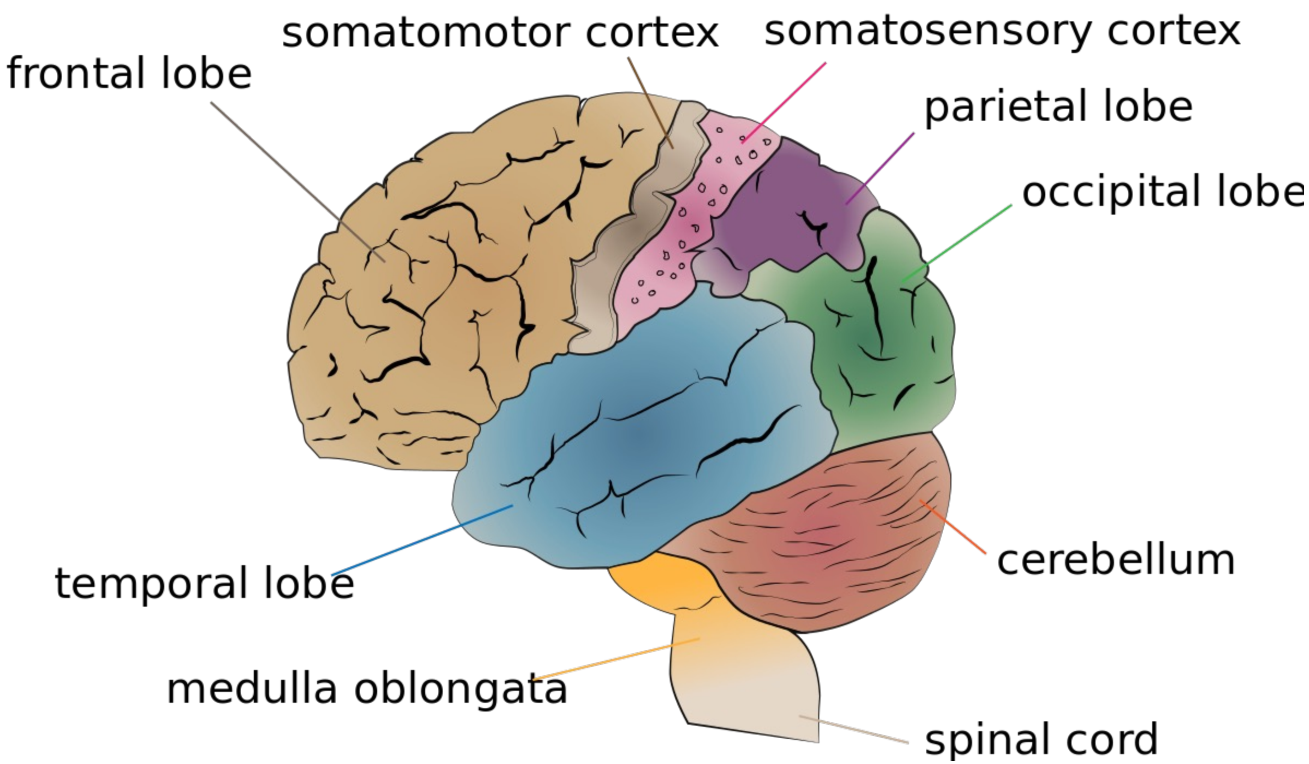
BCI-S2022

Basics of Neuroscience for BCI

The Human Brain



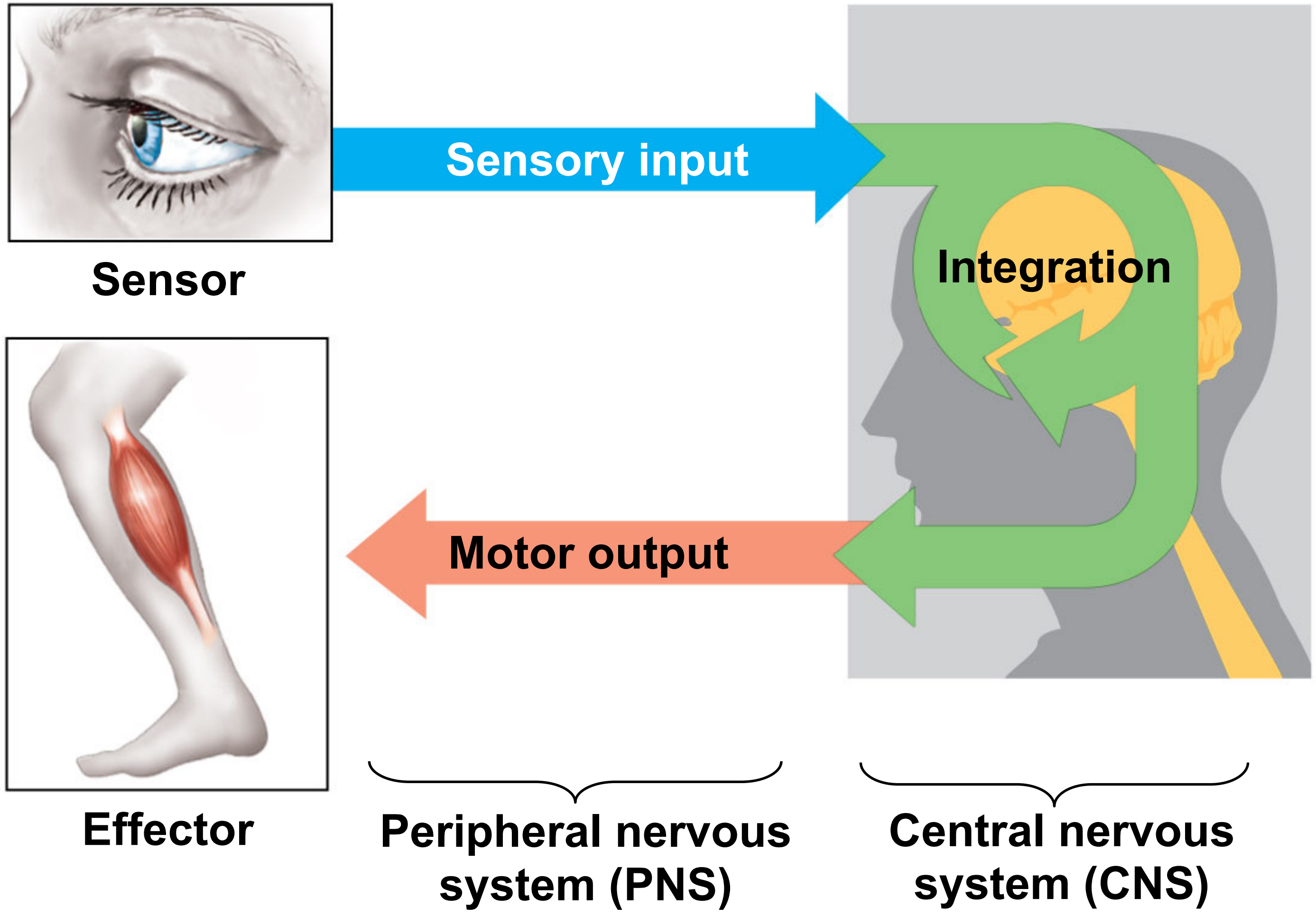
The Neuron

- The brain's unique information processing capabilities arise from its massively parallel and distributed way of computing.
- The workhorse of the brain is a type of cell known as a ***NEURON***.
- Neuron is a complex electrochemical device that receives information from hundreds of other neurons, processes this information, and conveys its output to hundreds of other neurons

The Neuron

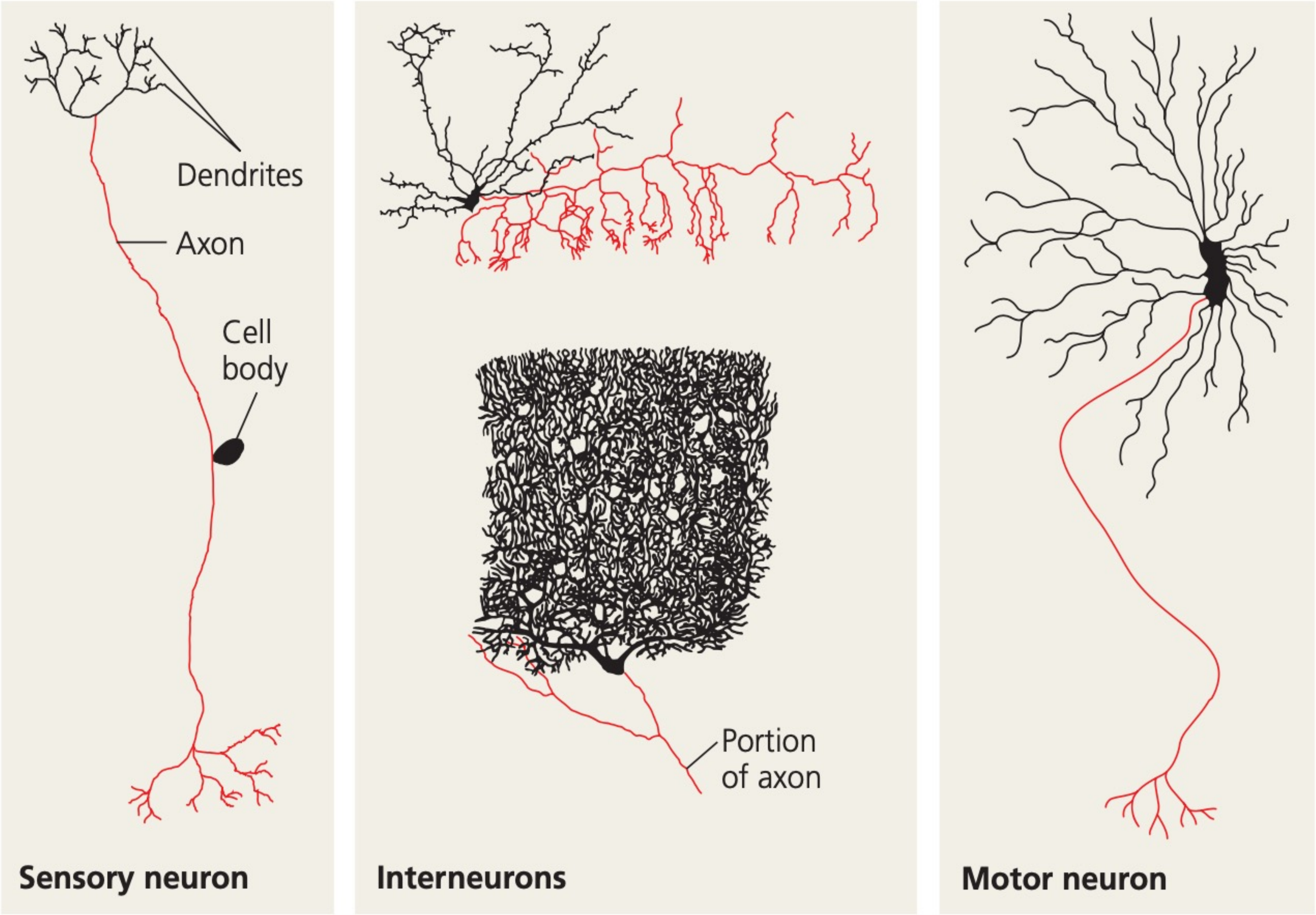
- The neuron can be regarded as a leaky bag of charged liquid.
- The membrane of a neuron is made up of a lipid bi-layer that is impermeable except for openings called ionic channel.
- The ionic channels selectively allow the passage of a few ions

REVISIT : Introduction to Information Processing



Many animals have a complex nervous system that consists of

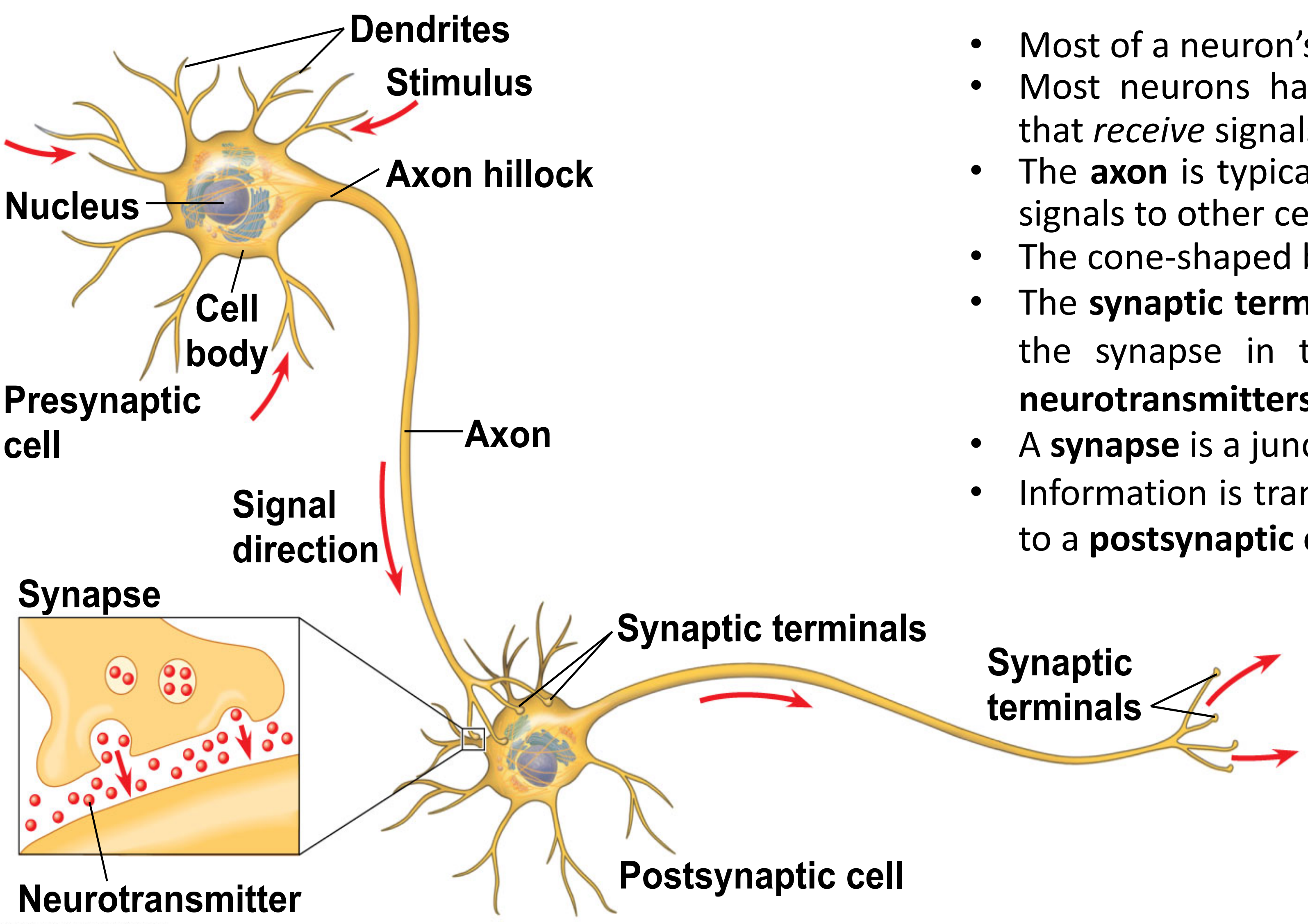
- A **central nervous system (CNS)** where integration takes place; this includes the brain and a nerve cord
- A **peripheral nervous system (PNS)**, which carries information into and out of the CNS
- The neurons of the PNS, when bundled together, form **nerves**



Structural diversity of neurons. *Cell bodies and dendrites are black in these diagrams; axons are red. In the sensory neuron, unlike the other neurons here, the cell body is located partway along the axon that conveys signals from the dendrites to the axon's terminal branches.*

- Sensors detect external stimuli and internal conditions and transmit information along **sensory neurons**
- Sensory information is sent to the brain, where **interneurons** integrate the information
- Motor output leaves the brain via **motor neurons**, which trigger muscle or gland activity

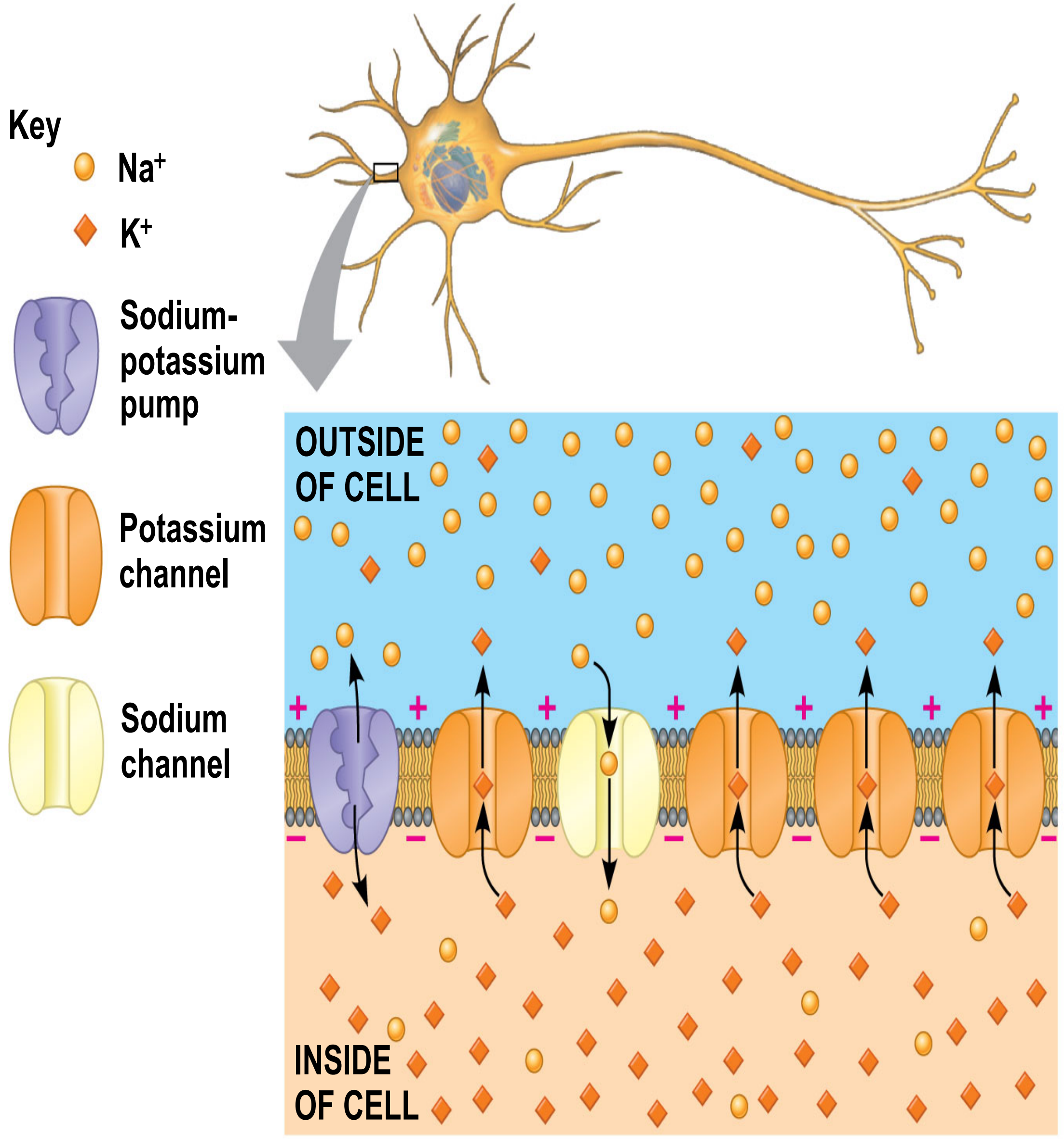
Neuron Structure and Function



- Most of a neuron's organelles are in the **cell body.**
- Most neurons have **dendrites**, highly branched extensions that *receive* signals from other neurons.
- The **axon** is typically a much longer extension that transmits signals to other cells at synapses.
- The cone-shaped base of an axon is called the **axon hillock.**
- The **synaptic terminal** of one axon passes information across the synapse in the form of chemical messengers called **neurotransmitters.**
- A **synapse** is a junction between an axon and another cell
- Information is transmitted from a **presynaptic cell** (a neuron) to a **postsynaptic cell** (a neuron, muscle, or gland cell).

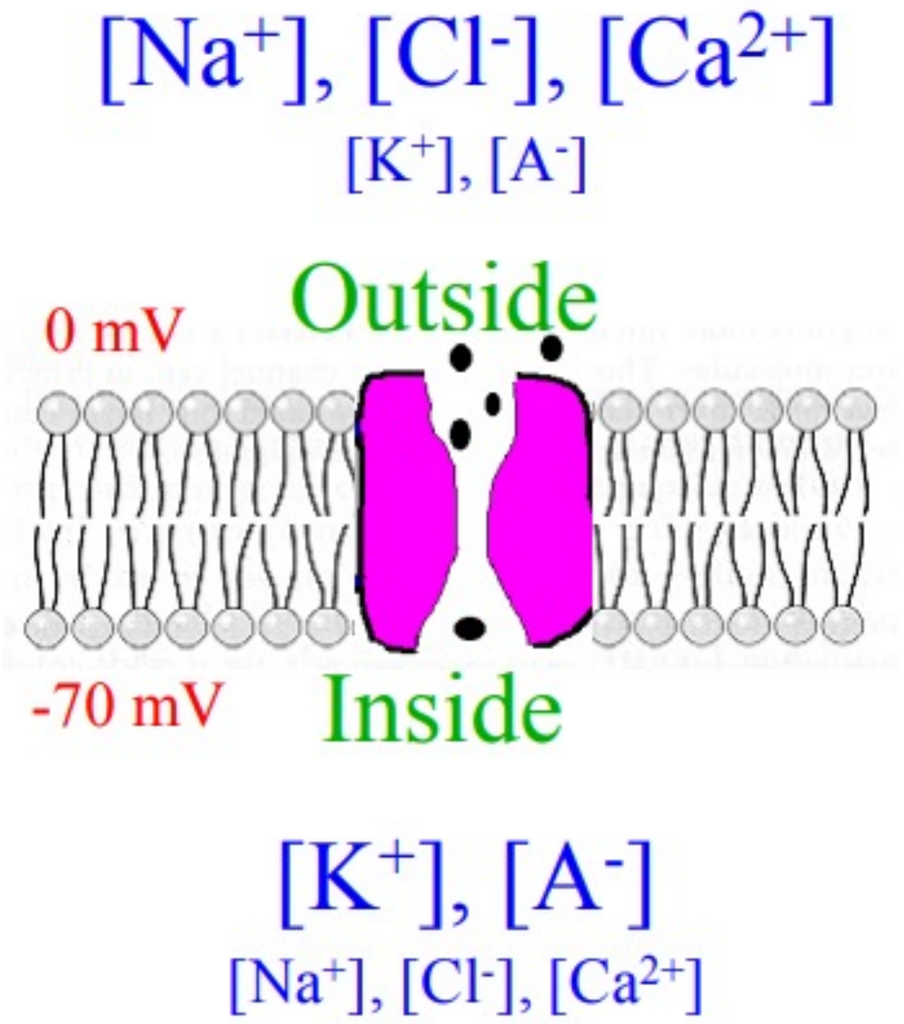
Ion pumps and ion channels establish the resting potential of a neuron

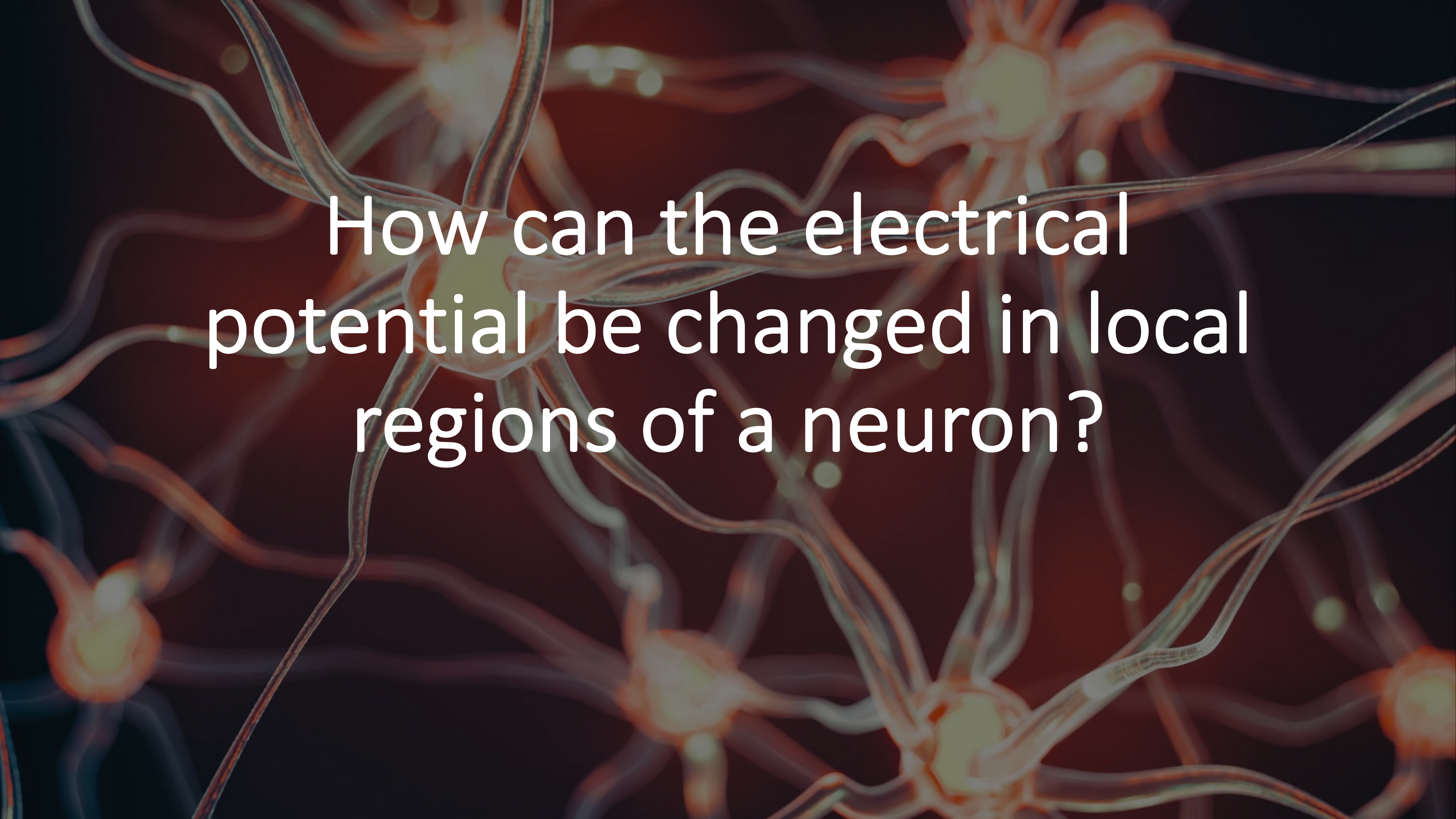
- Every cell has a voltage (difference in electrical charge) across its plasma membrane called a **membrane potential.**
- The **resting potential** is the membrane potential of a neuron not sending signals.
- Changes in membrane potential act as signals, transmitting and processing information.
- In a mammalian neuron at resting potential, the concentration of K^+ is highest inside the cell, while the concentration of Na^+ is highest outside the cell.
- The opening of **ion channels** in the plasma membrane converts chemical potential to electrical potential.
- A neuron at resting potential contains many open K^+ channels and fewer open Na^+ channels; K^+ diffuses out of the cell.
- The resulting buildup of negative charge within the neuron is the major source of membrane potential.



The Electrical Personality of a Neuron

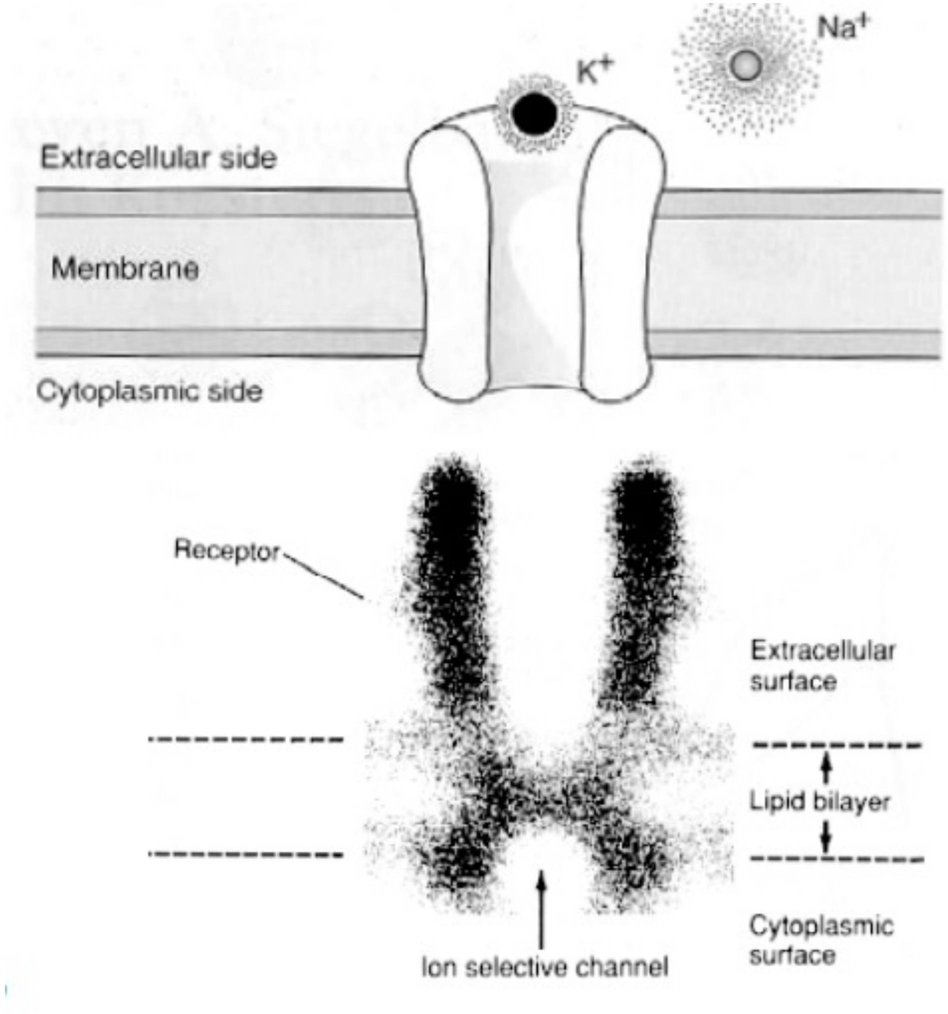
- Each neuron maintains a potential difference across its membrane
- Inside is ±65 to ±70 mV relative to outside
- [Na+], [Cl-] and [Ca2+] higher outside; [K+] and organic anions [A-] higher inside
- Ionic pump maintains -70 mV difference by expelling Na+ out and allowing K+ ions in
- In a resting neuron, the currents of K^+ and Na^+ are equal and opposite, and the resting potential across the membrane remains steady




How can the electrical potential be changed in local regions of a neuron?

Ionic Channels: The Gatekeepers

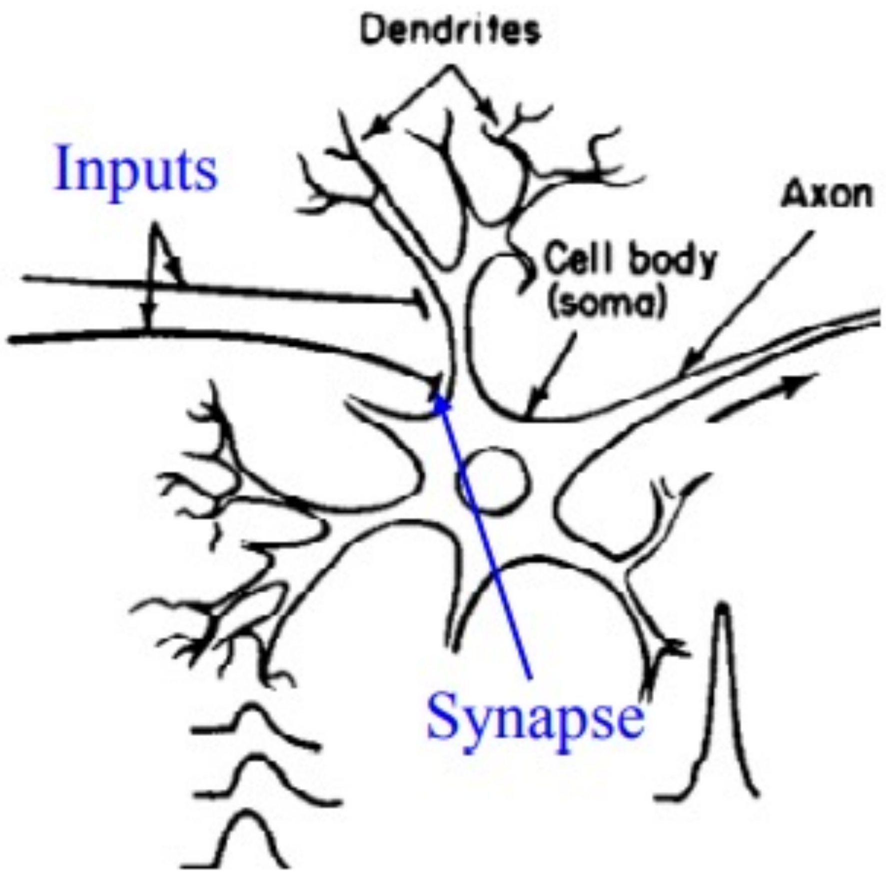
- Changes in membrane potential occur because neurons contain **gated ion channels** that open or close in response to stimuli
- Proteins in membranes act as channels that allow specific ions to pass through.
  - E.g.: Pass K+ but not Cl- or Na+
- These **IONIC CHANNELS** are gated
  - Voltage-gated: Probability of opening depends on membrane voltage
  - Chemically-gated: Binding to a chemical causes channel to open
  - Mechanically-gated: Sensitive to pressure or stretch



From Kandel, Schwartz, Jessel, Principles of Neural Science, 3rd edn., 1991, pgs. 68 & 137

Gated Channels allow Neuronal Signaling

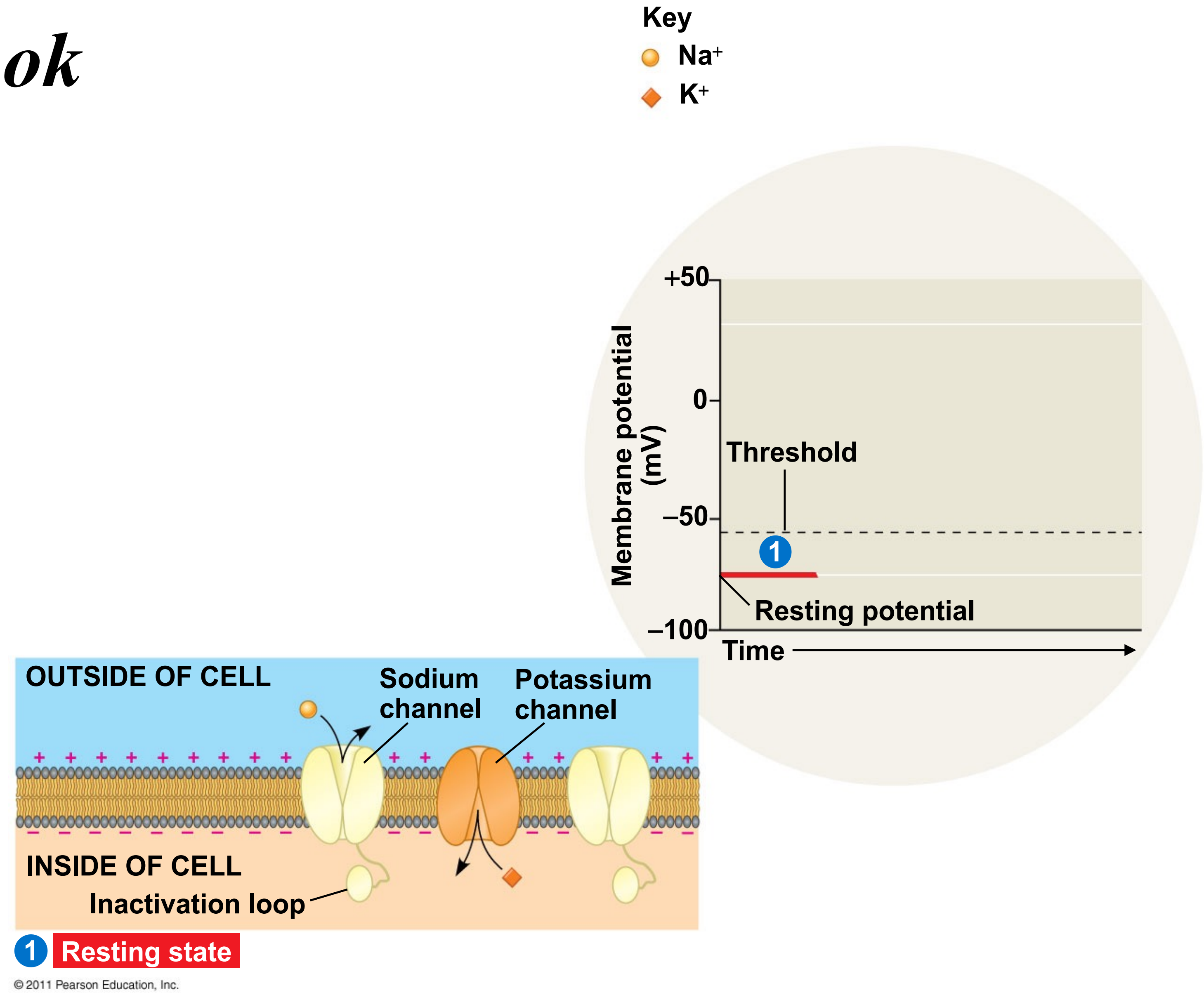
- Inputs from other neurons -> chemically-gated channels (at "synapses") -> Changes in local membrane potential
- This causes opening/closing of voltage-gated channels in dendrites, body, and axon, resulting in depolarization (positive change in voltage) or hyperpolarization (negative change)



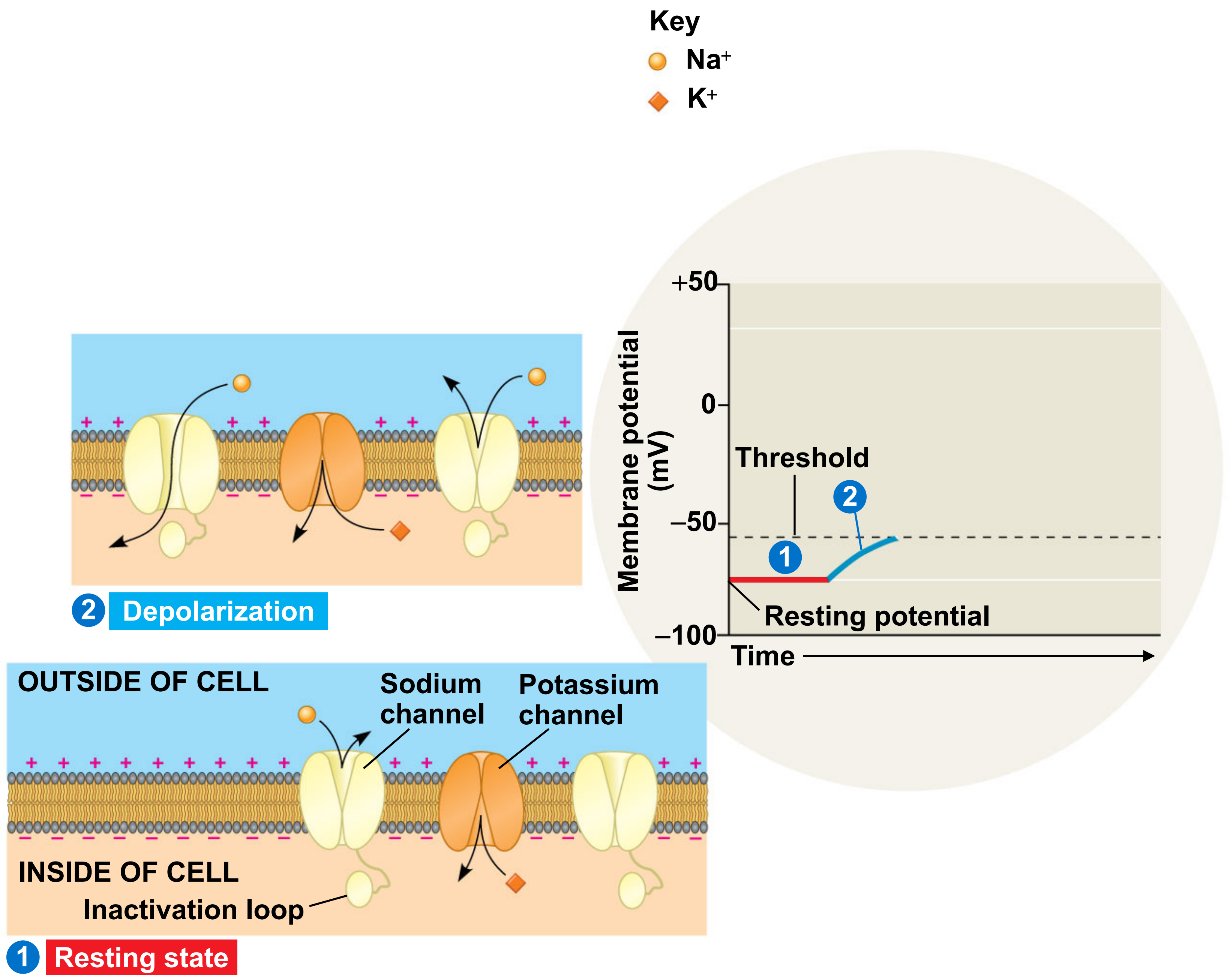
Generation of Action Potentials: *A Closer Look*

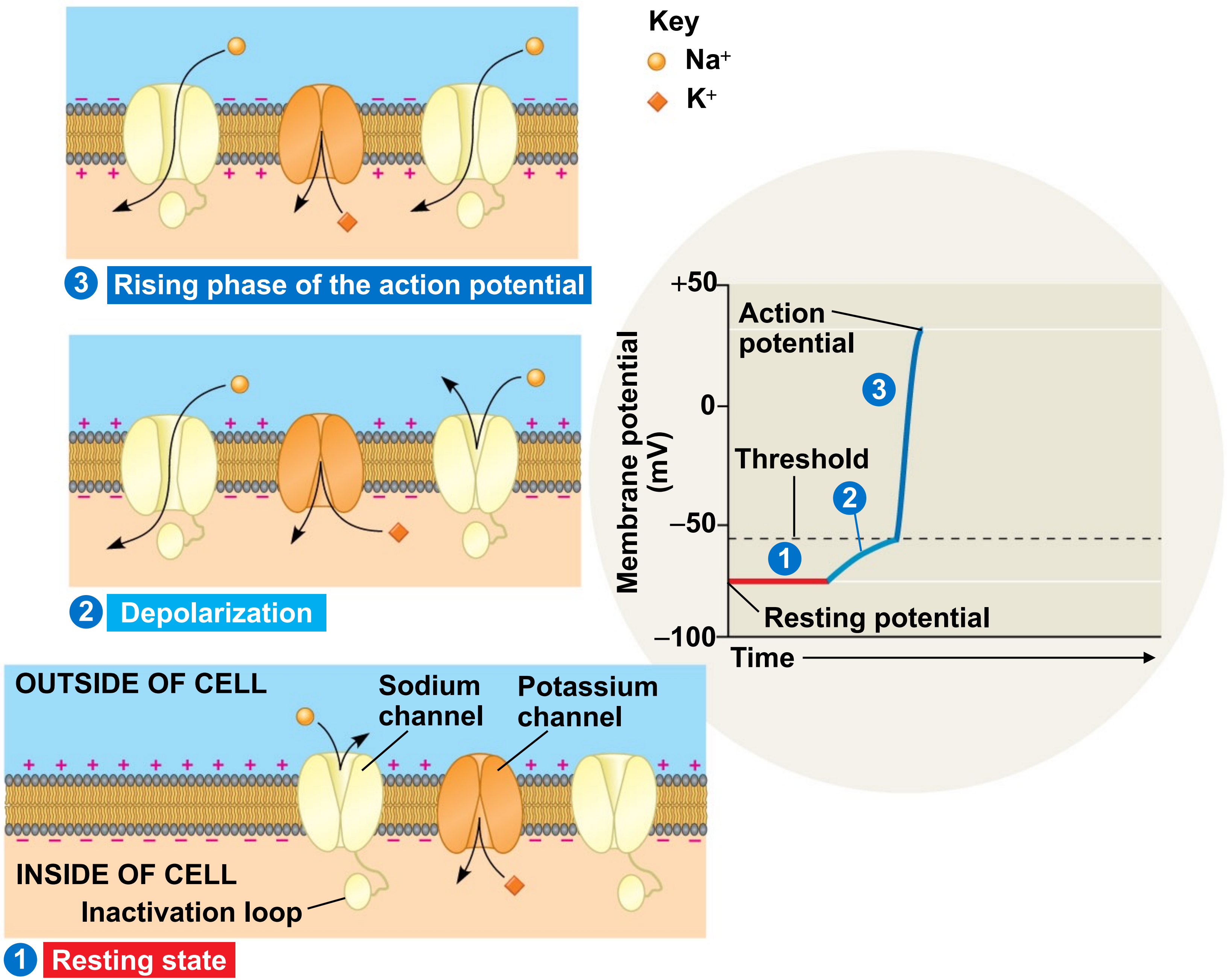
An action potential can be considered as a series of stages

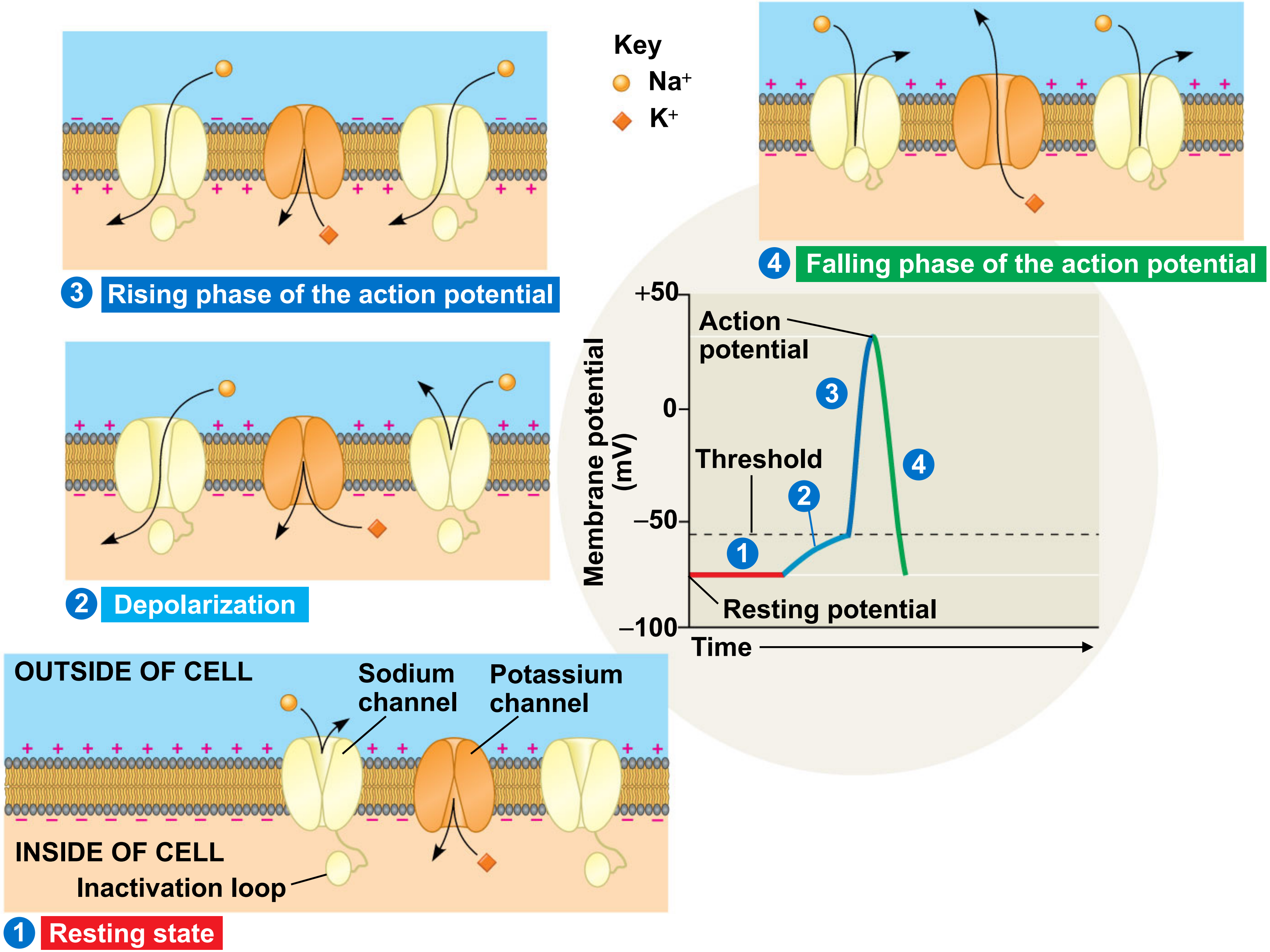
- At resting potential
    1. Most voltage-gated sodium (Na^+) channels are closed; most of the voltage-gated potassium (K^+) channels are also closed



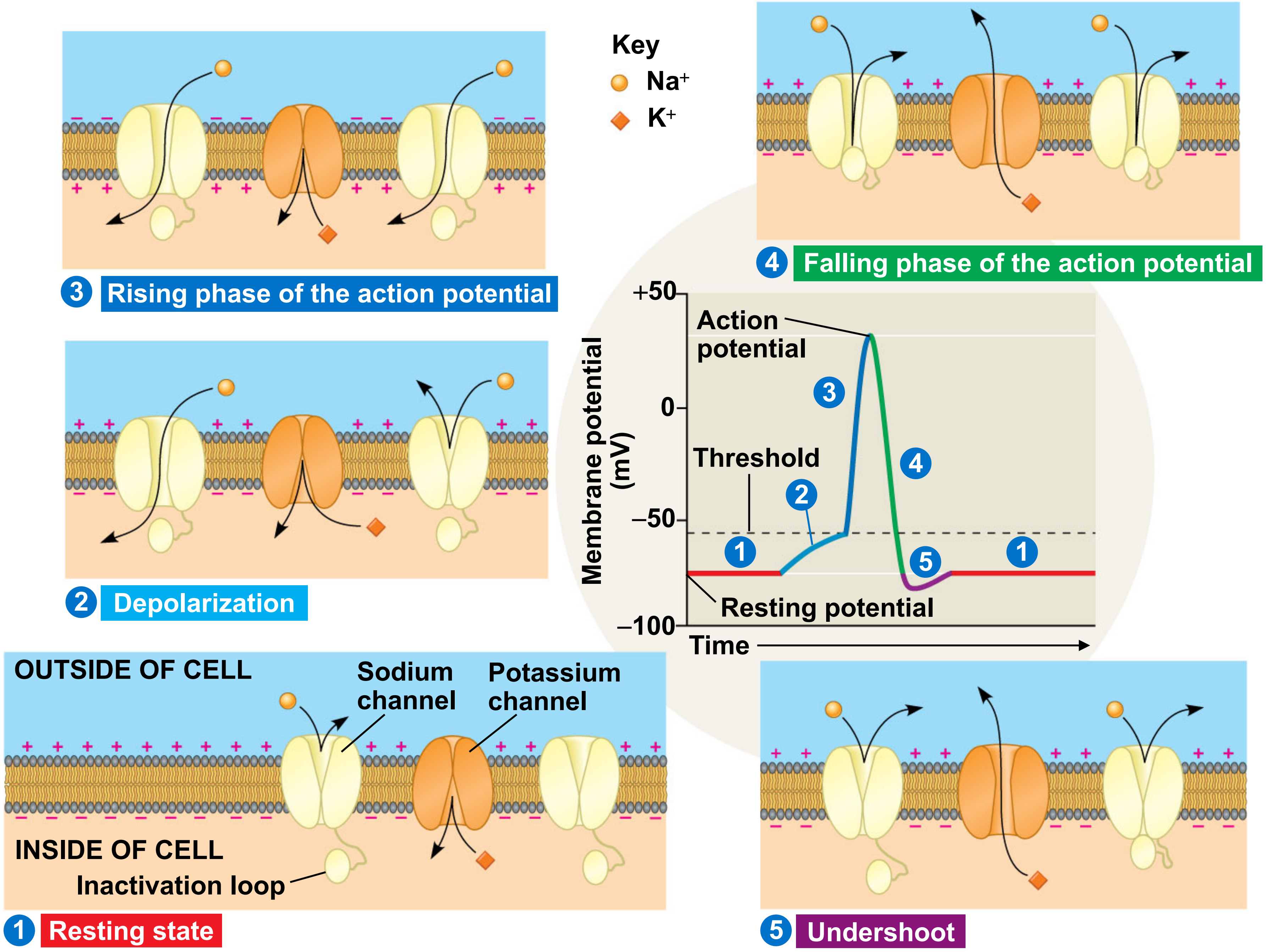
- When an action potential is generated
  2. Voltage-gated Na^+ channels open first and Na^+ flows into the cell
  3. During the *rising phase*, the threshold is crossed, and the membrane potential increases
  4. During the *falling phase*, voltage-gated Na^+ channels become inactivated; voltage-gated K^+ channels open, and K^+ flows out of the cell


Key
Na+
K+
+50
0
−50
−100
Membrane potential (mV)
Threshold
2
1
Resting potential
Time
2 Depolarization
OUTSIDE OF CELL
Sodium channel
Potassium channel
INSIDE OF CELL
Inactivation loop
1 Resting state

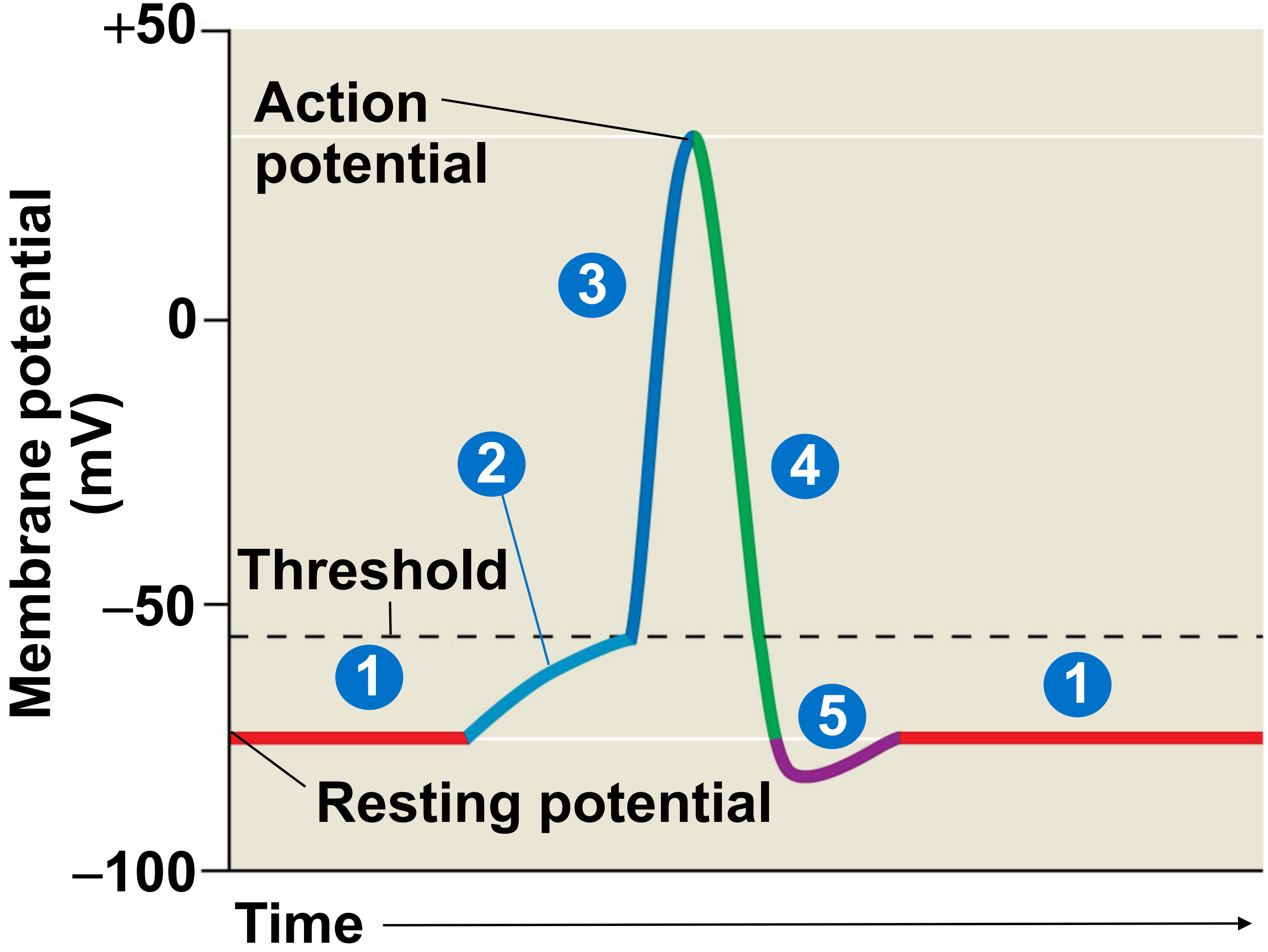

Key
Na+
K+
Rising phase of the action potential
Depolarization
OUTSIDE OF CELL
Sodium channel
Potassium channel
INSIDE OF CELL
Inactivation loop
Resting state
+50
0
–50
–100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time


Key
Na+
K+
Rising phase of the action potential
Falling phase of the action potential
Depolarization
Resting state
OUTSIDE OF CELL
INSIDE OF CELL
Sodium channel
Potassium channel
Inactivation loop
Membrane potential (mV)
+50
0
–50
–100
Action potential
Threshold
Resting potential
Time
1
2
3
4

5. During the *undershoot*, membrane permeability to K^+ is at first higher than at rest, then voltage-gated K^+ channels close and resting potential is restored



Key
Na+
K+
3 Rising phase of the action potential
4 Falling phase of the action potential
2 Depolarization
Membrane potential (mV)
+50
0
–50
–100
Action potential
Threshold
Resting potential
Time
3
4
2
1
5
1
OUTSIDE OF CELL
Sodium channel
Potassium channel
INSIDE OF CELL
Inactivation loop
1 Resting state
5 Undershoot


+50
0
–50
–100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time
1
2
3
4
5
1

- During the **refractory period** after an action potential, a second action potential cannot be initiated
- The refractory period is a result of a temporary inactivation of the Na^+ channels