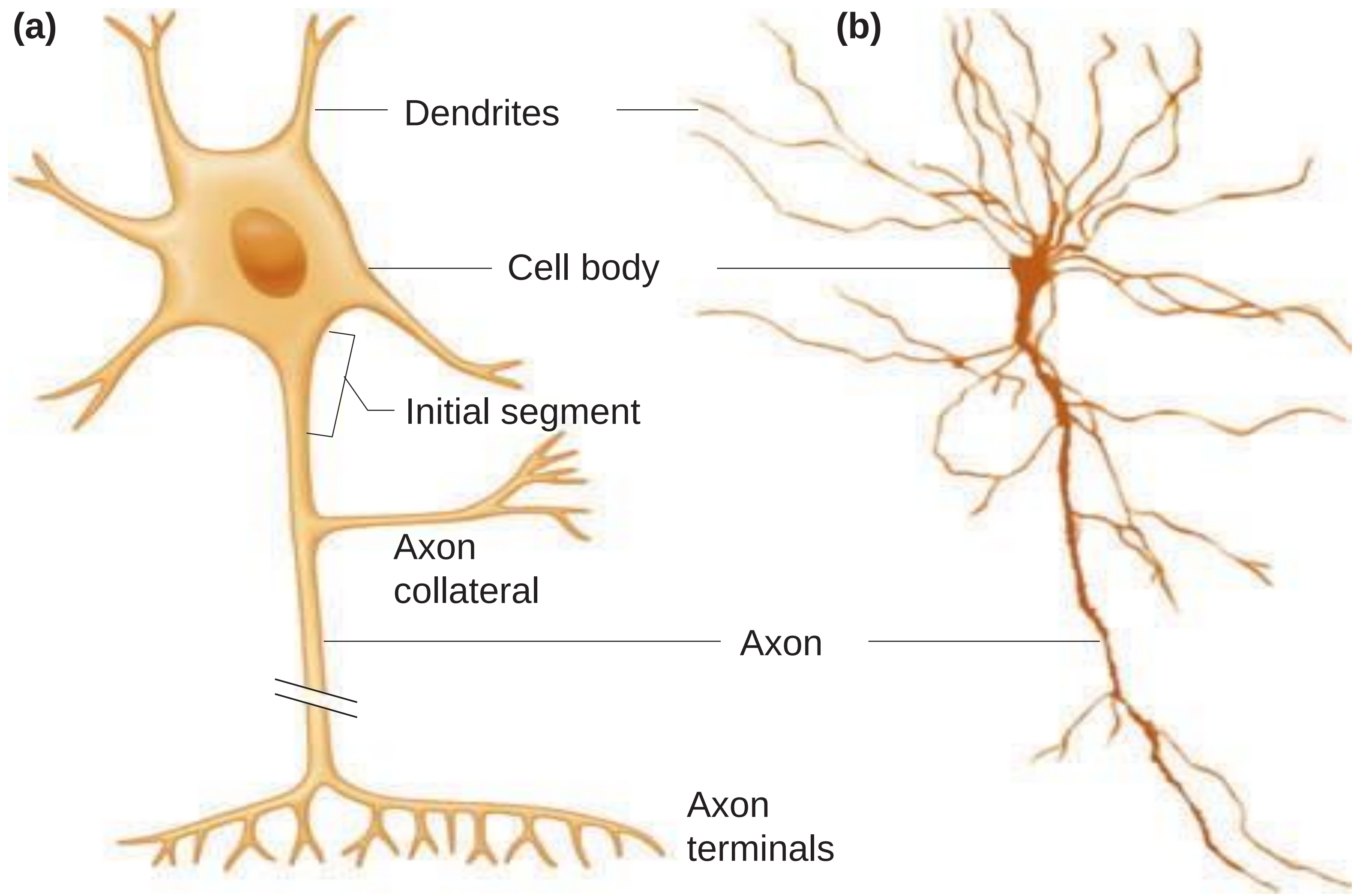
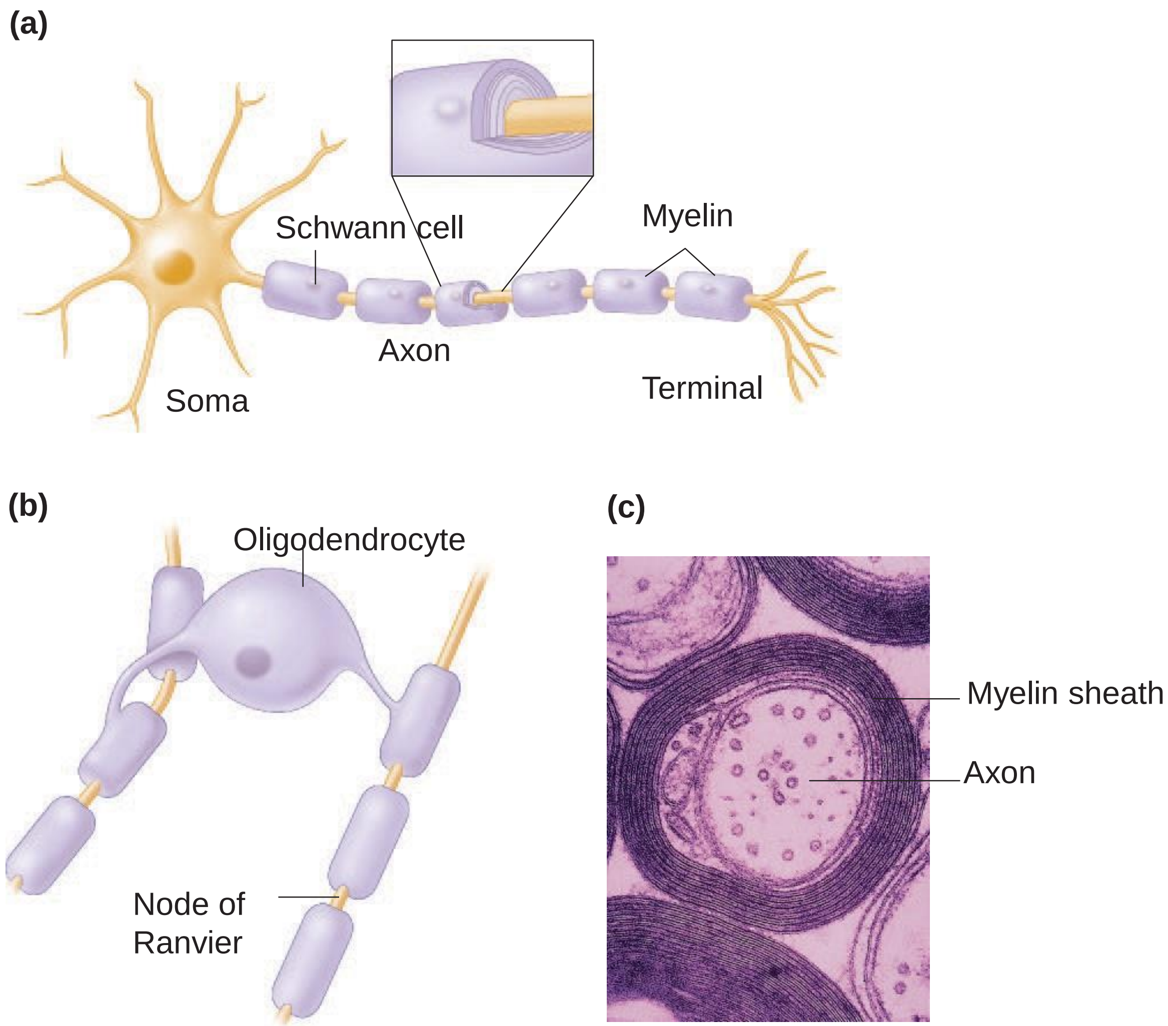
STRUCTURAL ELEMENTS OF THE NERVOUS SYSTEM

STRUCTURE AND MAINTENANCE OF NEURONS



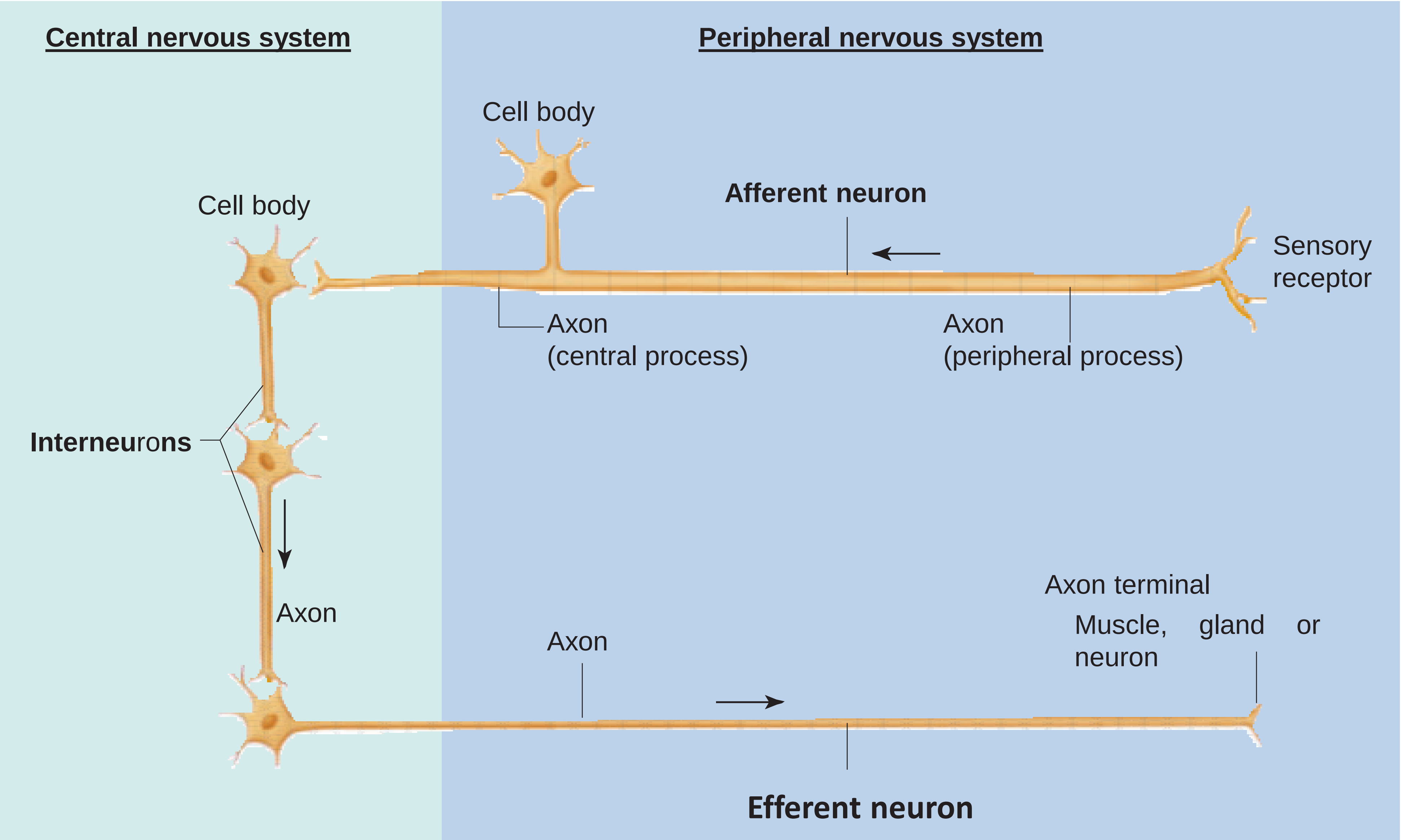
(a) Diagrammatic representation of a neuron. The break in the axon indicates that axons may extend for long distances and may be 5000 to 10,000 times longer than the cell body is wide. This neuron is a common type, but there are a wide variety of neuronal morphologies, one of which has no axon. (b) A neuron as observed through a microscope. The axon terminals cannot be seen at this magnification.

NEURONAL AND GLIAL ELEMENTS



Myelin formed by Schwann cells (a) and oligodendrocytes (b) on axons. Electron micrograph of transverse sections of myelinated axons in brain (c).

FUNCTIONAL CLASSES OF NEURONS



Three classes of neurons. The arrows indicate the direction of transmission of neural activity. Afferent neurons in the peripheral nervous system generally receive input at sensory receptors. Efferent components of the peripheral nervous system may terminate on muscle, gland, or neuron effectors. Both afferent and efferent components may consist of two neurons, not one as shown here.

CHARACTERISTICS OF THREE CLASSES OF NEURONS

I. Afferent neurons

A. Transmit information into the central nervous system from receptors at their peripheral endings

B. Cell body and the long peripheral process of the axon are in the peripheral nervous system; only the short central process of the axon enters the central nervous system

C. Have no dendrites (do not receive inputs from other neurons)

II. Efferent neurons

A. Transmit information out of the central nervous system to effector cells, particularly muscles, glands, or other neurons

B. Cell body, dendrites, and a small segment of the axon are in the central nervous system; most of the axon is in the peripheral nervous system

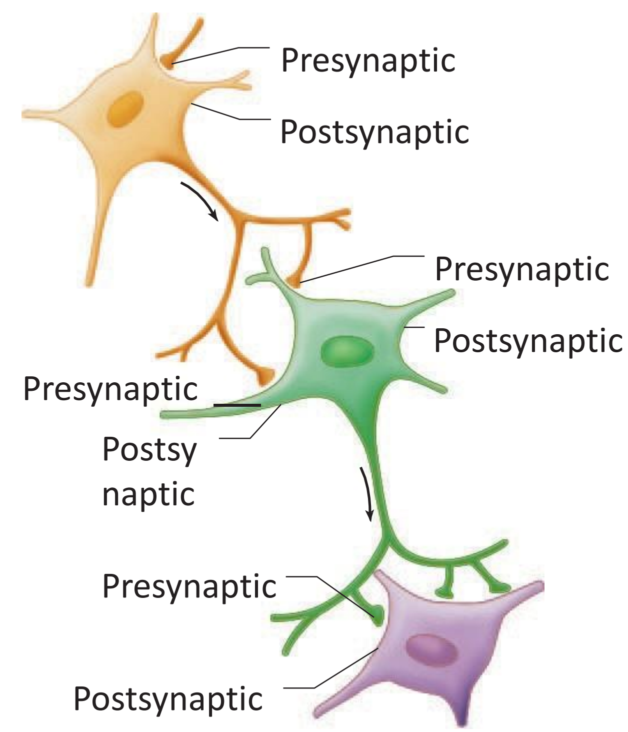
III. Interneurons

A. Function as integrators and signal changers

B. Integrate groups of afferent and efferent neurons into reflex circuits

C. Lie entirely within the central nervous system

D. Account for 99 percent of all neurons



A neuron postsynaptic to one cell can be presynaptic to another. Arrows indicate direction of neural transmission.

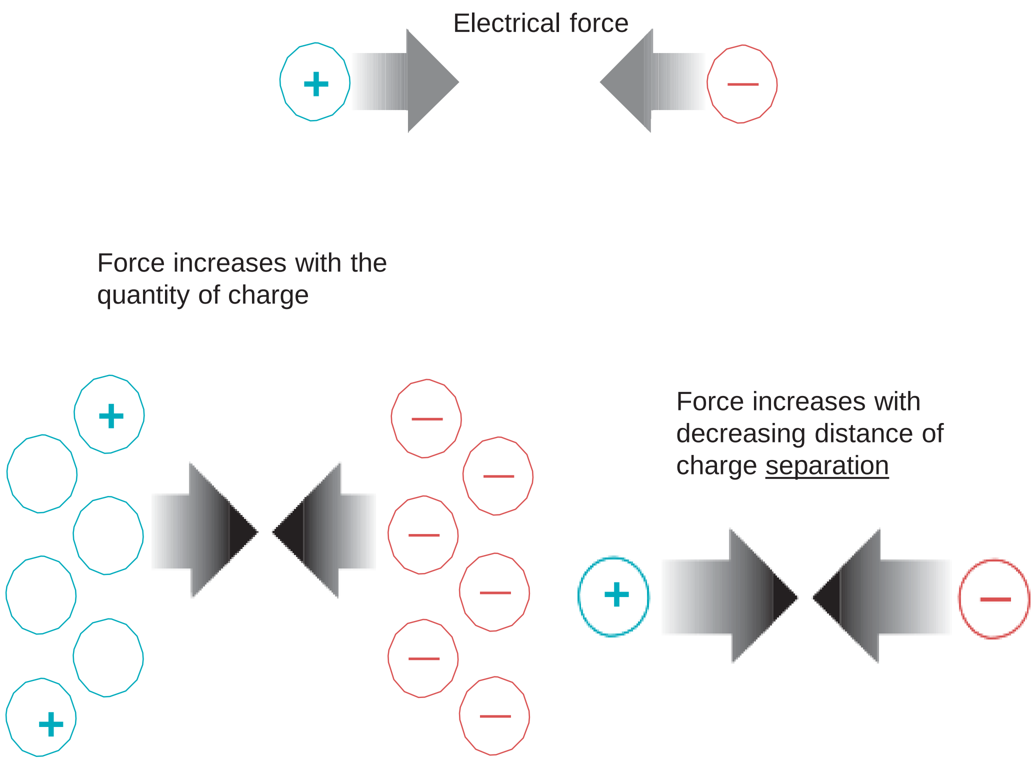
GLIAL CELLS

- The CNS also contains glial cells, which help regulate the extracellular fluid composition, sustain the neurons metabolically, form myelin and the blood-brain barrier, serve as guides for developing neurons, and provide immune functions.

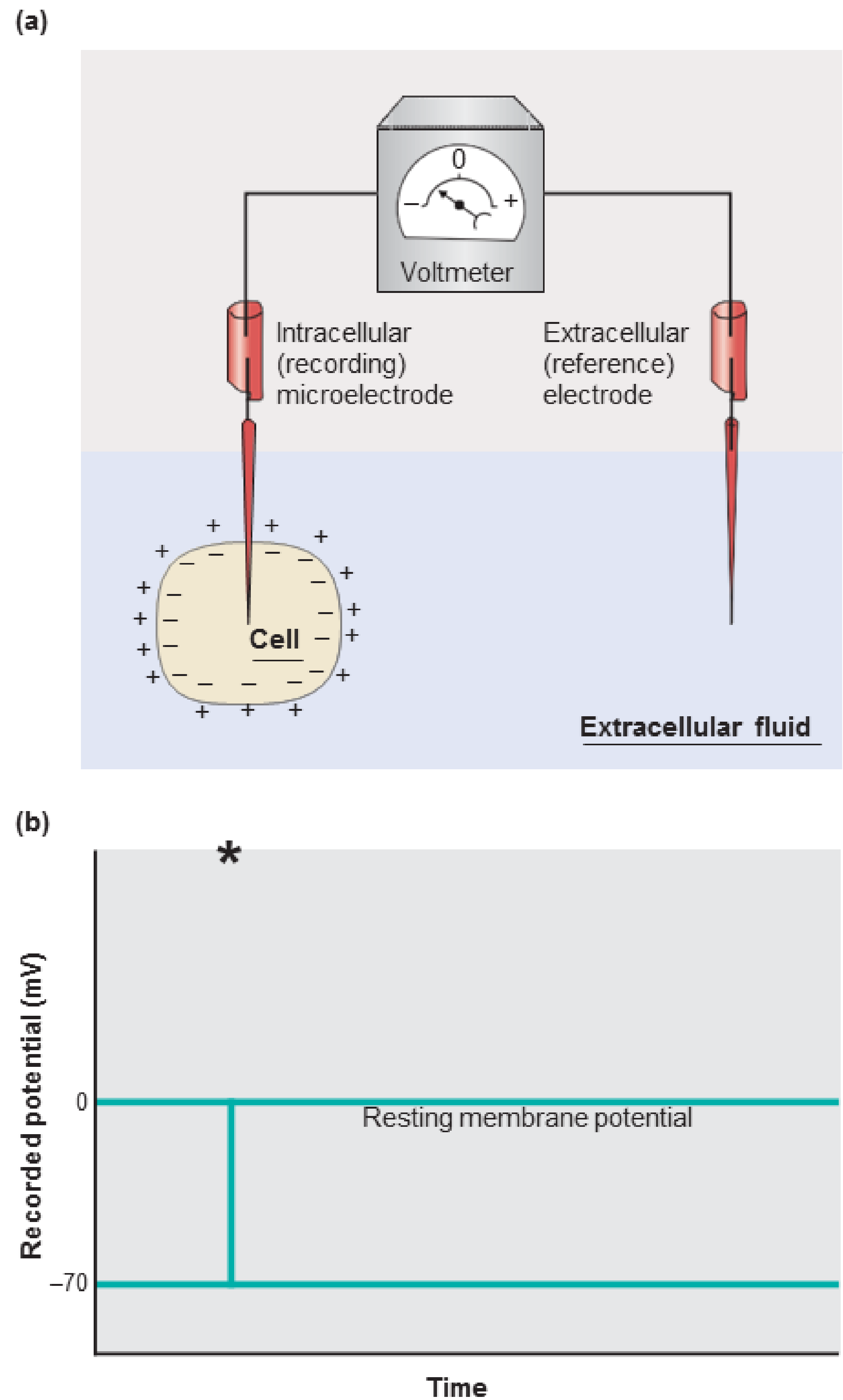
NEURAL GROWTH AND REGENERATION

- Neurons develop from stem cells, migrate to their final location, and send out processes to their target cells.
- Cell division to form new neurons is markedly slowed after birth.
- After degeneration of a severed axon, damaged peripheral neurons may regrow the axon to their target organ. In the CNS, there is some regeneration of neurons, but it is not yet known how significant this is for function.

MEMBRANE POTENTIALS



The electrical force of attraction between positive and negative charges increases with the quantity of charge and with decreasing distance between charges.

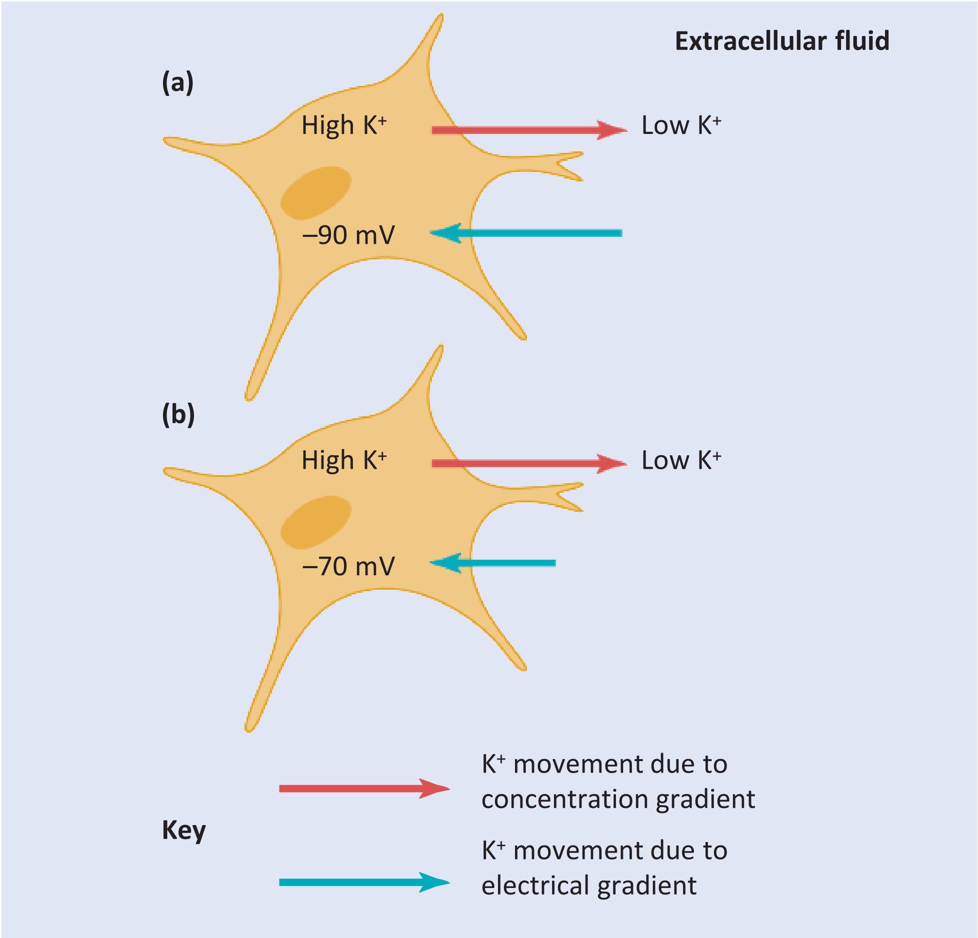


(a) Apparatus for measuring membrane potentials. The voltmeter records the difference measured by the intracellular and extracellular electrodes.
(b) The potential difference across a plasma membrane as measured by an intracellular microelectrode. The asterisk indicates the moment the electrode entered the cell.

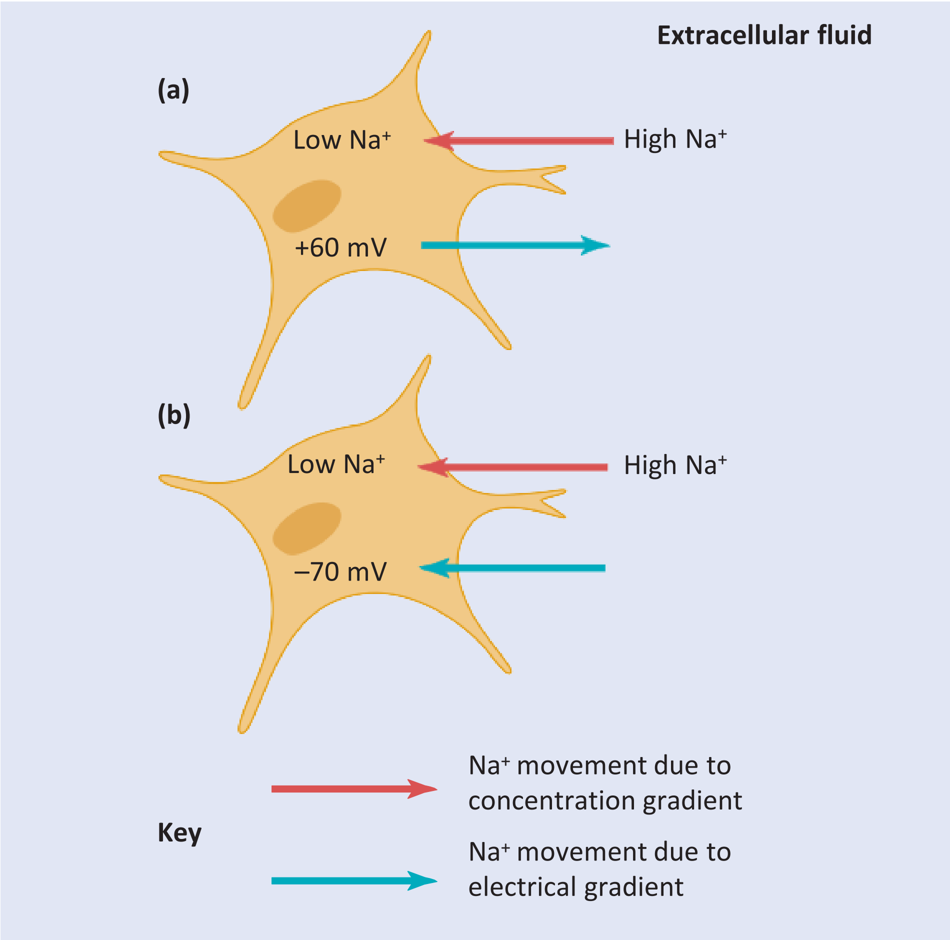
DISTRIBUTION OF MAJOR MOBILE IONS ACROSS THE PLASMA MEMBRANE OF A TYPICAL NERVE CELL

ION	*Concentration, mmol/L*	
	EXTRACELLULAR	INTRACELLULAR
Na^+	150	15
Cl^-	110	10
K^+	5	140

DRIVING FORCES FOR MOVEMENT OF THE BASIC IONS THROUGH MEMBRAINE

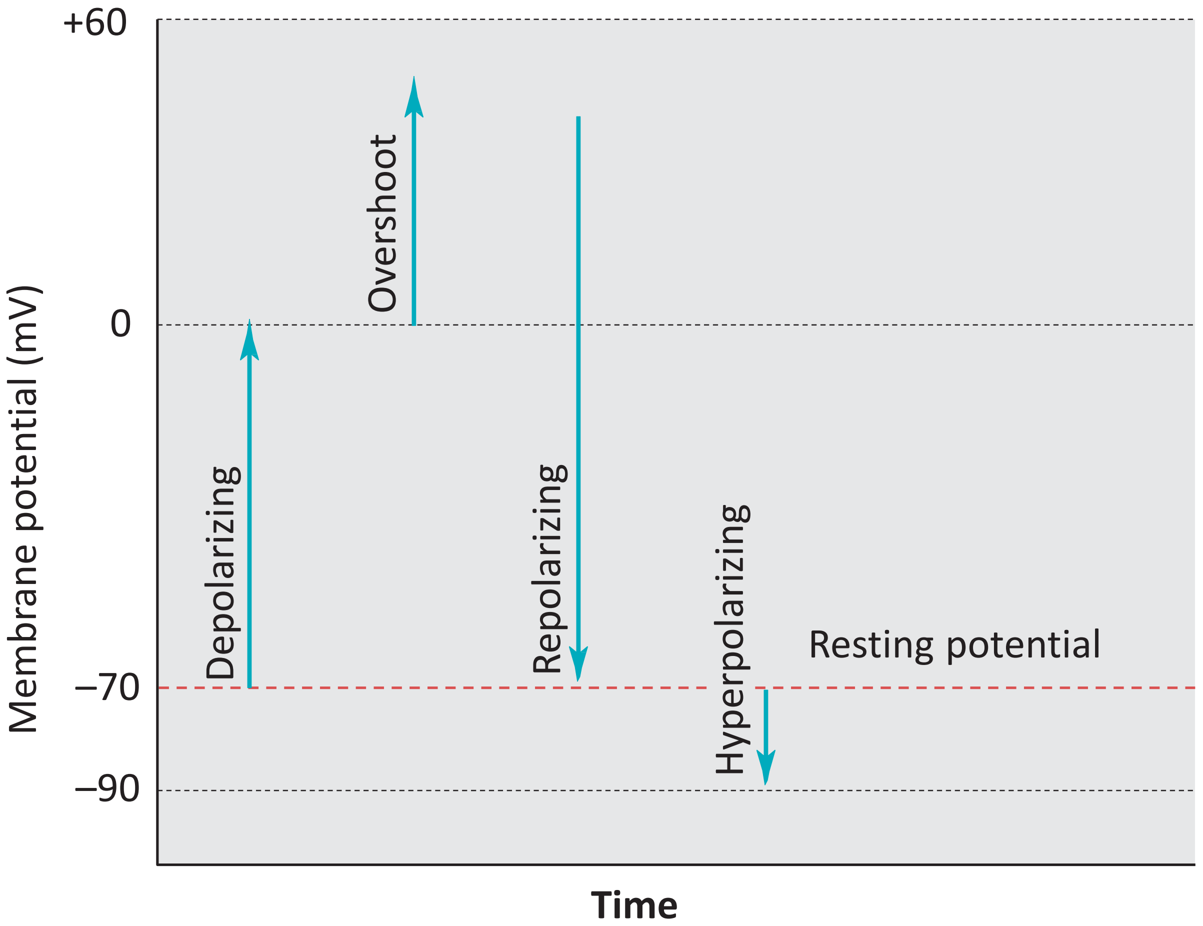


Forces driving potassium through open channels in the neuronal membrane when the membrane is at (a) the potassium equilibrium potential (- 90 mV, inside negative), and (b) the resting potential (- 70 mV, inside negative).



Forces driving sodium through open channels in the neuronal membrane when the membrane is at (a) the sodium equilibrium potential (+60 mV, inside positive), and (b) the resting potential (- 70 mV, inside negative).

GRADED POTENTIALS AND ACTION POTENTIALS

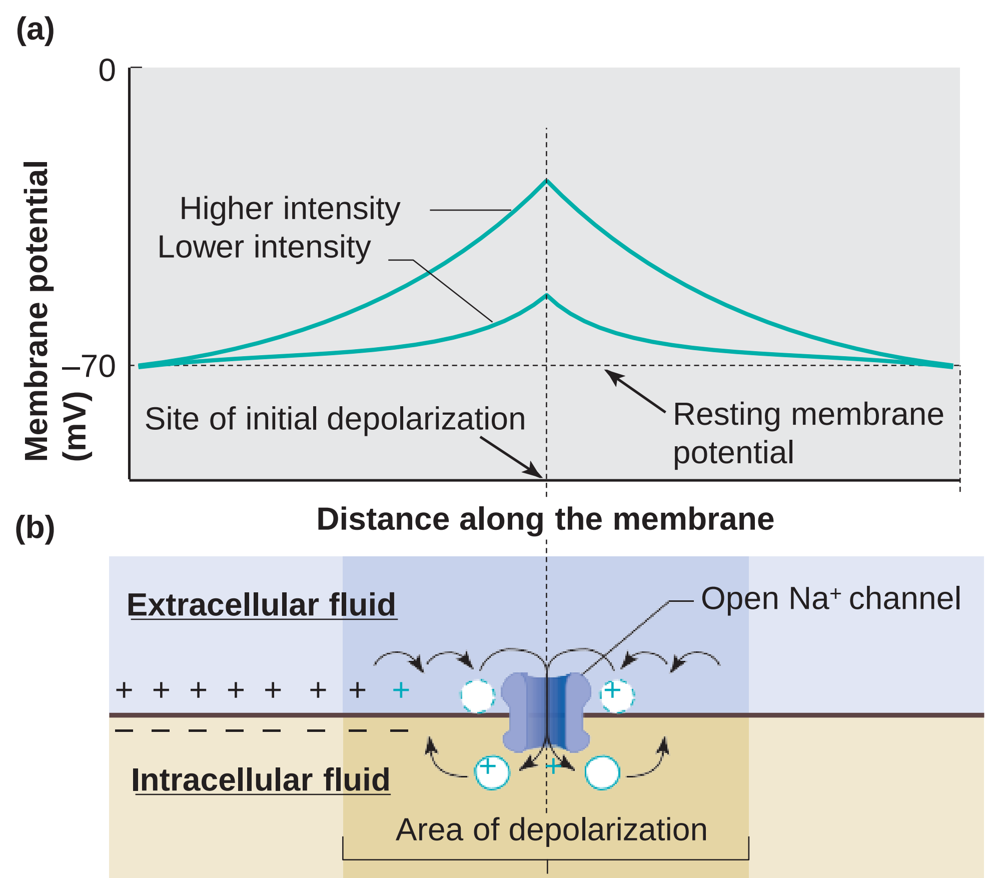


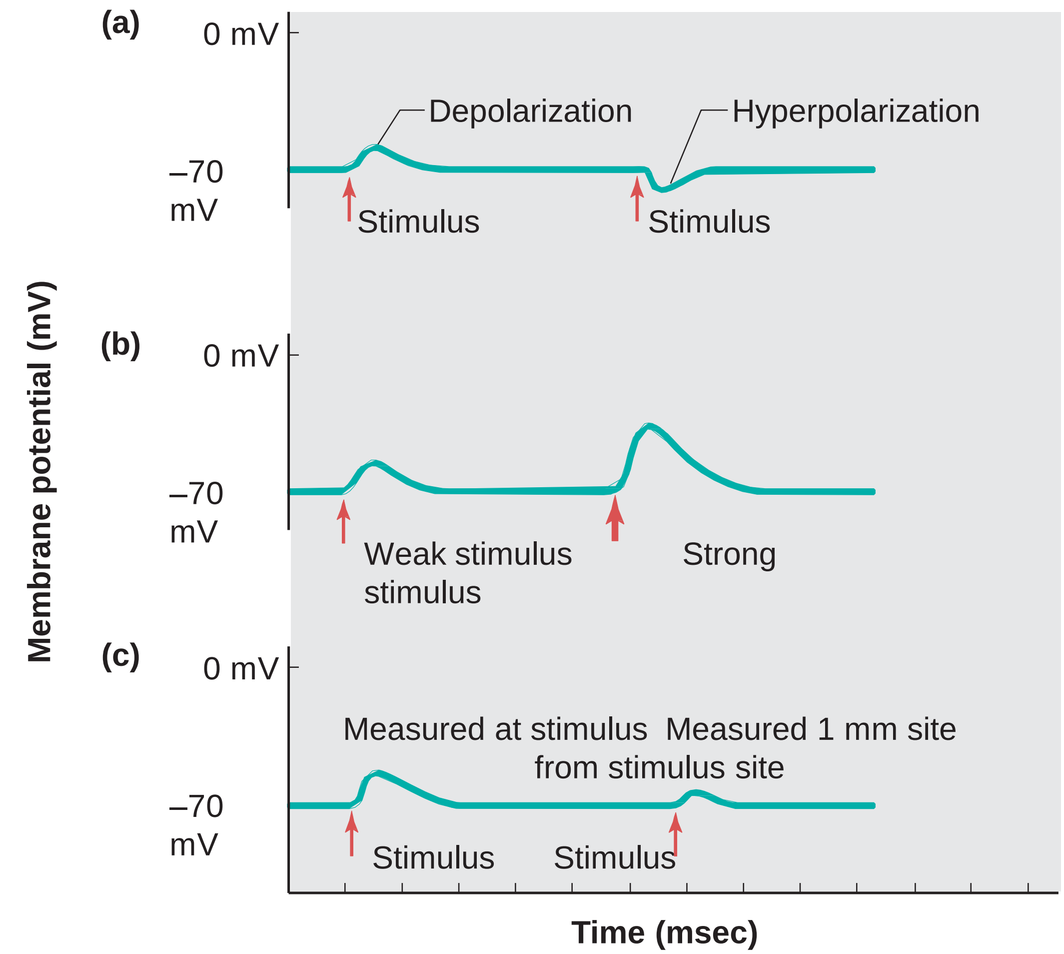
Depolarizing, repolarizing, hyperpolarizing, and overshoot changes in membrane potential, relative to the resting potential.

TERMS DESCRIBING THE MEMBRANE POTENTIAL

Potential = potential difference	The voltage difference between two points.
Membrane potential = transmembrane potential	The voltage difference between the inside and outside of a cell.
Equilibrium potential	The voltage difference across a membrane that produces a flux of a given ion species that is equal but opposite to the flux due to the concentration gradient of that same ion species.
Resting membrane potential = resting potential	The steady transmembrane potential of a cell that is not producing an electric signal.
Graded potential	A potential change of variable amplitude and duration that is conducted decrementally; it has no threshold or refractory period.
Action potential	A brief all-or-none depolarization of the membrane, reversing polarity in neurons; it has a threshold and refractory period and is conducted without decrement.
Synaptic potential	A graded potential change produced in the postsynaptic neuron in response to the release of a neurotransmitter by a presynaptic terminal; it may be depolarizing (an excitatory postsynaptic potential or EPSP) or hyperpolarizing (an inhibitory postsynaptic potential or IPSP).
Receptor potential	A graded potential produced at the peripheral endings of afferent neurons (or in separate receptor cells) in response to a stimulus.
Pacemaker potential	A spontaneously occurring graded potential change that occurs in certain specialized cells.
Threshold potential	The membrane potential at which an action potential is initiated.

GRADED POTENTIALS

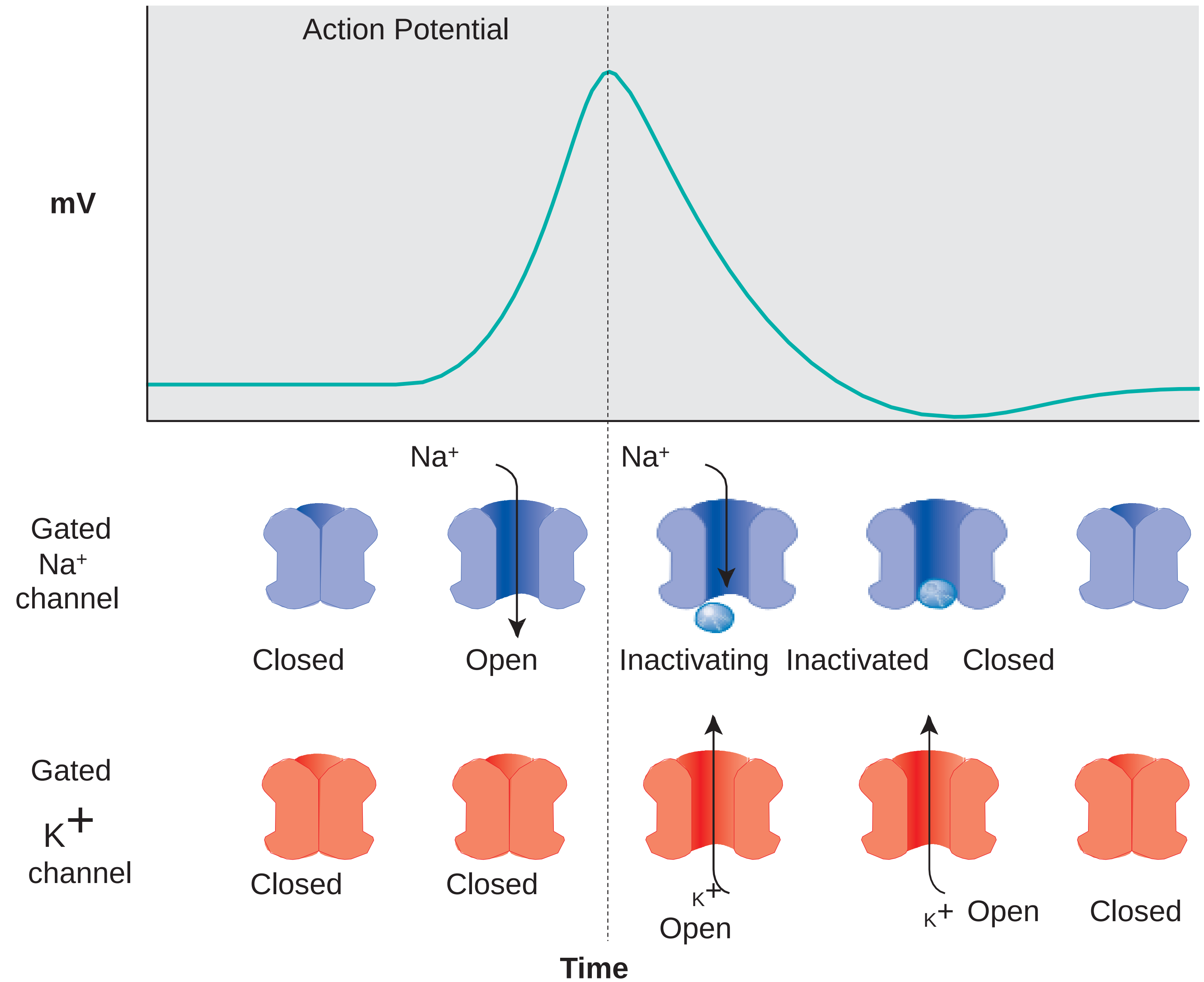




The membrane potential of a cell can be depolarized by using a stimulating current generator, and the potential can be recorded by a pair of electrodes, one inside the cell and the other in the extracellular fluid. (a) Different stimulus intensities result in different degrees of depolarization. The membrane potential is closer to the resting potential with increasing distance from the depolarization site. (b) Local current through ion channels surrounding the depolarized region produces depolarization of adjacent regions.

Graded potentials can be recorded under experimental conditions in which the stimulus can be varied. Such experiments show that graded potentials (a) can be depolarizing or hyperpolarizing, (b) can vary in size, (c) are conducted decrementally. The resting membrane potential is - 70 mV.

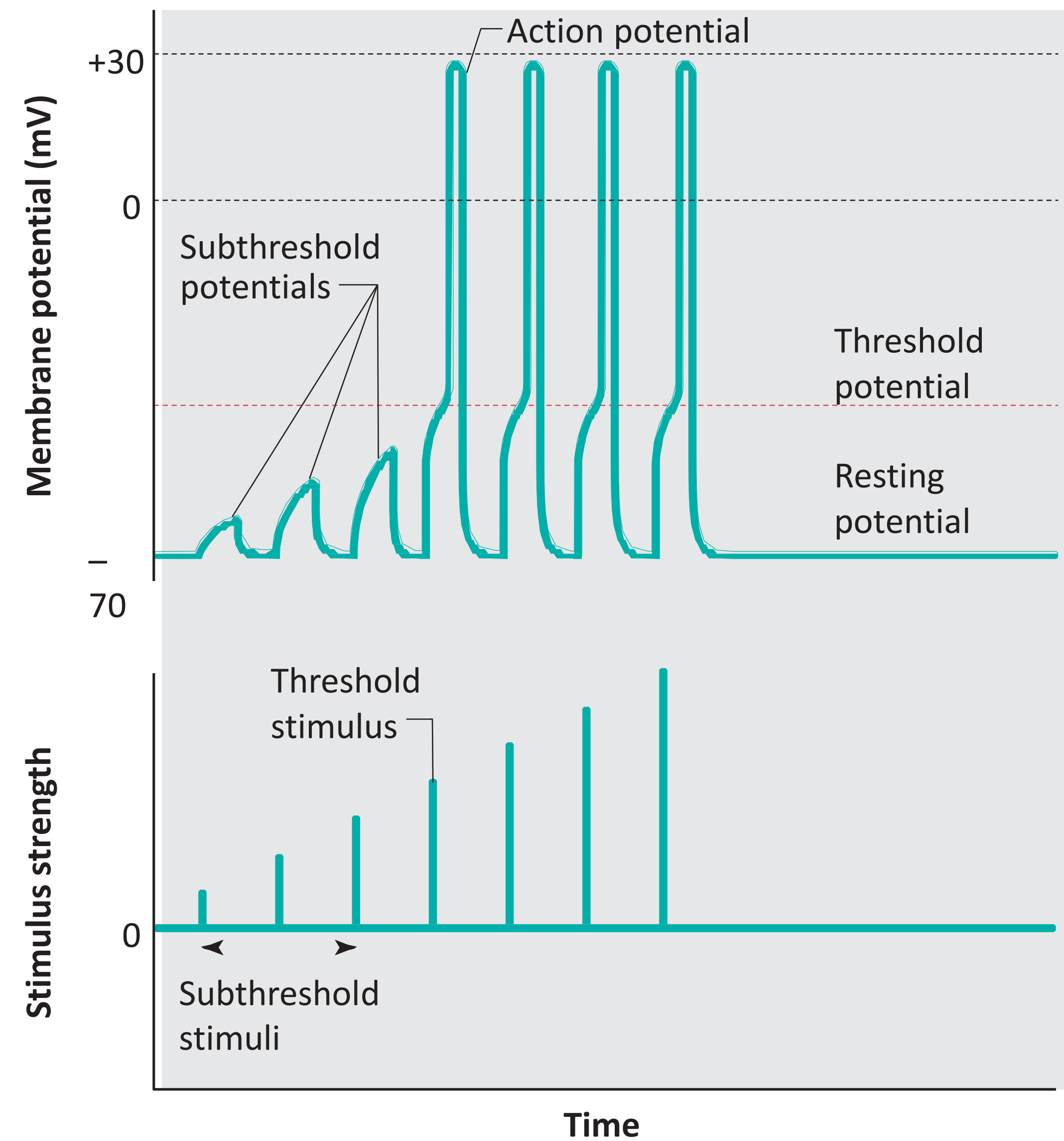
MECHANISM OF ION CHANNEL CHANGES IN ACTION POTENTIALS



Sodium and potassium channel function during the action potential. Both channels respond to voltage changes that result in opening, i.e., activation. Sodium channels, but not potassium channels have an inactivation gate (light blue) that temporarily prevents ion flux. Voltage-gated potassium channels open later than sodium channels. Missing from the figure are the Na^+ and K^+ leak channels, which are open when the cell is at rest.

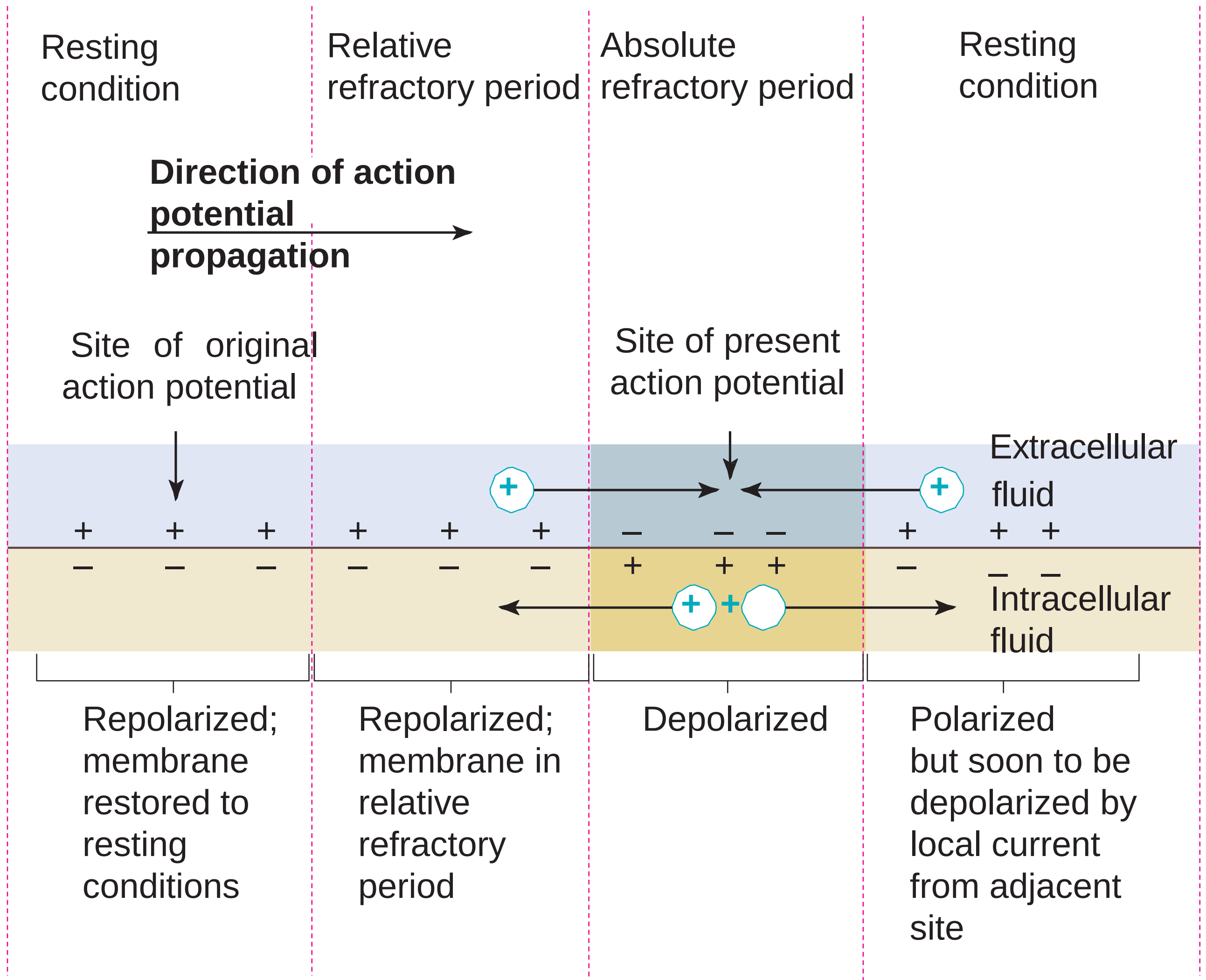
DIFFERENCES BETWEEN VOLTAGE-GATED SODIUM AND POTASSIUM CHANNELS

VOLTAGE-GATED SODIUM CHANNELS	VOLTAGE-GATED POTASSIUM CHANNELS
(1) Fast opening (2) Fast closing (3) Inactivate spontaneously	(1) Slow opening (2) Slow closing (3) Only inactivate when membrane repolarizes



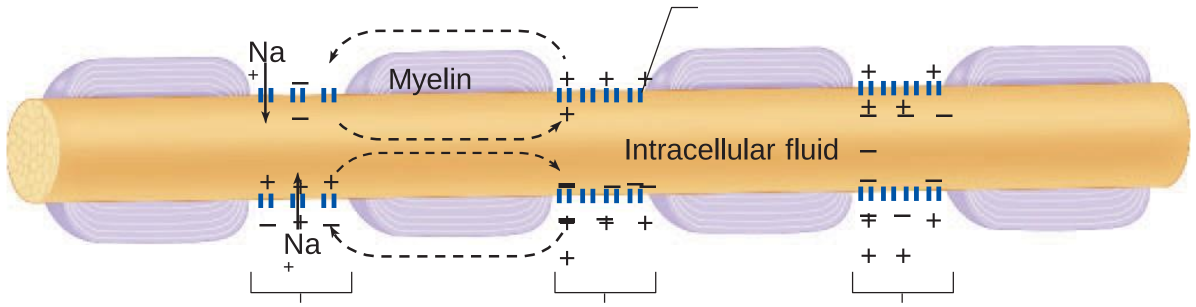
Changes in the membrane potential with increasing strength of depolarizing stimulus. When the membrane potential reaches threshold, action potentials are generated. Increasing the stimulus strength above threshold level does not cause larger action potentials.

ACTION POTENTIAL PROPAGATION



Propagation of an action potential along a plasma membrane. Local currents produced at the site of the action potential will trigger another action potential at the polarized portion of adjacent membrane. The refractory state of the repolarizing portion of adjacent membrane will prevent backward propagation.

SALTATORY CONDUCTION OF ACTION POTENTIALS



Myelinization and saltatory conduction of action potentials. Potassium channels are not depicted.

GRADED POTENTIALS AND ACTION POTENTIALS

GRADED POTENTIAL	ACTION POTENTIAL
Amplitude varies with conditions of the initiating	All-or-none. Once membrane is depolarized to threshold, event amplitude is independent of initiating event
Can be summed	Cannot be summed
Has no threshold	Has a threshold that is usually about 15 mV depolarized relative to the resting potential
Has no refractory period	Has a refractory period
Is conducted decrementally; that is, amplitude decreases with distance	Is conducted without decrement; the depolarization is amplified to a constant value at each point along the membrane
Duration varies with initiating conditions	Duration constant for a given cell type under constant conditions
Can be a depolarization or a hyperpolarization	Is only a depolarization
Initiated by environmental stimulus (receptor),	Initiated by a graded potential by neurotransmitter (synapse), or spontaneously
Mechanism depends on ligand-sensitive	Mechanism depends on voltage-gated channels channels or other chemical or physical changes

REVIEW QUESTIONS

- Where are afferent neurons, efferent neurons, and interneurons located in the nervous system? Are there places where they all could be found?
- Draw a simple cell; indicate where the concentrations of Na^+, K^+, and Cl^- are high and low and the electrical potential difference across the membrane when the cell is at rest.
- Explain the conditions that give rise to the resting membrane potential. What effect does membrane permeability have on this potential?
- What is the role of Na^+/K^+-ATPase membrane pumps in the membrane potential? Is this role direct or indirect?
- Which two factors involving ion diffusion determine the magnitude of the resting membrane potential? Explain why the resting membrane potential is not equal to the potassium equilibrium potential.