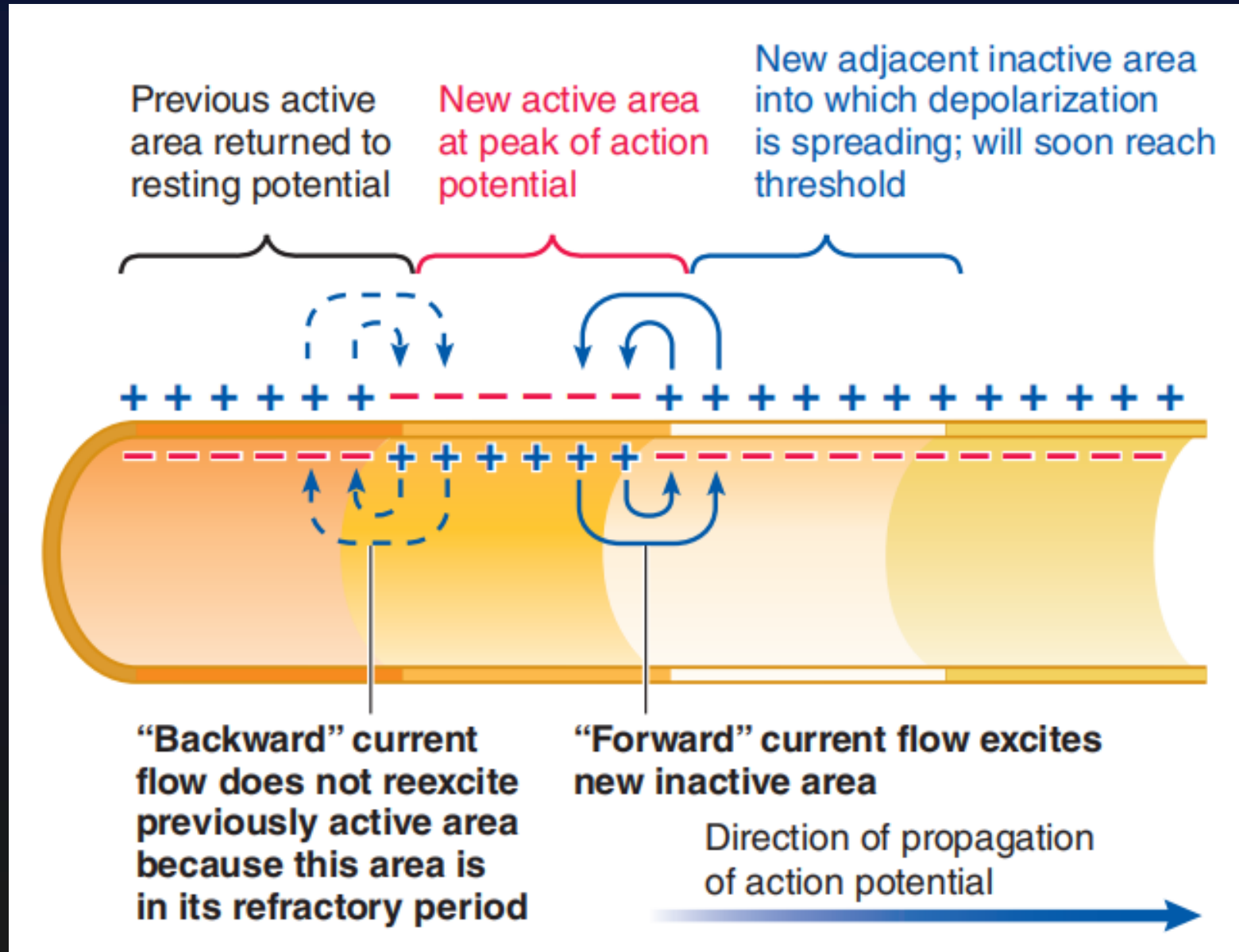
RELATIVE REFRACTORY PERIOD

- Causes:
- **First**, the voltage-gated Na^+ channels that opened during the action potential do **not all reset at once when resting potential is reached**. Some take a little **longer** to be restored to their capable of opening conformation.
- **Second**, the **voltage-gated K^+** channels that opened at the peak of the action potential **are slow to close**.



REFRACTORY PERIOD

- Thus, the refractory period ensures the one-way propagation of the action potential down the axon away from the initial site of activation.



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THANK YOU