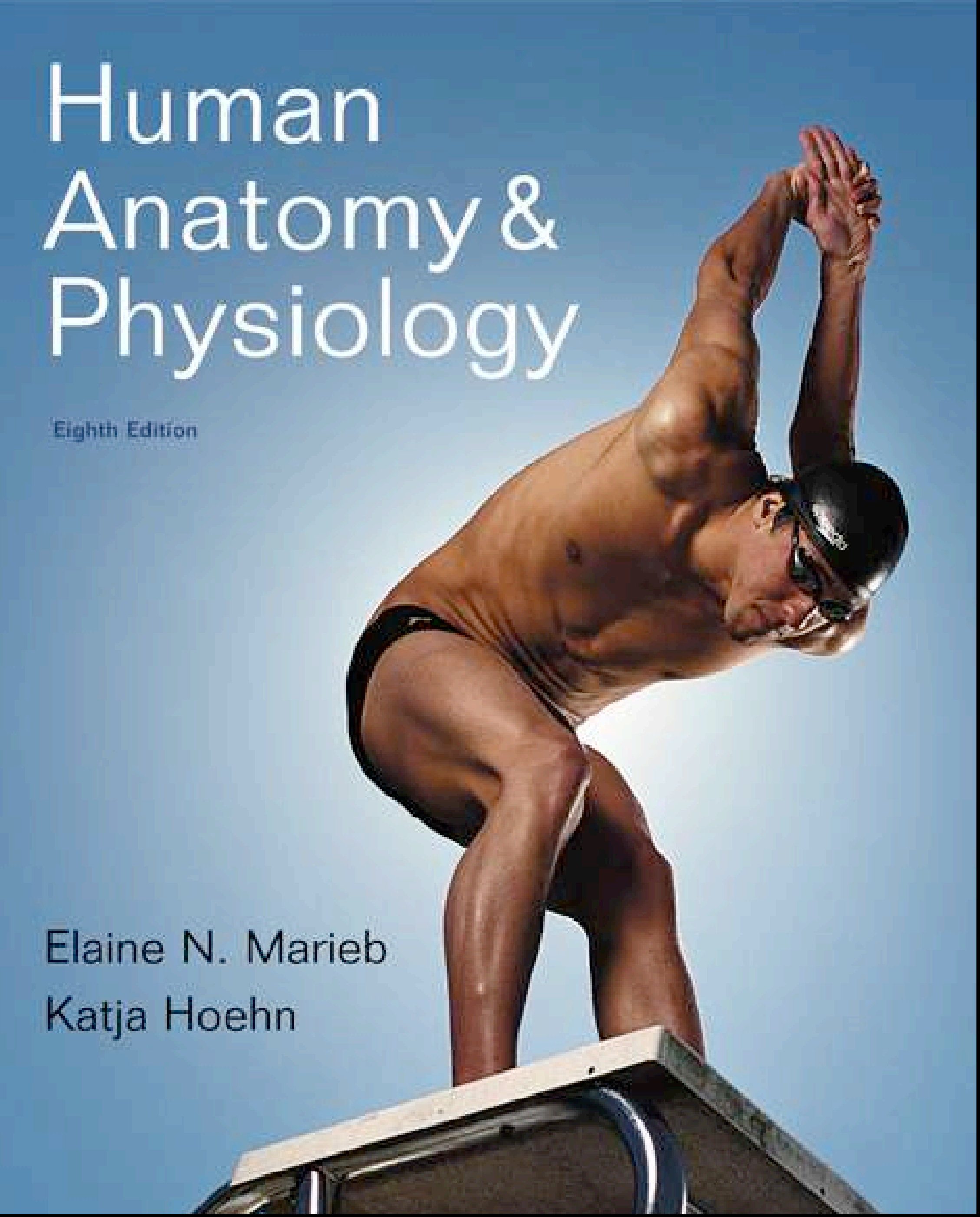

PowerPoint® Lecture Slides
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CHAPTER 11

Fundamentals of the Nervous System and Nervous Tissue: Part B

Neuron Function

- Neurons are highly irritable
- Respond to adequate stimulus by generating an action potential (nerve impulse)
- Impulse is always the same regardless of stimulus

Principles of Electricity

- Opposite charges attract each other
- Energy is required to separate opposite charges across a membrane
- Energy is liberated when the charges move toward one another
- If opposite charges (charges in general) are separated, the system has potential energy

Definitions

- Voltage (V): measure of potential energy generated by separated charge
- Potential difference: voltage measured between two points
- Current (I): the flow of electrical charge (ions) between two points

Definitions

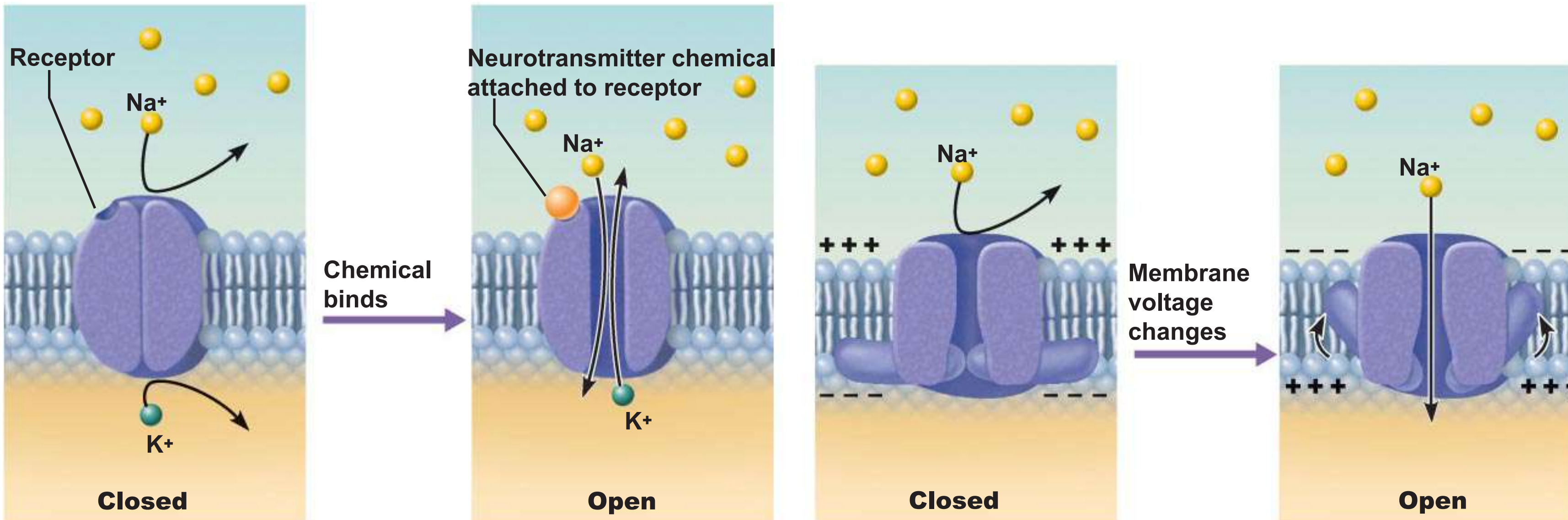
- Resistance (R): hindrance to charge flow (provided by the plasma membrane)
- Insulator: substance with high electrical resistance
- Conductor: substance with low electrical resistance

Role of Membrane Ion Channels

- Proteins serve as membrane ion channels
- Two main types of ion channels
  1. Leakage (nongated) channels—always open

Role of Membrane Ion Channels

2. Gated channels (three types):
   - Chemically gated (ligand-gated) channels—open with binding of a specific neurotransmitter
   - Voltage-gated channels—open and close in response to changes in membrane potential
   - Mechanically gated channels—open and close in response to physical deformation of receptors



(a) Chemically (ligand) gated ion channels open when the appropriate neurotransmitter binds to the receptor, allowing (in this case) simultaneous movement of Na^+ and K^+.

(b) Voltage-gated ion channels open and close in response to changes in membrane voltage.

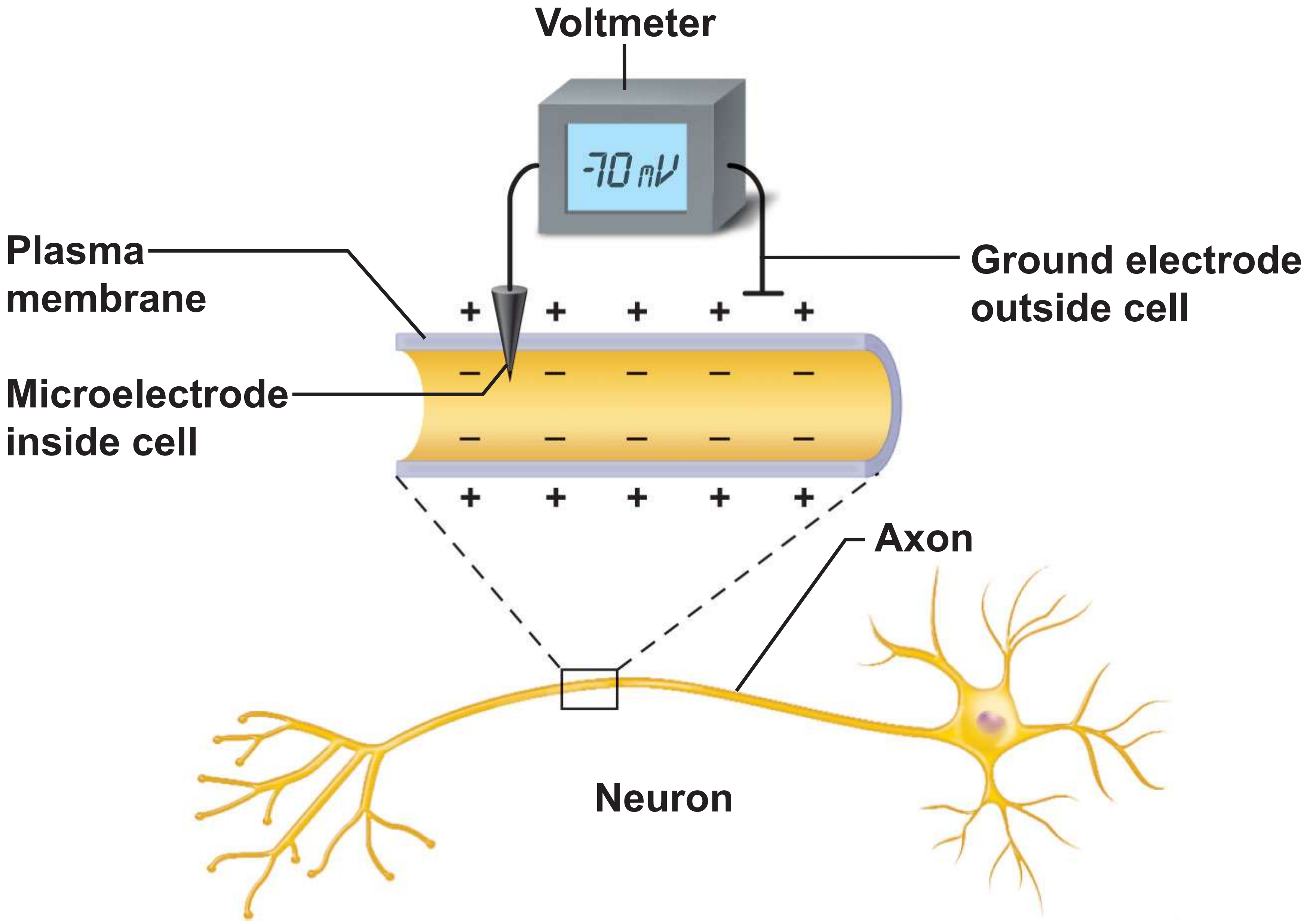
Figure 11.6

Gated Channels

- When gated channels are open:
  - Ions diffuse quickly across the membrane along their electrochemical gradients
    - Along chemical concentration gradients from higher concentration to lower concentration
    - Along electrical gradients toward opposite electrical charge
  - Ion flow creates an electrical current and voltage changes across the membrane

Resting Membrane Potential (Vr)

- Potential difference across the membrane of a resting cell
  - Approximately –70 mV in neurons (cytoplasmic side of membrane is negatively charged relative to outside)
- Generated by:
  - Differences in ionic makeup of ICF and ECF
  - Differential permeability of the plasma membrane



Voltmeter
-70 mV
Plasma membrane
Ground electrode outside cell
Microelectrode inside cell
Axon
Neuron

Figure 11.7

Resting Membrane Potential

- Differences in ionic makeup
  - ICF has lower concentration of Na^+ and Cl^- than ECF
  - ICF has higher concentration of K^+ and negatively charged proteins (A^-) than ECF

Resting Membrane Potential

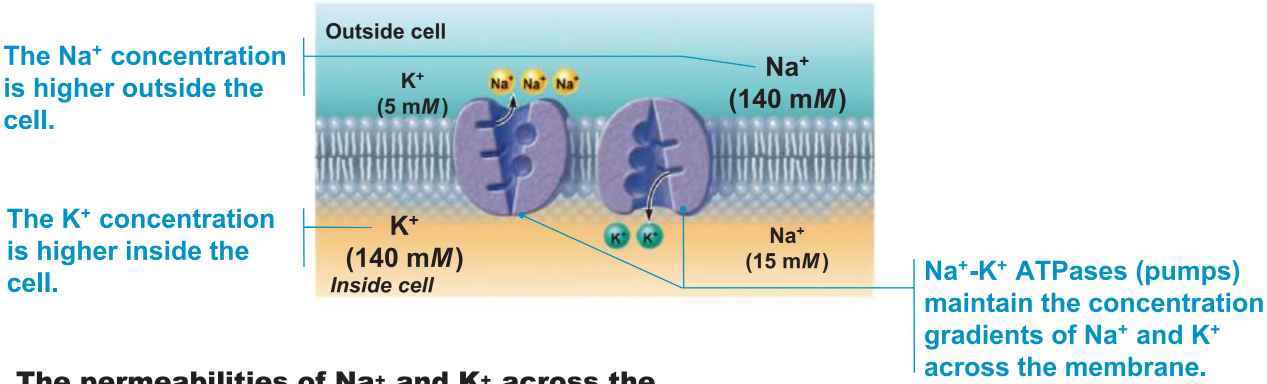
- Differential permeability of membrane
  - Impermeable to A^-
  - Slightly permeable to Na^+ (through leakage channels)
  - 75 times more permeable to K^+ (more leakage channels)
  - Freely permeable to Cl^-

Resting Membrane Potential

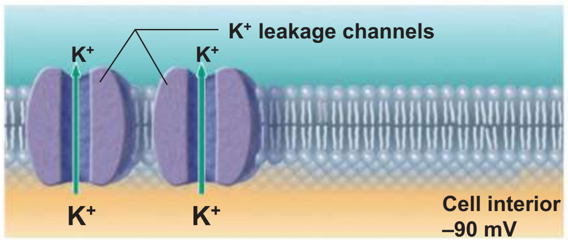
- Negative interior of the cell is due to much greater diffusion of K^+ out of the cell than Na^+ diffusion into the cell
- Sodium-potassium pump stabilizes the resting membrane potential by maintaining the concentration gradients for Na^+ (out) and $K^{+(in)}$

PLAY *A&P Flix*™: Resting Membrane Potential

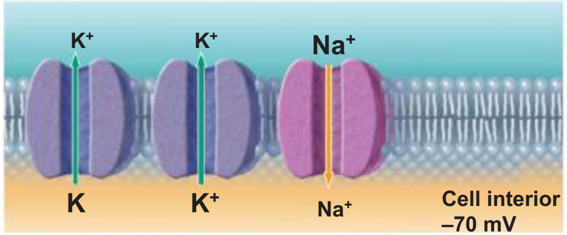
The concentrations of Na+ and K+ on each side of the membrane are different.



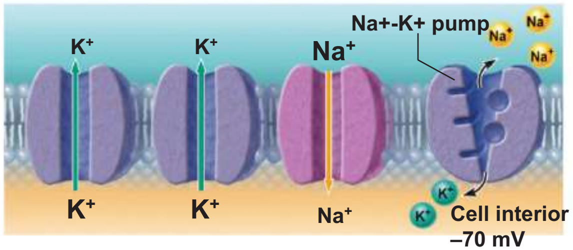
The permeabilities of Na+ and K+ across the membrane are different.



Suppose a cell has only K+ channels... K+ loss through abundant leakage channels establishes a negative membrane potential.



Now, let's add some Na+ channels to our cell... Na+ entry through leakage channels reduces the negative membrane potential slightly.



Finally, let's add a pump to compensate for leaking ions. Na+-K+ ATPases (pumps) maintain the concentration gradients, resulting in the resting membrane potential.

Figure 11.8

Membrane Potentials That Act as Signals

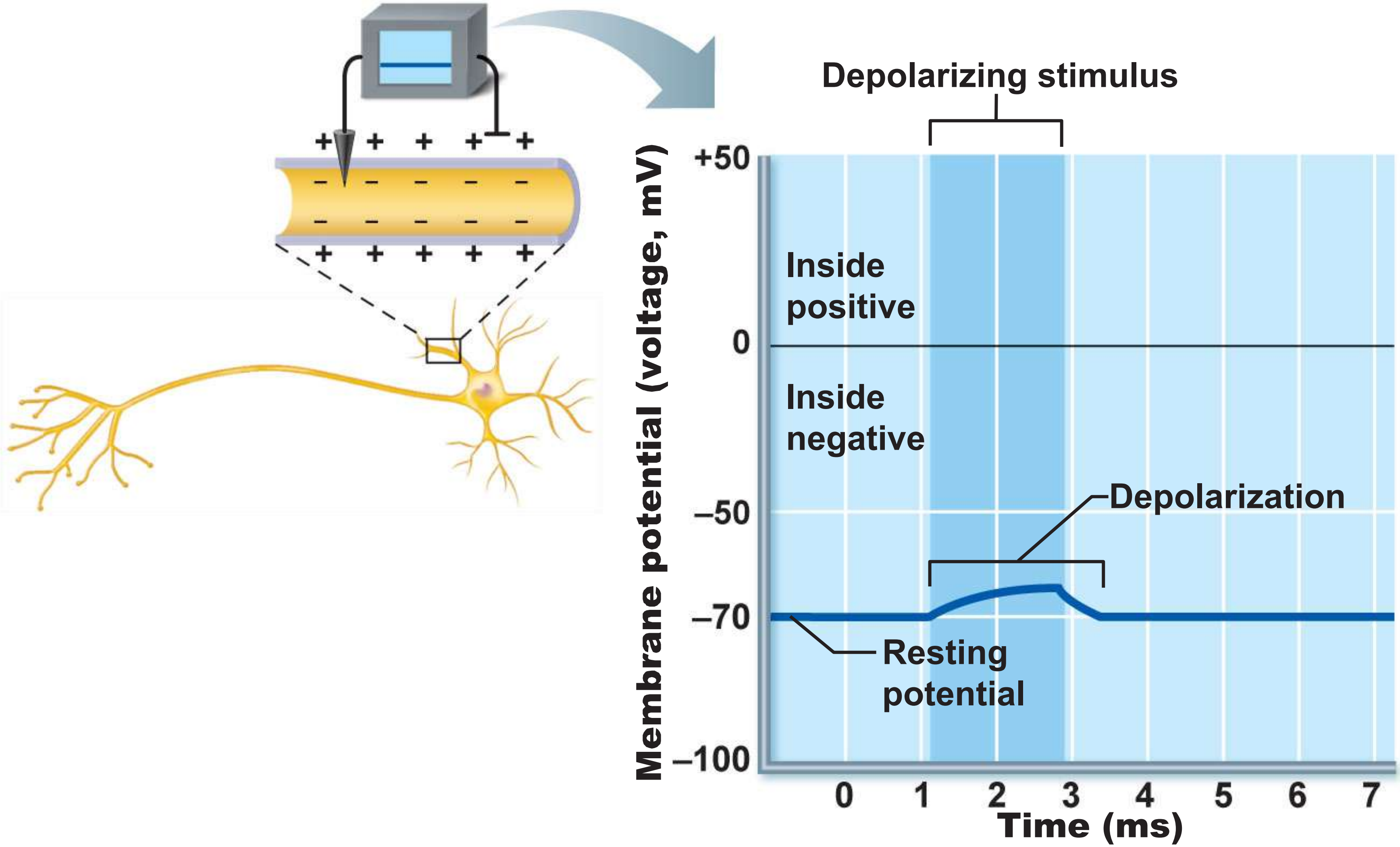
- Membrane potential changes when:
  - Concentrations of ions across the membrane change
  - Permeability of membrane to ions changes
- Changes in membrane potential are signals used to receive, integrate and send information

Membrane Potentials That Act as Signals

- Two types of signals
  - Graded potentials
    - Incoming short-distance signals
  - Action potentials
    - Long-distance signals of axons

Changes in Membrane Potential

- Depolarization
  - A reduction in membrane potential (toward zero)
  - Inside of the membrane becomes less negative than the resting potential
  - Increases the probability of producing a nerve impulse

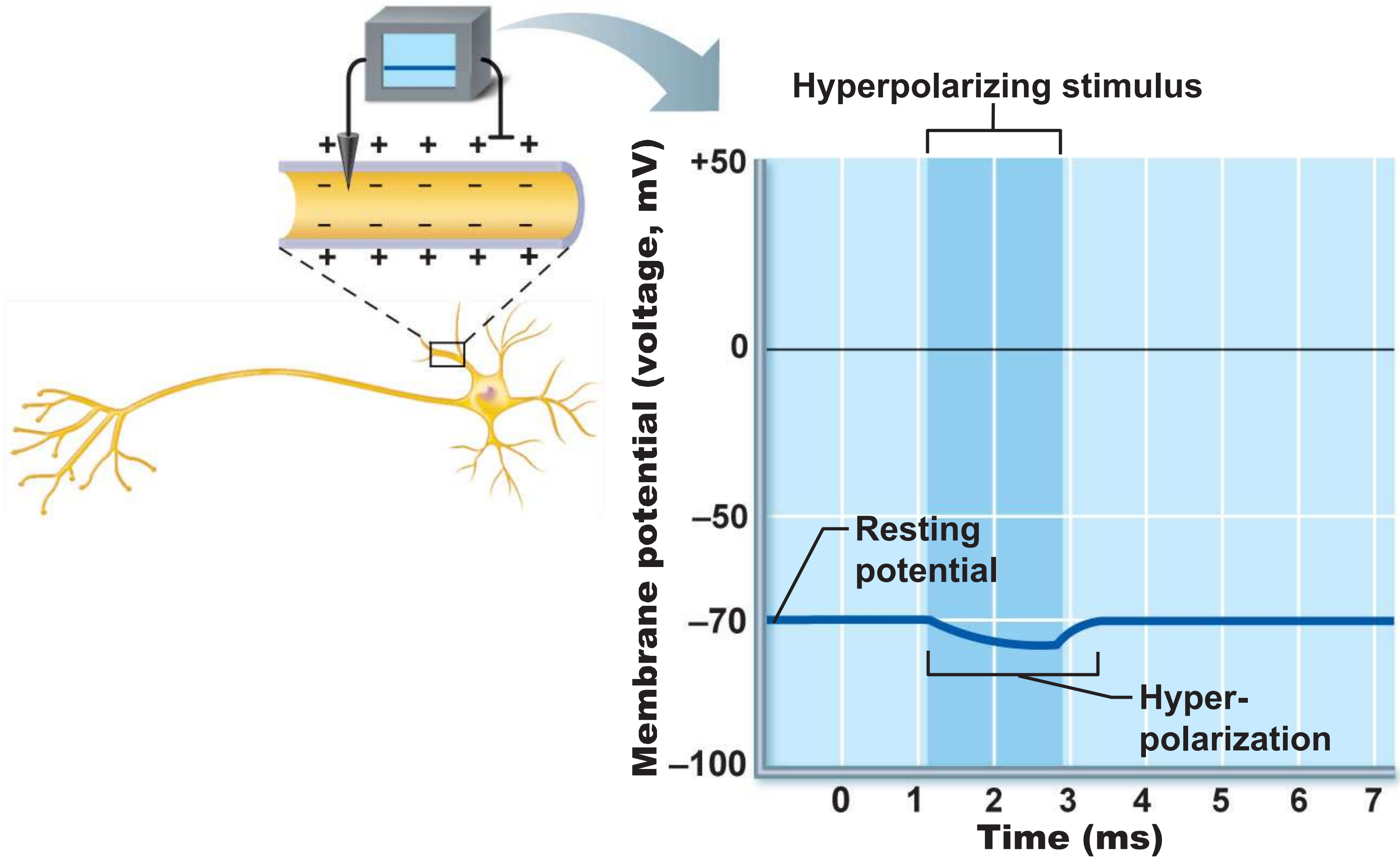


(a) Depolarization: The membrane potential moves toward 0 mV, the inside becoming less negative (more positive).

Figure 11.9a

Changes in Membrane Potential

- Hyperpolarization
  - An increase in membrane potential (away from zero) more negative
  - Inside of the membrane becomes more negative than the resting potential
  - Reduces the probability of producing a nerve impulse

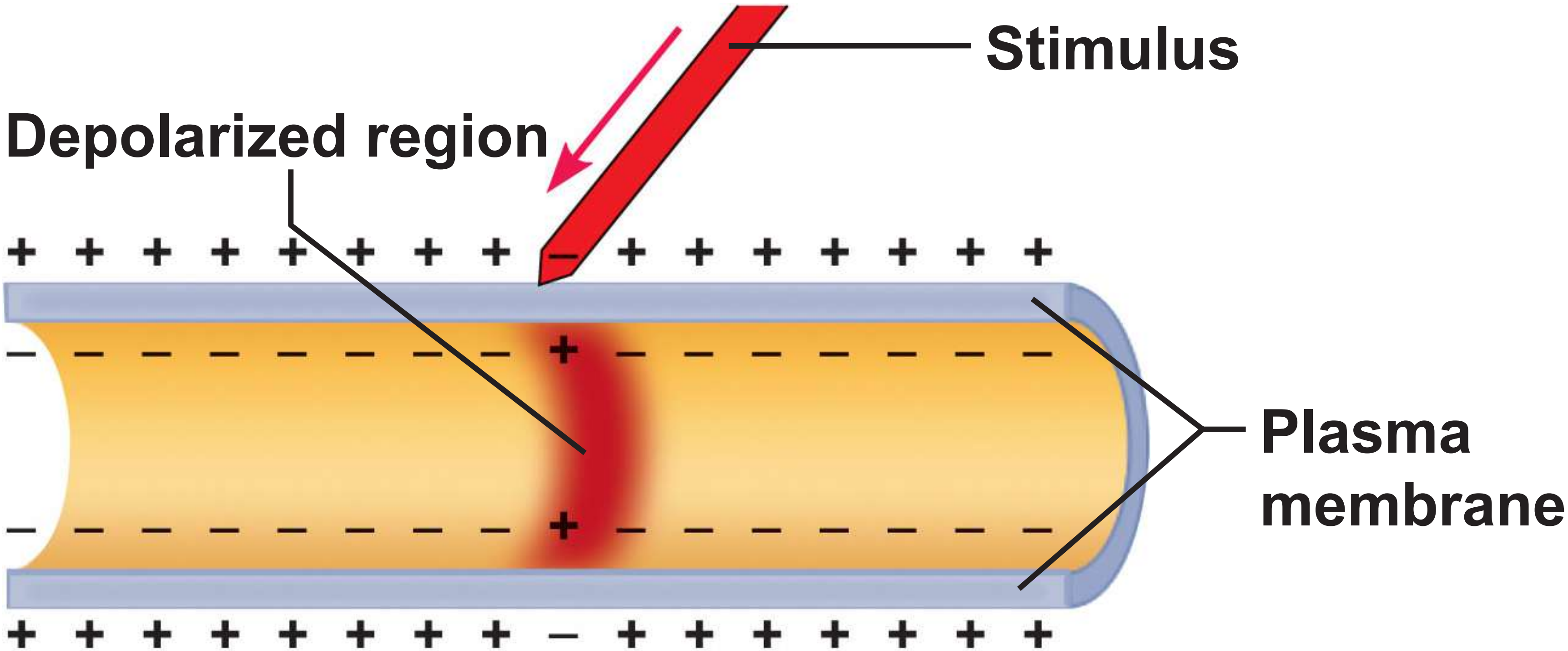


(b) Hyperpolarization: The membrane potential increases, the inside becoming more negative.

Figure 11.9b

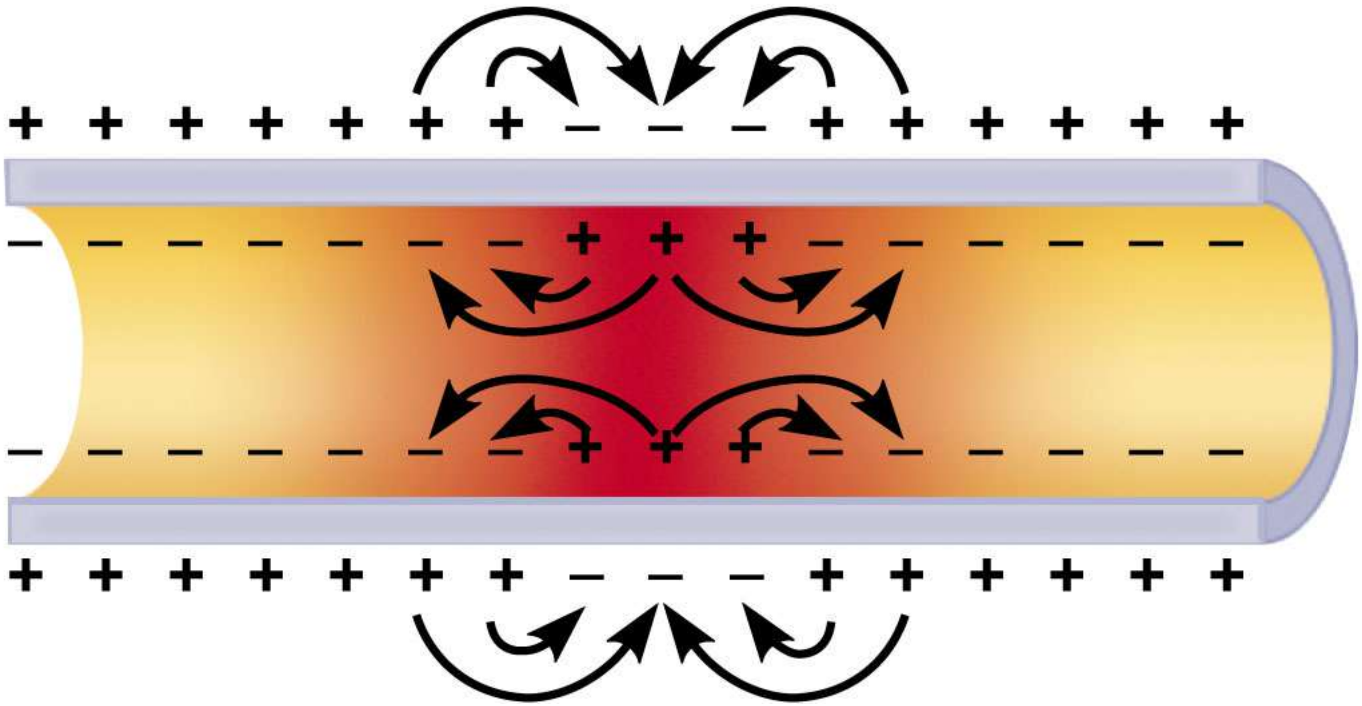
Graded Potentials

- Short-lived, localized changes in membrane potential
- Depolarizations or hyperpolarizations
- Graded potential spreads as local currents change the membrane potential of adjacent regions



(a) Depolarization: A small patch of the membrane (red area) has become depolarized.

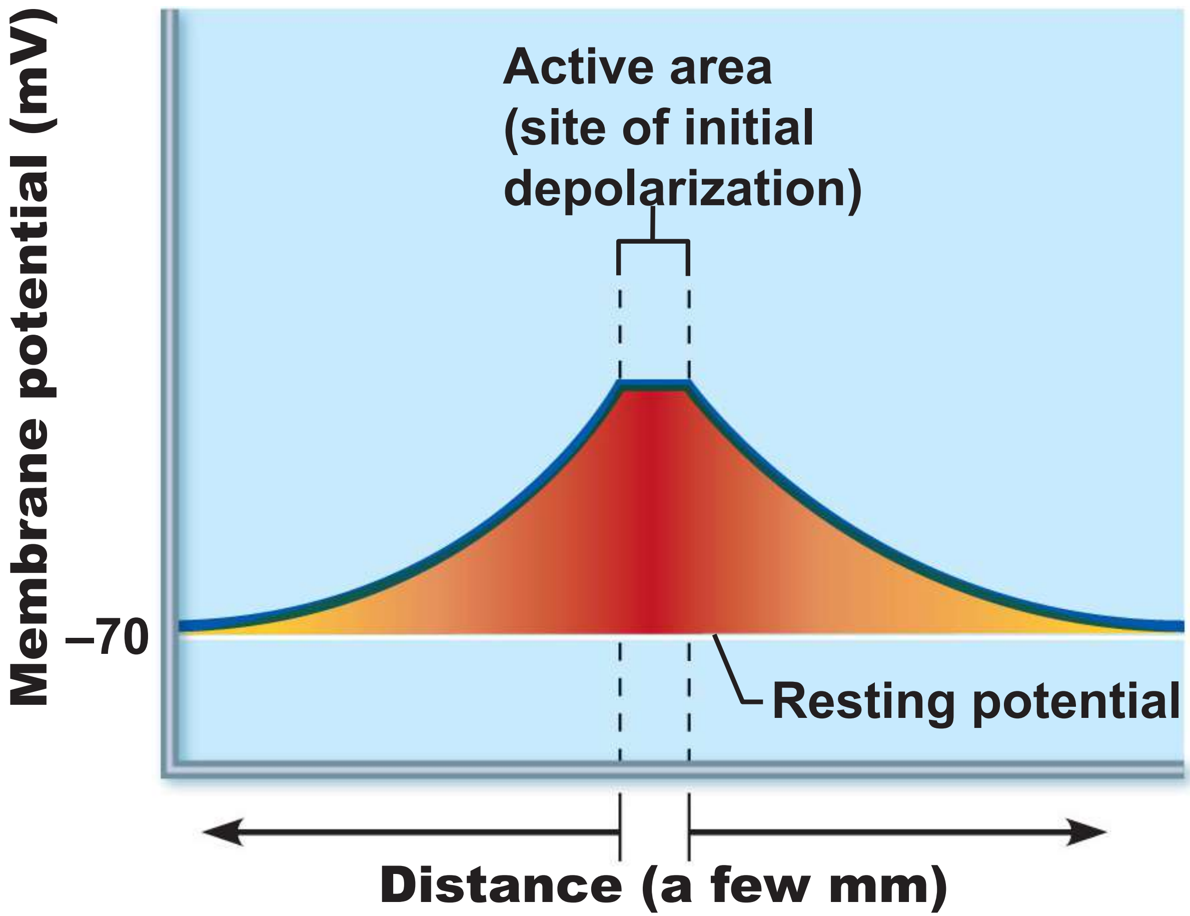
Figure 11.10a



(b) Spread of depolarization: The local currents (black arrows) that are created depolarize adjacent membrane areas and allow the wave of depolarization to spread.

Graded Potentials

- Occur when a stimulus causes gated ion channels to open
  - E.g., receptor potentials, generator potentials, postsynaptic potentials
- Magnitude varies directly (graded) with stimulus strength
- Decrease in magnitude with distance as ions flow and diffuse through leakage channels
- Short-distance signals



(c) Decay of membrane potential with distance: Because current is lost through the "leaky" plasma membrane, the voltage declines with distance from the stimulus (the voltage is *decremental*). Consequently, graded potentials are short-distance signals.

Figure 11.10c

Action Potential (AP)

- Brief reversal of membrane potential with a total amplitude of ~100 mV
- Occurs in muscle cells and axons of neurons
- Does not decrease in magnitude over distance
- Principal means of long-distance neural communication

The big picture

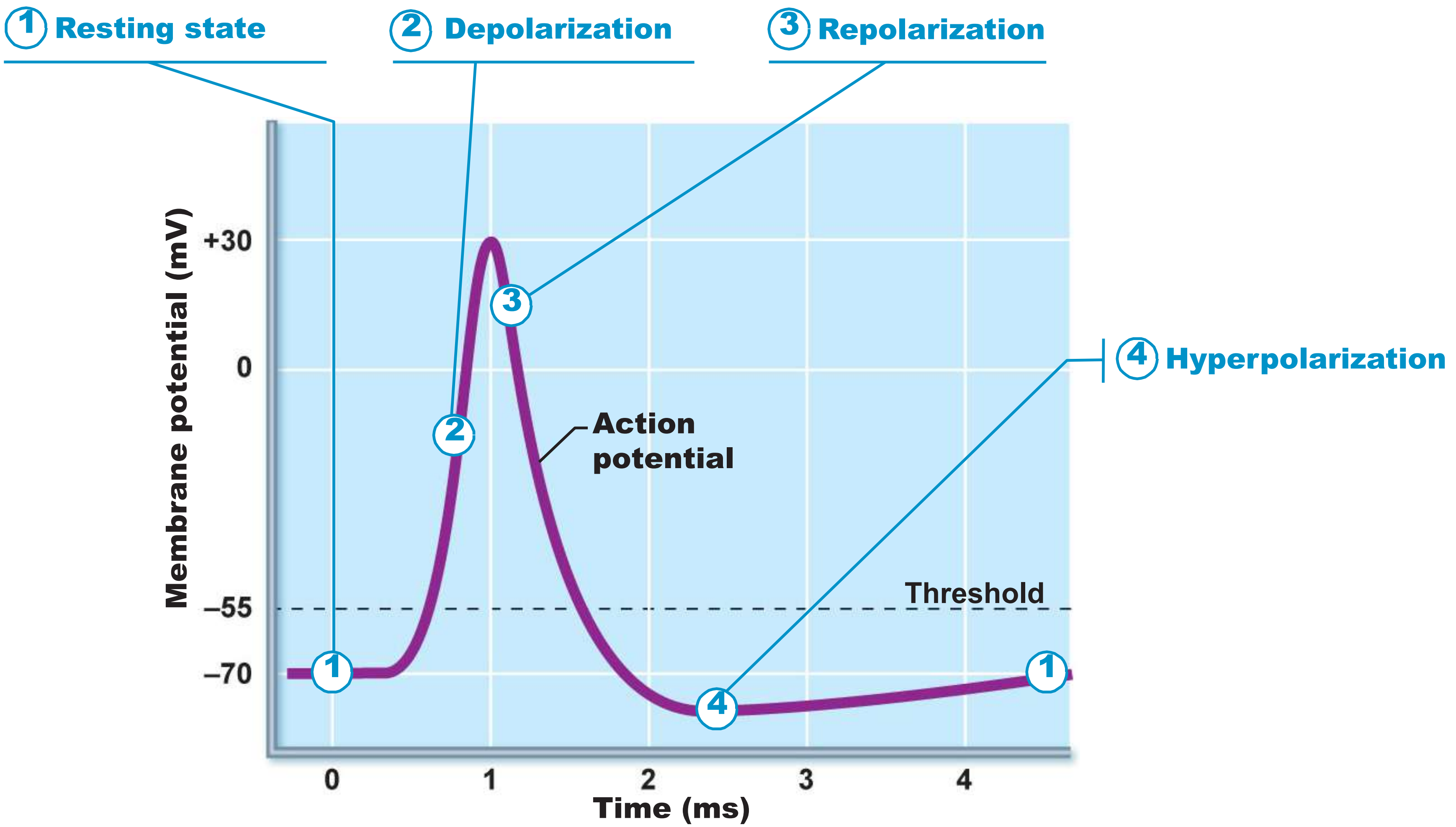


Figure 11.11 (1 of 5)

Generation of an Action Potential

- Resting state
  - Only leakage channels for Na^+ and K^+ are open
  - All gated Na^+ and K^+ channels are closed

Properties of Gated Channels

- Properties of gated channels
  - Each Na^+ channel has two voltage-sensitive gates
    - Activation gates
      - Closed at rest; open with depolarization
    - Inactivation gates
      - Open at rest; block channel once it is open

Properties of Gated Channels

- Each K^+ channel has one voltage-sensitive gate
- Closed at rest
- Opens slowly with depolarization

Depolarizing Phase

- Depolarizing local currents open voltage-gated Na^+ channels
- Na^+ influx causes more depolarization
- At threshold (–55 to –50 mV) positive feedback leads to opening of all Na^+ channels, and a reversal of membrane polarity to +30mV (spike of action potential)

Repolarizing Phase

- Repolarizing phase
  - Na^+ channel slow inactivation gates close
  - Membrane permeability to Na^+ declines to resting levels
  - Slow voltage-sensitive K^+ gates open
  - K^+ exits the cell and internal negativity is restored

Hyperpolarization

- Hyperpolarization
  - Some K^+ channels remain open, allowing excessive K^+ efflux
  - This causes after-hyperpolarization of the membrane (undershoot)

PLAY ***A&P Flix™*****: Generation of an Action Potential**

The AP is caused by permeability changes in the plasma membrane

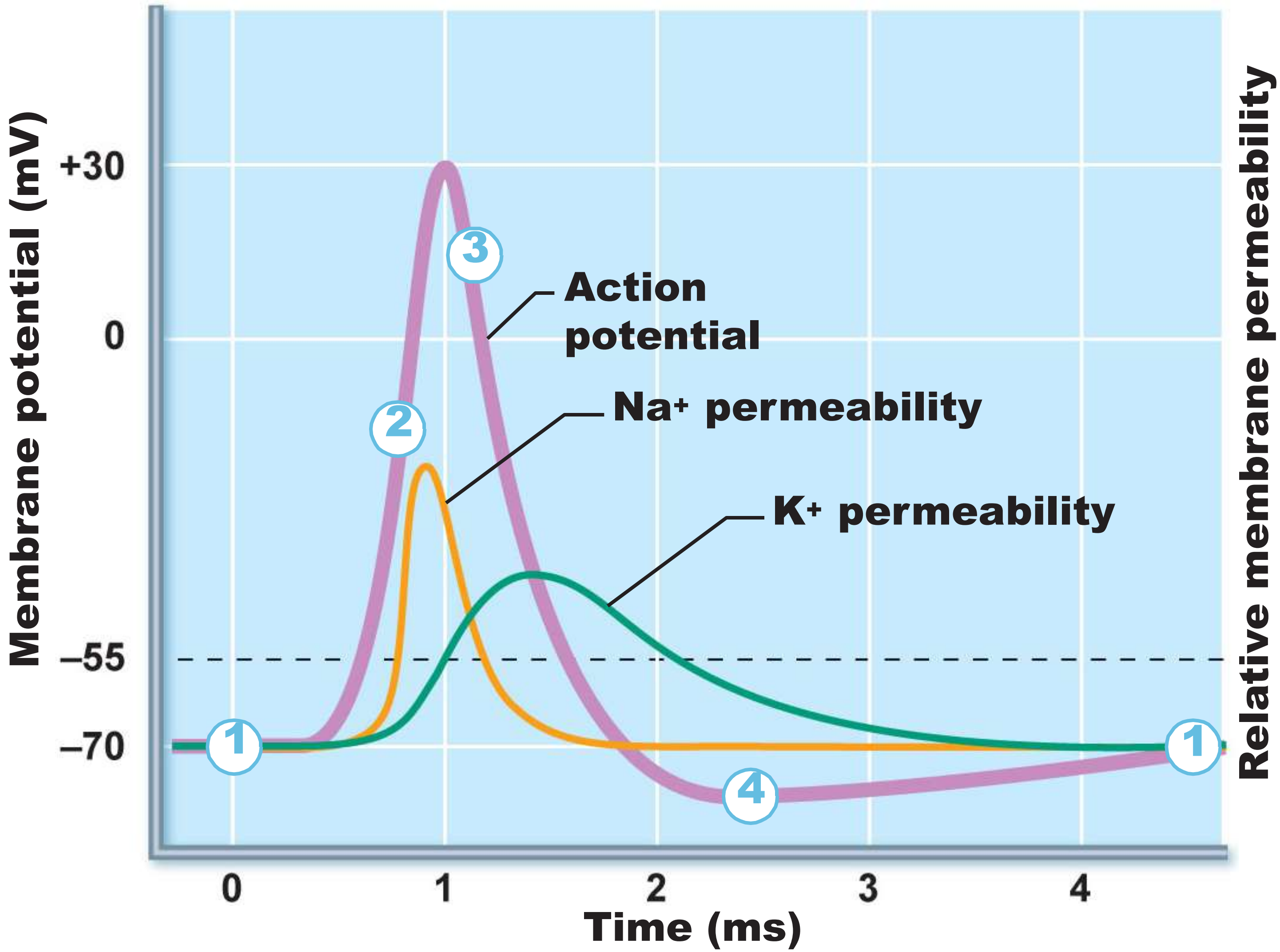


Figure 11.11 (2 of 5)

Role of the Sodium-Potassium Pump

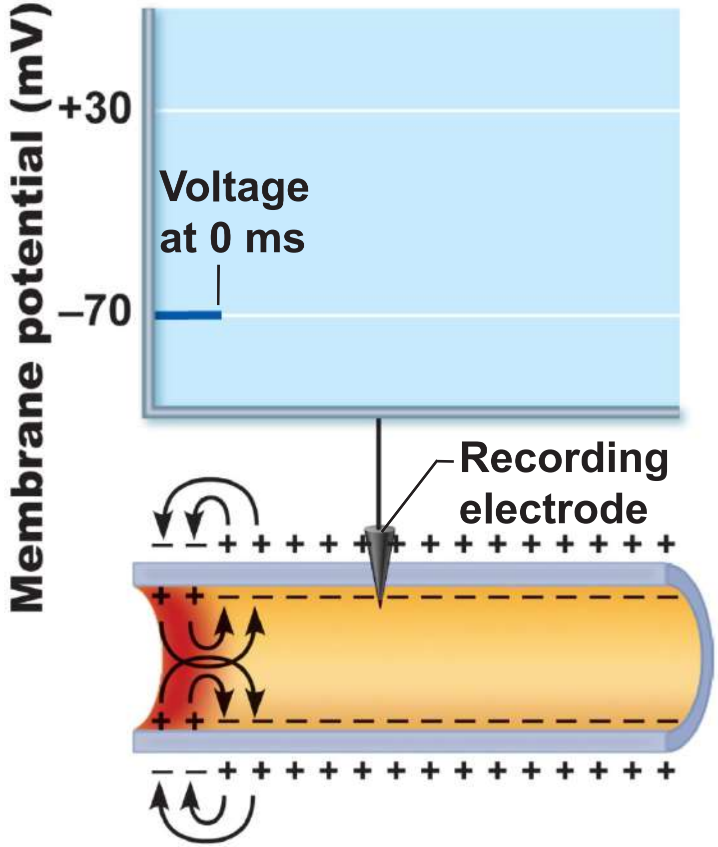
- Repolarization
  - Restores the resting electrical conditions of the neuron
  - Does not restore the resting ionic conditions
- Ionic redistribution back to resting conditions is restored by the thousands of sodium-potassium pumps

Propagation of an Action Potential

- Na^+ influx causes a patch of the axonal membrane to depolarize
- Local currents occur
- Na^+ channels toward the point of origin are inactivated and not affected by the local currents

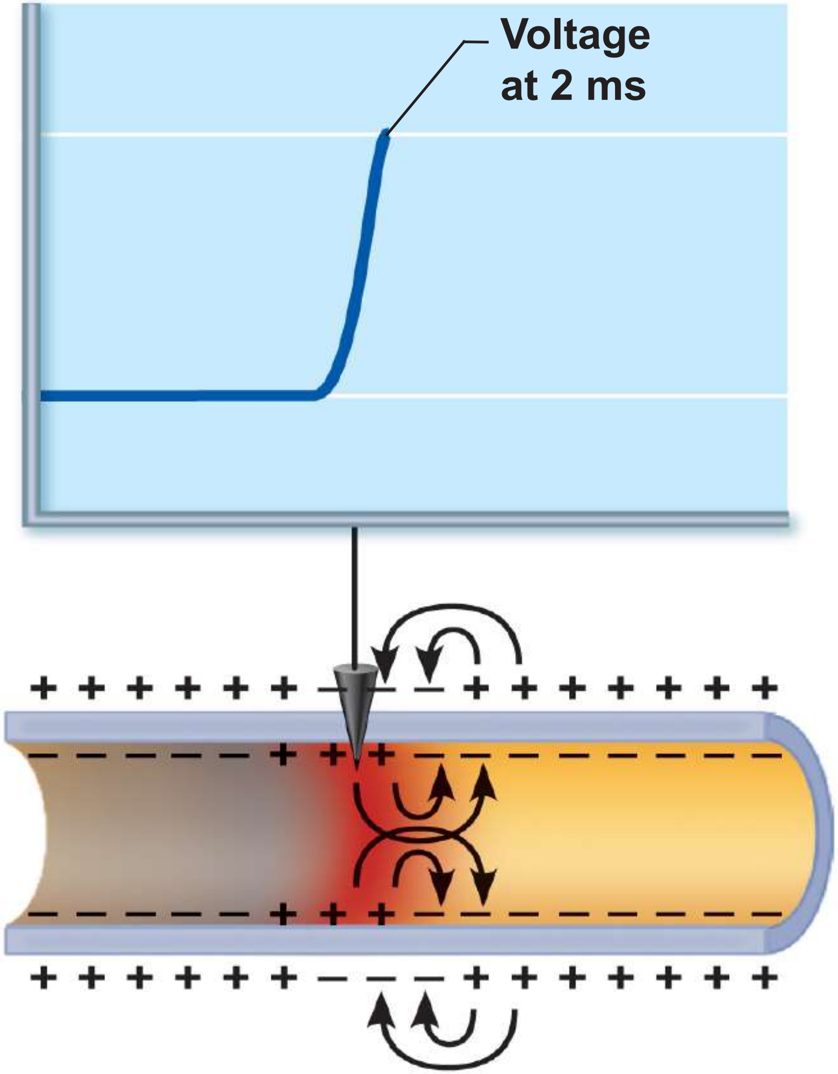
Propagation of an Action Potential

- Local currents affect adjacent areas in the forward direction
- Depolarization opens voltage-gated channels and triggers an AP
- Repolarization wave follows the depolarization wave
- (Fig. 11.12 shows the propagation process in unmyelinated axons.)



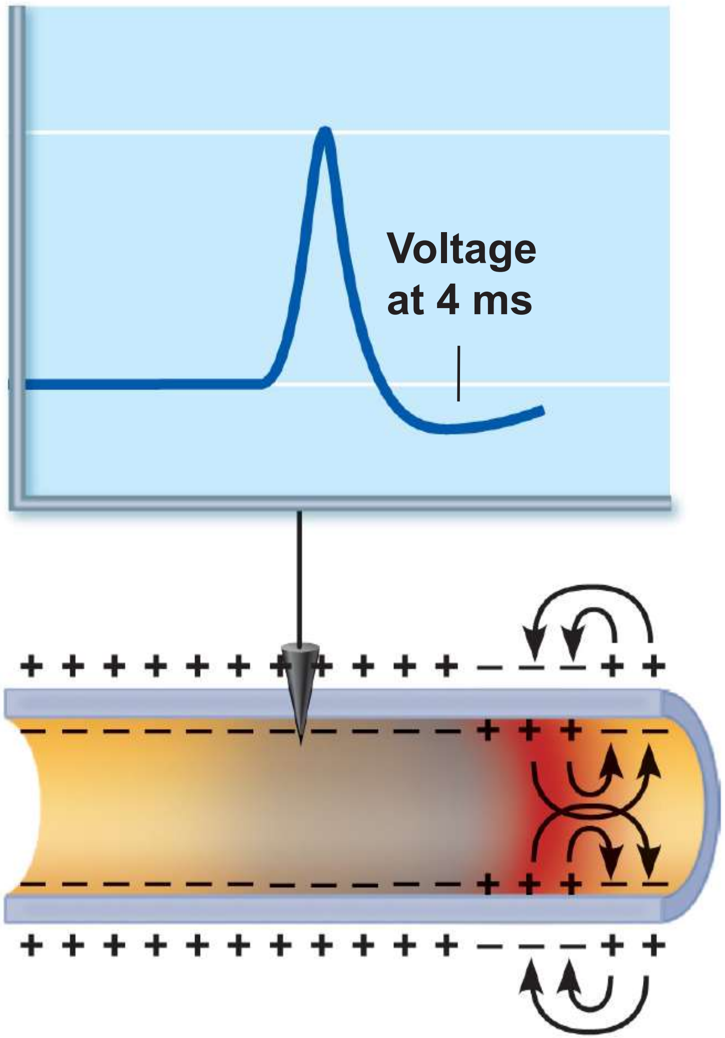
(a) Time = 0 ms. Action potential has not yet reached the recording electrode.

Figure 11.12a



(b) Time = 2 ms. Action potential peak is at the recording electrode.

Figure 11.12b



(c) Time = 4 ms. Action potential peak is past the recording electrode. Membrane at the recording electrode is still hyperpolarized.

PLAY ***A&P Flix***™**: Propagation of an Action Potential**

Figure 11.12c

Threshold

- At threshold:
  - Membrane is depolarized by 15 to 20 mV
  - Na^+ permeability increases
  - Na influx exceeds K^+ efflux
  - The positive feedback cycle begins

Threshold

- Subthreshold stimulus—weak local depolarization that does not reach threshold
- Threshold stimulus—strong enough to push the membrane potential toward and beyond threshold
- AP is an all-or-none phenomenon—action potentials either happen completely, or not at all

Coding for Stimulus Intensity

- All action potentials are alike and are independent of stimulus intensity
  - How does the CNS tell the difference between a weak stimulus and a strong one?
- Strong stimuli can generate action potentials more often than weaker stimuli
- The CNS determines stimulus intensity by the frequency of impulses

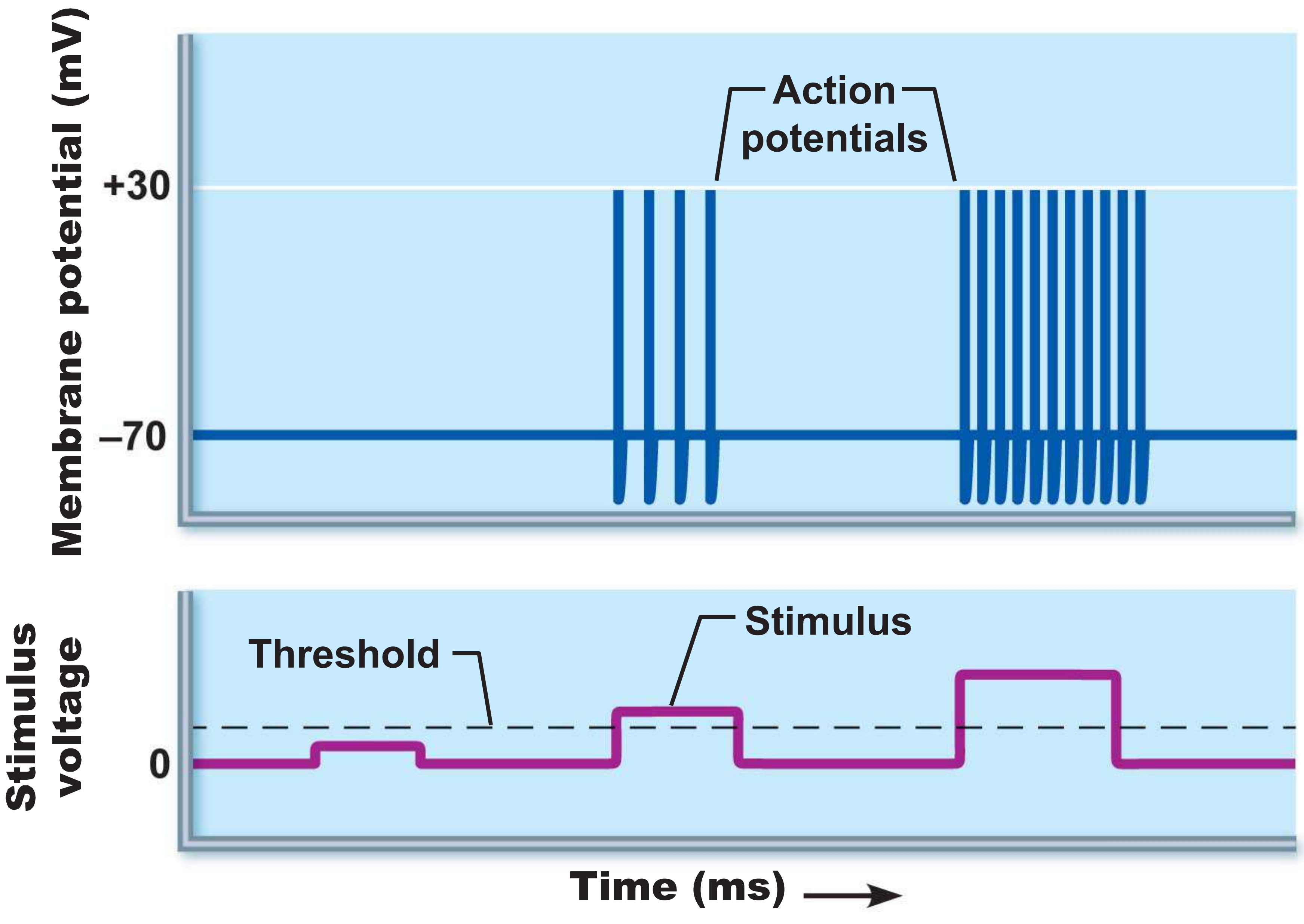

Membrane potential (mV)
+30
–70
Action potentials
Stimulus voltage
0
Threshold
Stimulus
Time (ms)

Figure 11.13

Absolute Refractory Period

- Time from the opening of the Na^+ channels until the resetting of the channels
- Ensures that each AP is an all-or-none event
- Enforces one-way transmission of nerve impulses

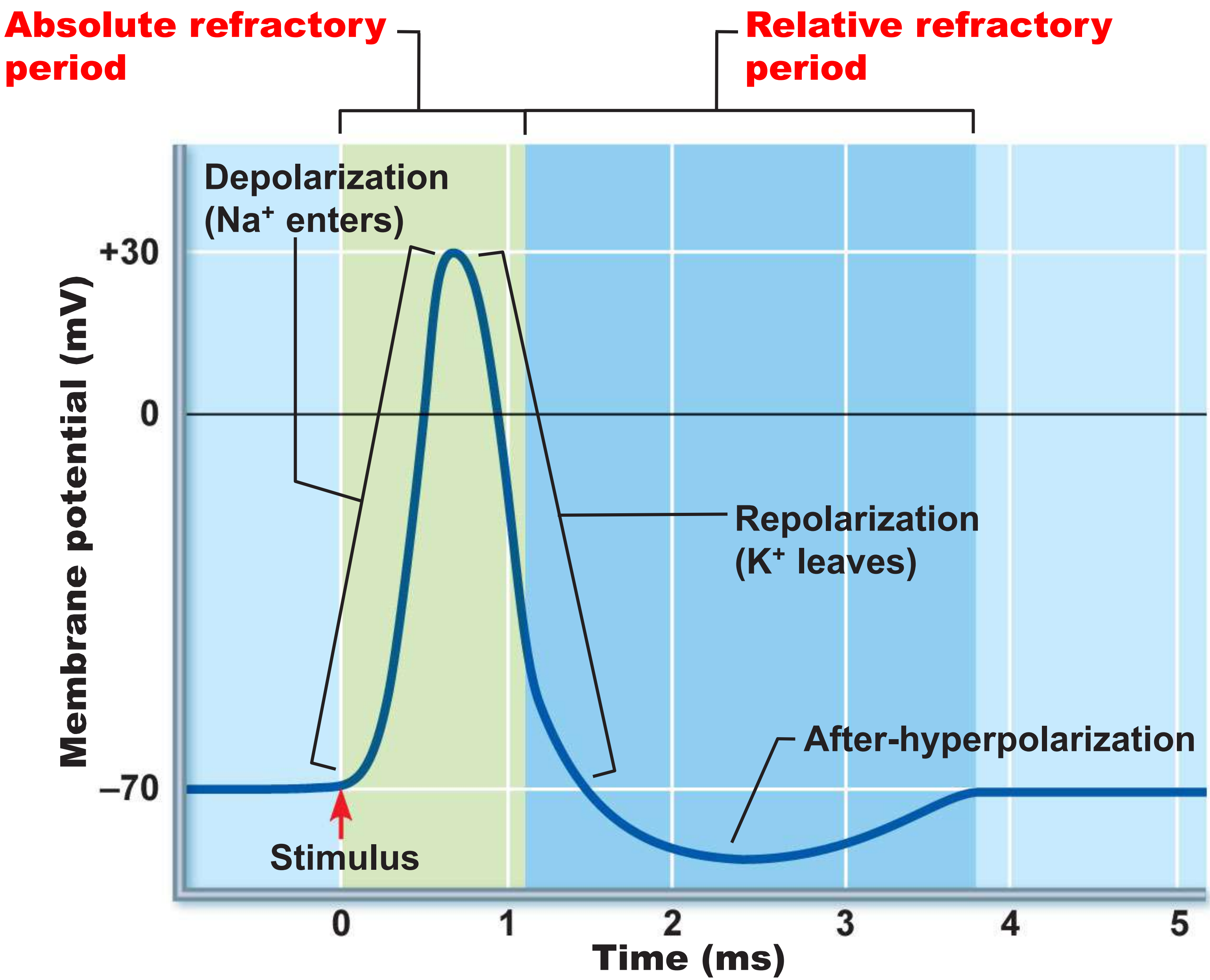

Absolute refractory period
Relative refractory period
Depolarization (Na+ enters)
Repolarization (K+ leaves)
After-hyperpolarization
Stimulus
+30
0
–70
Membrane potential (mV)
0
1
2
3
4
5
Time (ms)

Figure 11.14

Relative Refractory Period

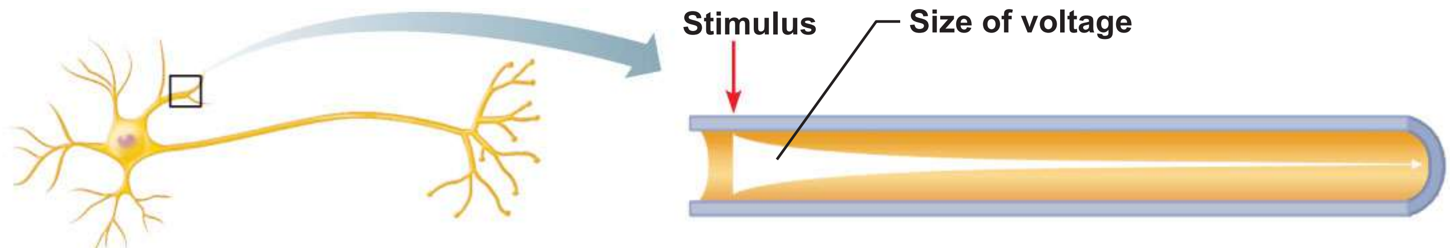
- Follows the absolute refractory period
  - Most Na^+ channels have returned to their resting state
  - Some K^+ channels are still open
  - Repolarization is occurring
- Threshold for AP generation is elevated
- Exceptionally strong stimulus may generate an AP

Conduction Velocity

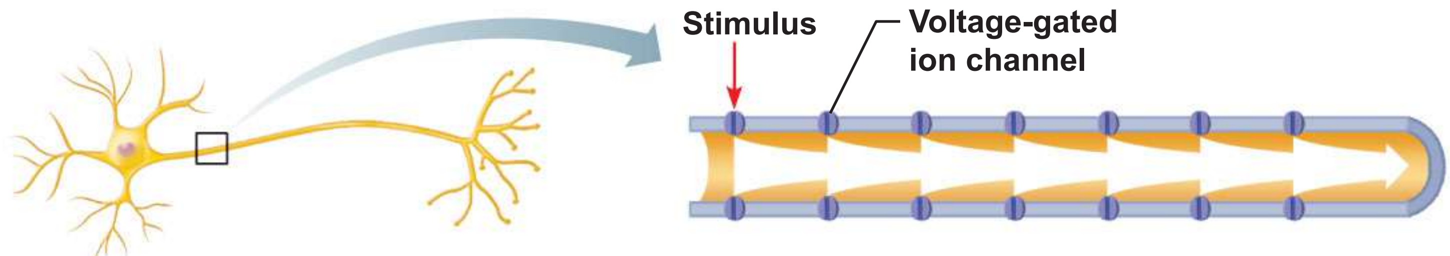
- Conduction velocities of neurons vary widely
- Effect of axon diameter
  - Larger diameter fibers have less resistance to local current flow and have faster impulse conduction
- Effect of myelination
  - Continuous conduction in unmyelinated axons is slower than saltatory conduction in myelinated axons

Conduction Velocity

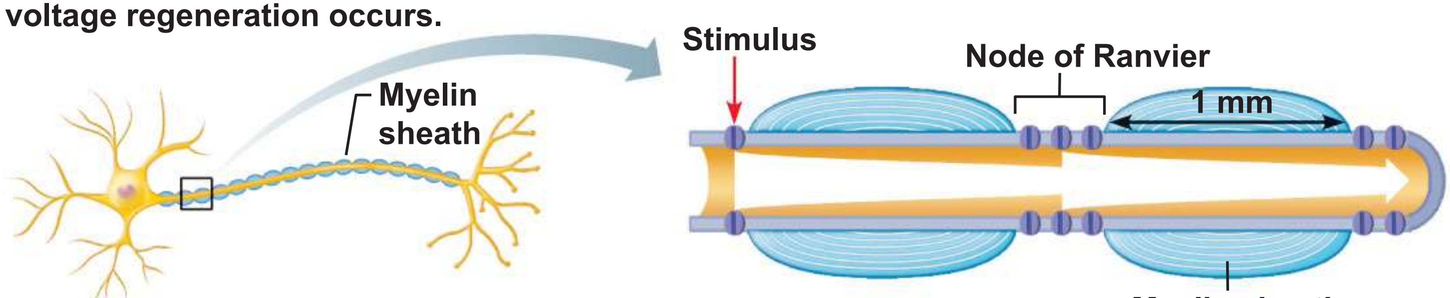
- Effects of myelination
  - Myelin sheaths insulate and prevent leakage of charge
  - Saltatory conduction in myelinated axons is about 30 times faster
    - Voltage-gated Na^+ channels are located at the nodes
    - APs appear to jump rapidly from node to node



(a) In a **bare plasma membrane** (without voltage-gated channels), as on a dendrite, voltage decays because current leaks across the membrane.



(b) In an **unmyelinated axon**, voltage-gated Na^+ and K^+ channels regenerate the action potential at each point along the axon, so voltage does not decay. Conduction is *slow* because movements of ions and of the gates of channel proteins take time and must occur before voltage regeneration occurs.



(c) In a **myelinated axon**, myelin keeps current in axons (voltage doesn't decay much). APs are generated *only* in the nodes of Ranvier and appear to jump *rapidly* from node to node.

Figure 11.15

Multiple Sclerosis (MS)

- An autoimmune disease that mainly affects young adults
- Symptoms: visual disturbances, weakness, loss of muscular control, speech disturbances, and urinary incontinence
- Myelin sheaths in the CNS become nonfunctional scleroses
- Shunting and short-circuiting of nerve impulses occurs
- Impulse conduction slows and eventually ceases

Multiple Sclerosis: Treatment

- Some immune system–modifying drugs, including interferons and Copazone:
  - Hold symptoms at bay
  - Reduce complications
  - Reduce disability

Nerve Fiber Classification

- Nerve fibers are classified according to:
  - Diameter
  - Degree of myelination
  - Speed of conduction

Nerve Fiber Classification

- Group A fibers
  - Large diameter, myelinated somatic sensory and motor fibers
- Group B fibers
  - Intermediate diameter, lightly myelinated ANS fibers
- Group C fibers
  - Smallest diameter, unmyelinated ANS fibers