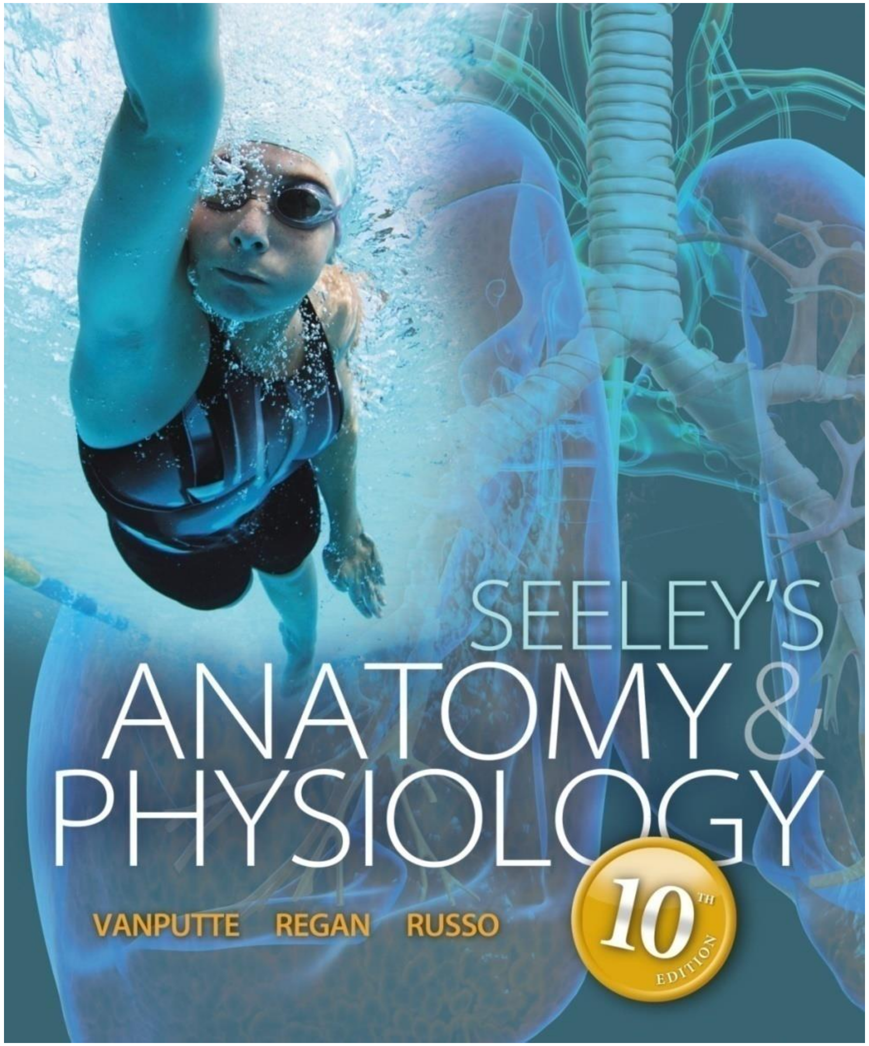

Chapter 11

Lecture Outline

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes and animations.

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Chapter 11
Functional Organization of Nervous Tissue

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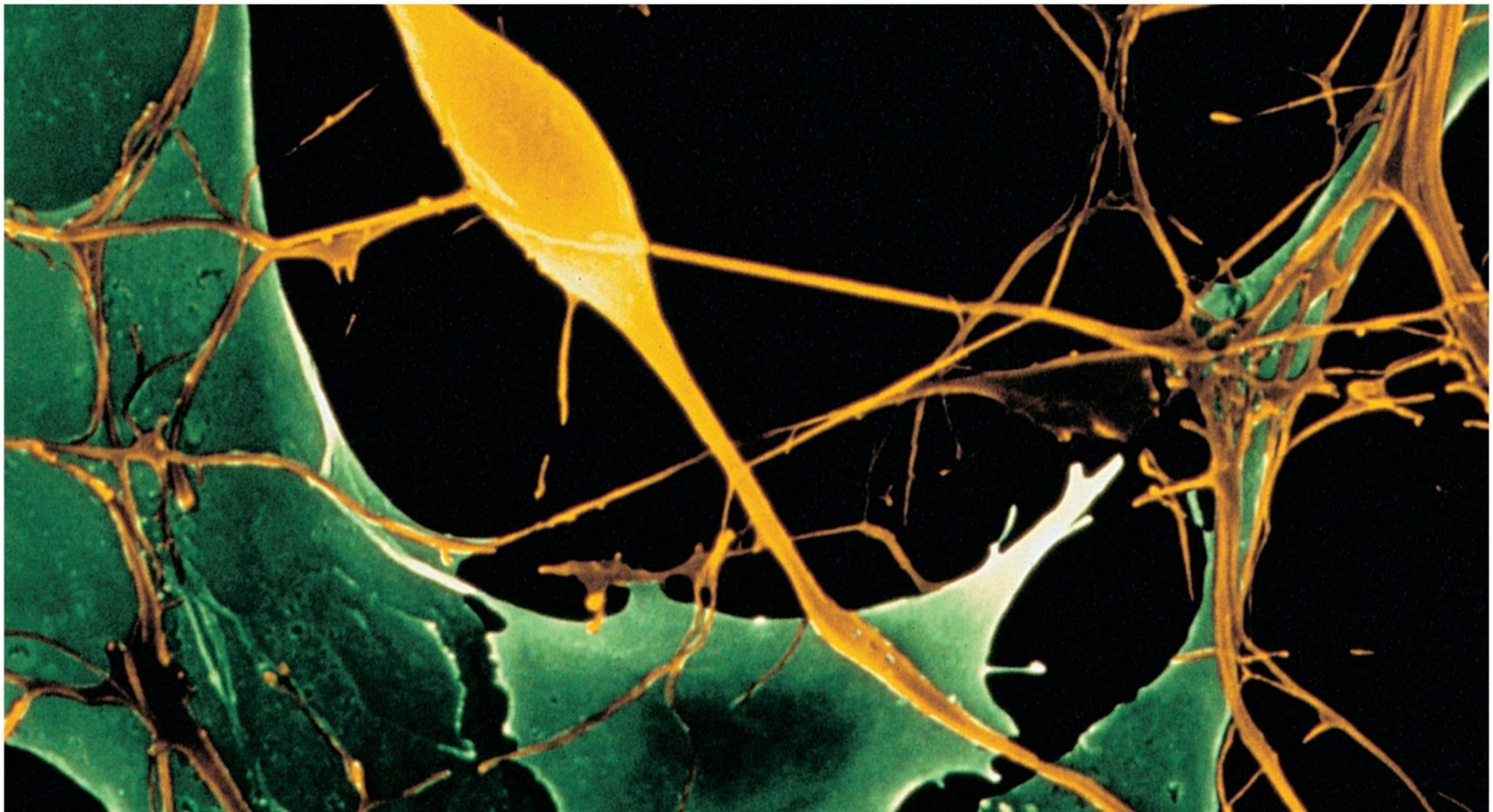

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11.1 Functions of the Nervous System

1. Receiving sensory input. Monitor internal and external stimuli
2. Integrating information. Brain and spinal cord process sensory input and initiate responses
3. Controlling muscles and glands
4. Maintaining homeostasis. Regulate and coordinate physiology
5. Establishing and maintaining mental activity. Consciousness, thinking, memory, emotion

11.2 Divisions of the Nervous System

- Components
  - Brain, spinal cord, nerves, sensory receptors
- Subdivisions
  - Central nervous system (CNS): brain and spinal cord
  - Peripheral nervous system (PNS): sensory receptors and nerves

Divisions of the Nervous System

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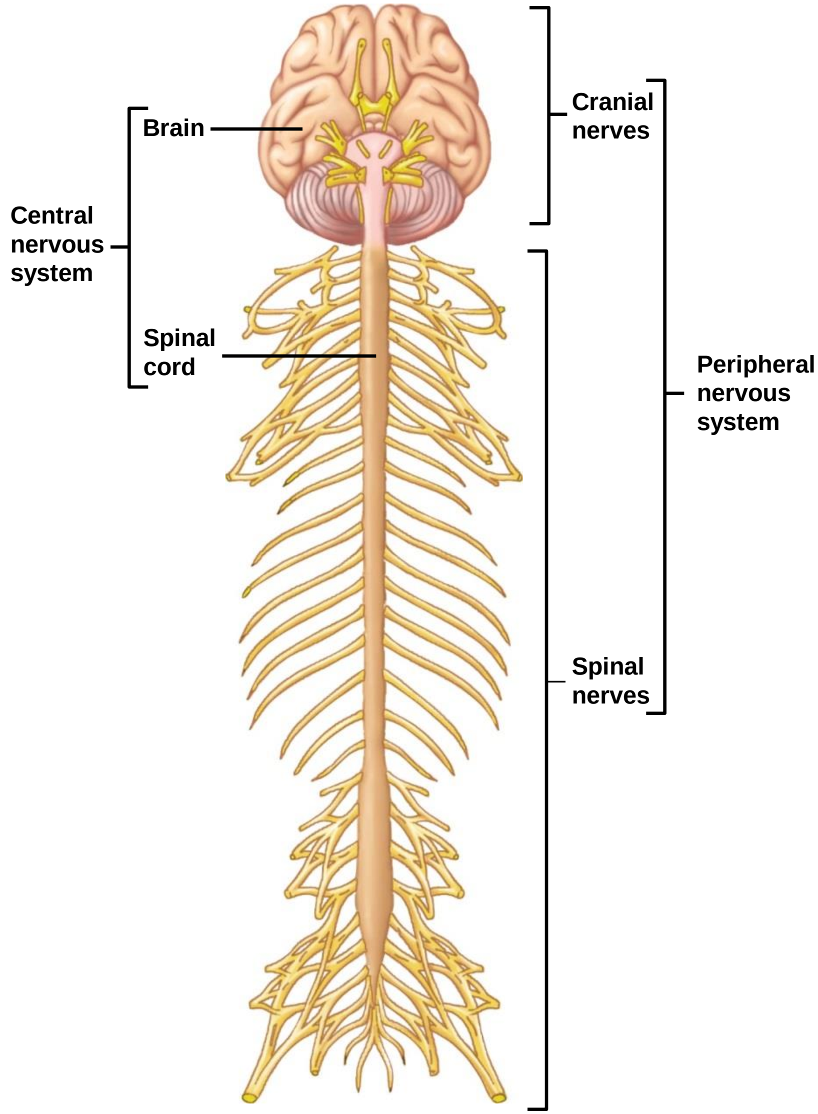

PNS

- **Sensory receptors**: ending of neurons or separate, specialized cells that detect such things as temperature, pain, touch, pressure, light, sound, odors
- **Nerve**: a bundle of axons and their sheaths that connects CNS to sensory receptors, muscles, and glands
  - **Cranial nerves**: originate from the brain; 12 pairs
  - **Spinal nerves**: originate from spinal cord; 31 pairs
- **Ganglion**: collection of neuron cell bodies outside CNS
- **Plexus**: extensive network of axons, and sometimes neuron cell bodies, located outside CNS

Divisions of PNS

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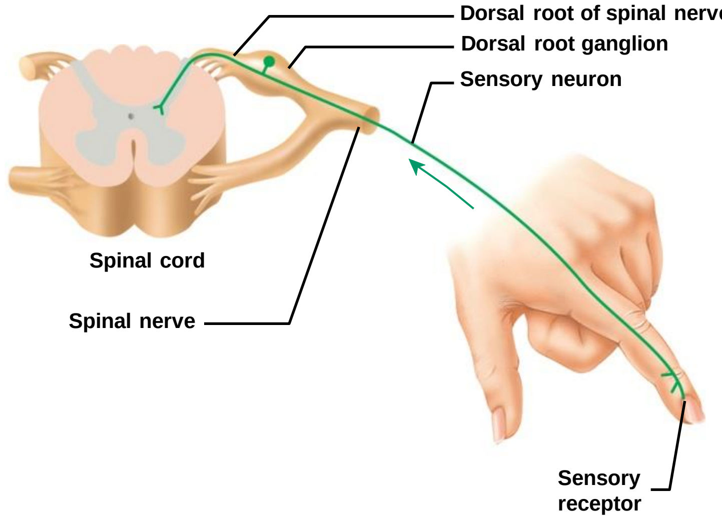
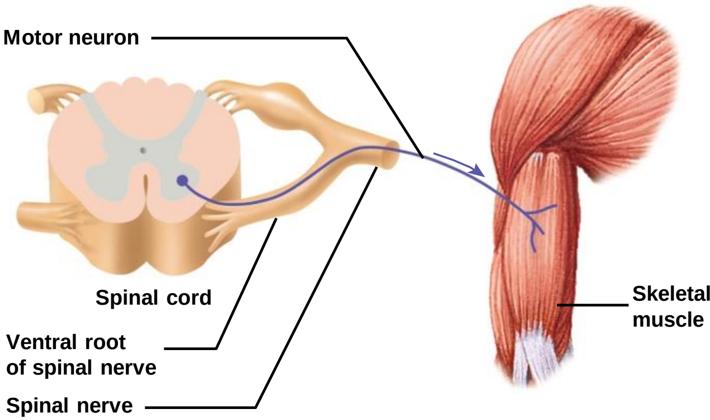
- **Sensory** (afferent): transmits action potentials from receptors to CNS.
- **Motor** (efferent): transmits action potentials from CNS to effectors (muscles, glands)



(a) Sensory division



(b) Somatic nervous system

Motor Division of PNS

- **Somatic nervous system**: from CNS to skeletal muscles.
  - Voluntary.
  - Single neuron system.
  - **Synapse**: junction of a nerve cell with another cell. E.g., neuromuscular junction is a synapse between a neuron and skeletal muscle cell.
- **Autonomic nervous system** (ANS): from CNS to smooth muscle, cardiac muscle and certain glands.
  - Subconscious or involuntary control.
  - Two neuron system: first from CNS to ganglion; second from ganglion to effector.
  - Divisions of ANS
    - **Sympathetic**. Prepares body for physical activity.
    - **Parasympathetic**. Regulates resting or vegetative functions such as digesting food or emptying of the urinary bladder.
    - **Enteric**. plexuses within the wall of the digestive tract. Can control the digestive tract independently of the CNS, but still considered part of ANS because of the parasympathetic and sympathetic neurons that contribute to the plexi.

Autonomic Nervous System

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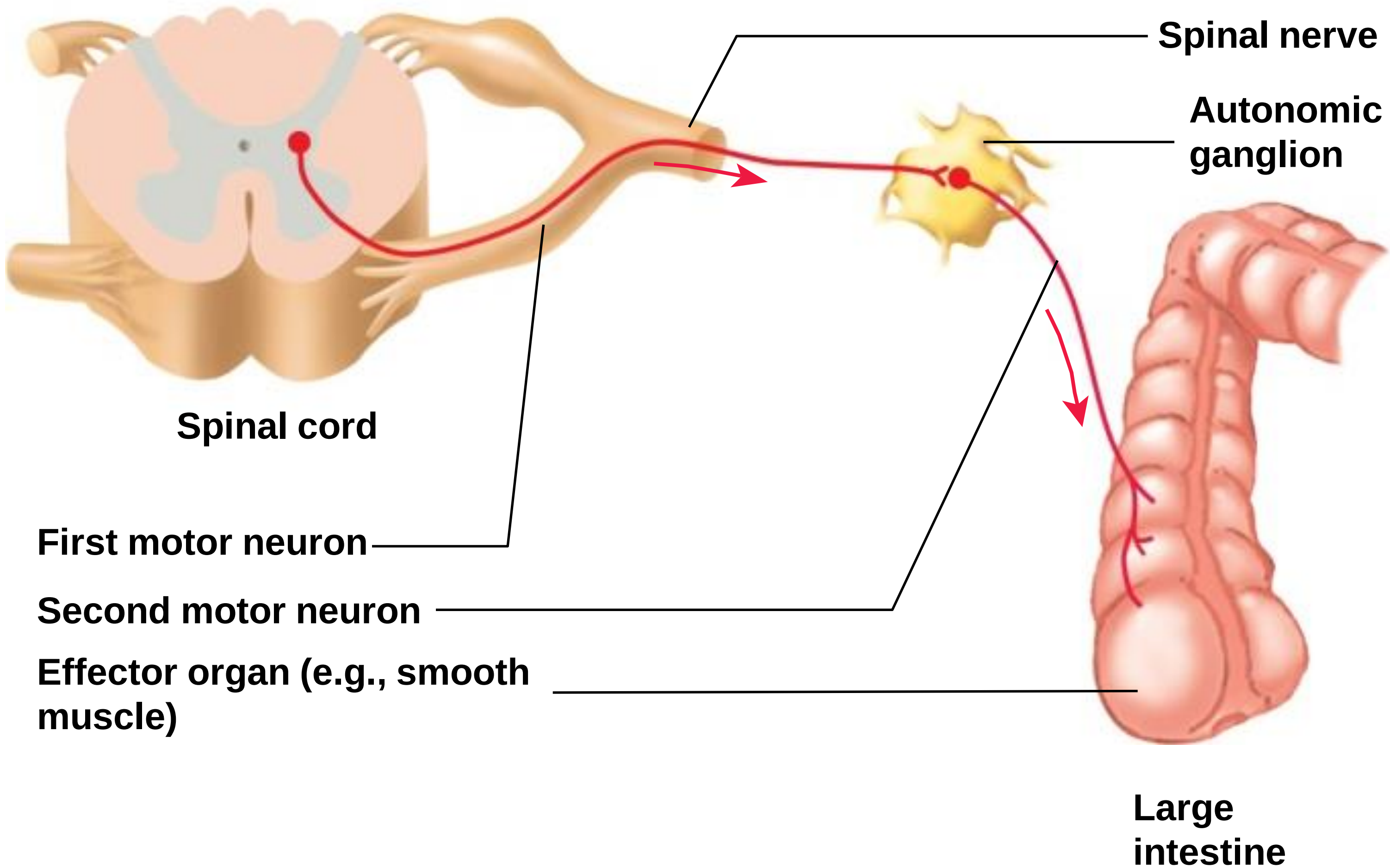

(c) Autonomic nervous system

Organization of the Nervous System

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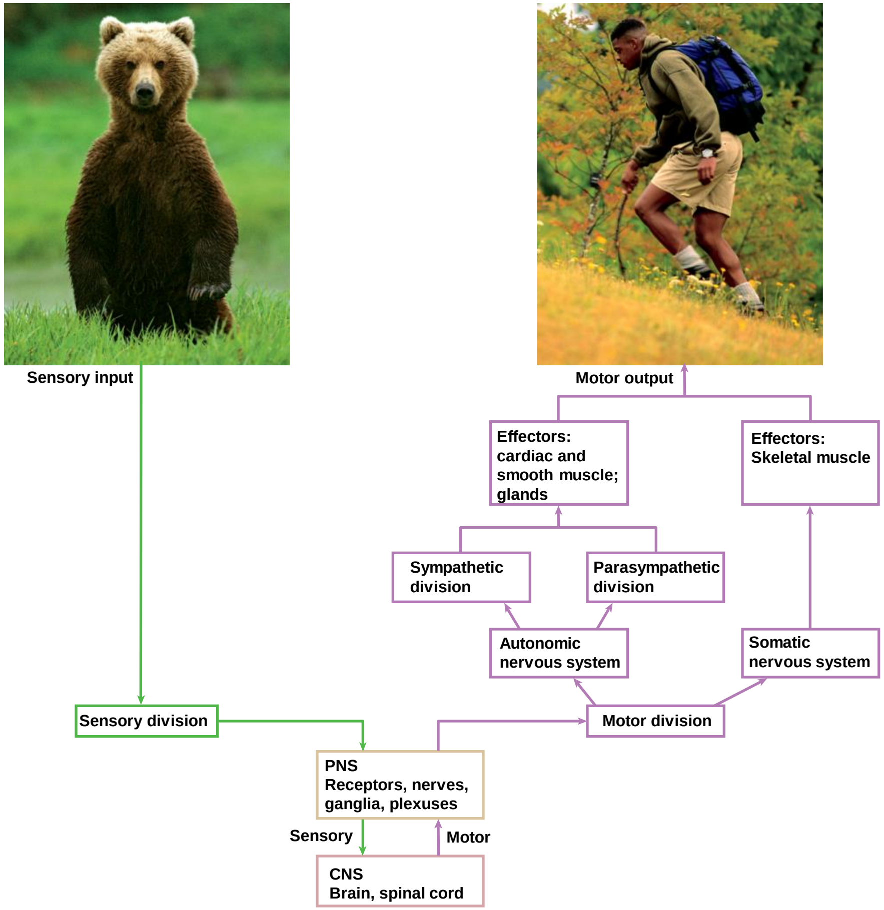

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Receptor → Sensory NS → CNS → Motor NS → Effector

11.3 Cells of Nervous System

- **Neuroglia**
  - Support and protect neurons
- **Neurons** or nerve cells receive stimuli and transmit action potentials
  - Organization
    - **Cell body** or soma
    - **Dendrites**: input
    - **Axons**: output

Parts of the Neuron

- Neuron Cell Body. Nucleus, Nissl substance.
  - Nissl substance = chromatophilic substance = rough E.R: primary site of protein synthesis.
- Dendrites: short, often highly branched.
  - Dendritic spines: little protuberance where axons synapse with dendrite.
- Axons. Can branch to form collaterals.
  - Axon hillock
  - Initial segment: beginning of axon
  - Trigger zone: site where action potentials are generated; axon hillock and part of axon nearest cell body
  - Axoplasm
  - Axolemma
  - Presynaptic terminals (terminal boutons)
  - Synaptic vesicles

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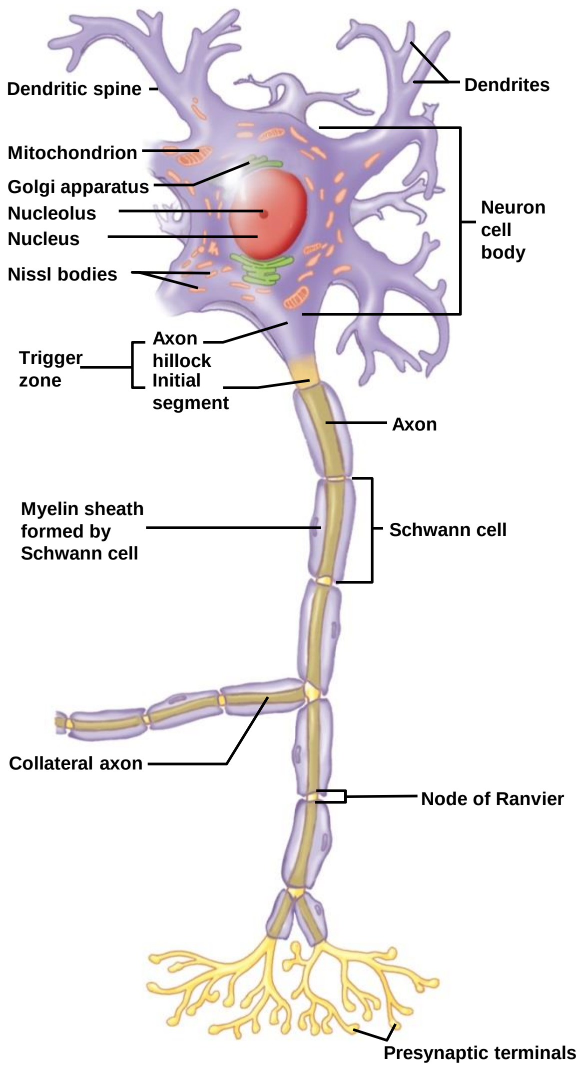

Axonic Transport Mechanisms

- Axoplasm moved from cell body toward terminals. Supply for growth, repair, renewal. Can move cytoskeletal proteins, organelles away from cell body toward axon terminals.
- Into cell body: damaged organelles, recycled plasma membrane, and substances taken in by endocytosis can be transported up axon to cell body. Rabies and herpes virus can enter axons in damaged skin and be transported to CNS.

Types of Neurons

- Functional classification
  - **Sensory** or **afferent**: action potentials toward CNS
  - **Motor** or **efferent**: action potentials away from CNS
  - **Interneurons** or **association neurons**: within CNS from one neuron to another
- Structural classification
  - **Multipolar**: most neurons in CNS; motor neurons
  - **Bipolar**: sensory in retina of the eye and nose
  - **Unipolar**: single process that divides into two branches. Part that extends to the periphery has dendrite-like sensory receptors

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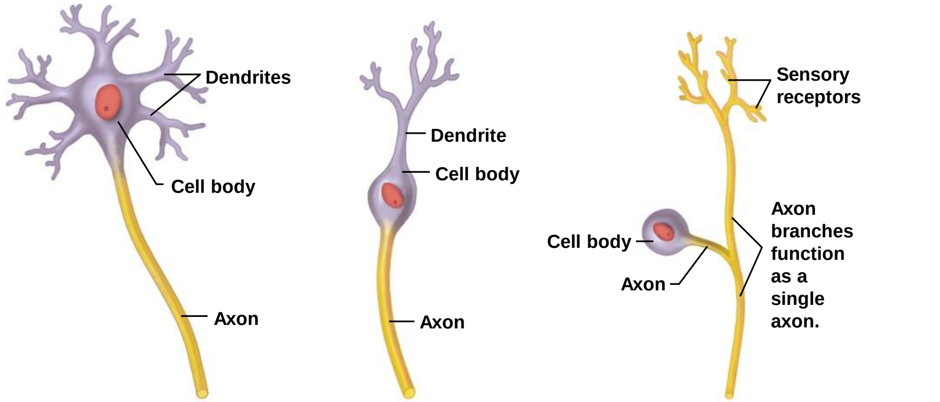

(a) A multipolar neuron has many dendrites and an axon. (b) A bipolar neuron has a dendrite and an axon. (c) A pseudo-unipolar neuron appears to have an axon and no dendrites.

Neuroglia of the CNS: Astrocytes

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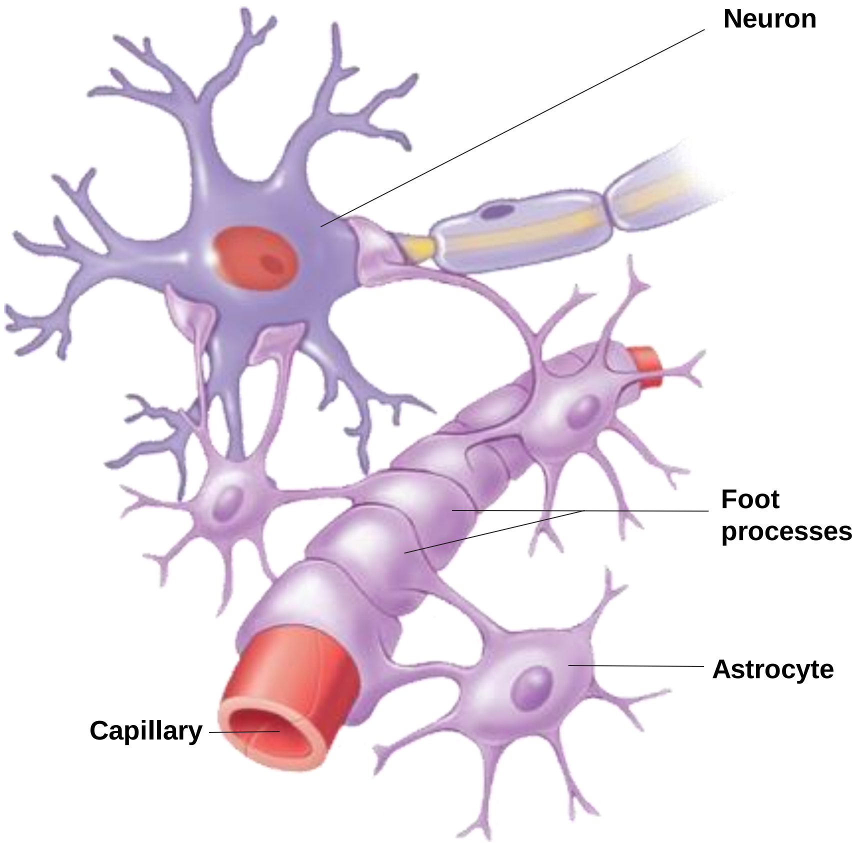

- Processes form feet that cover the surfaces of neurons and blood vessels and the pia mater.
- Regulate what substances reach the CNS from the blood (blood-brain barrier). Lots of microfilaments for support.
- Produce chemicals that promote tight junctions to form blood-brain barrier
  - **Blood-brain barrier**: protects neurons from toxic substances, allows the exchange of nutrients and waste products between neurons and blood, prevents fluctuations in the composition of the blood from affecting the functions of the brain.
- Regulate extracellular brain fluid composition

Neuroglia of the CNS: Ependymal Cells

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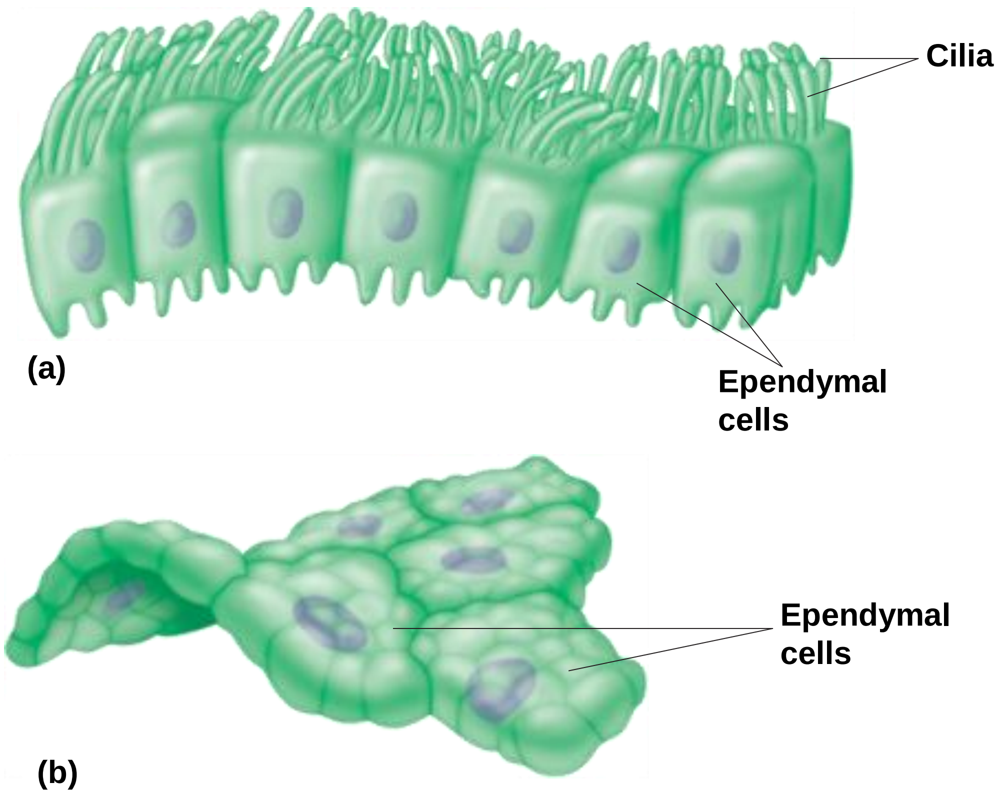

- Line brain ventricles and spinal cord central canal. Specialized versions of ependymal form choroid plexuses.
- **Choroid plexus** within certain regions of ventricles. Secrete cerebrospinal fluid. Cilia help move fluid thru the cavities of the brain. Have long processes on basal surface that extend within the brain tissue, may have astrocyte-like functions.

Neuroglia of the CNS: Microglia and Oligodendrocytes

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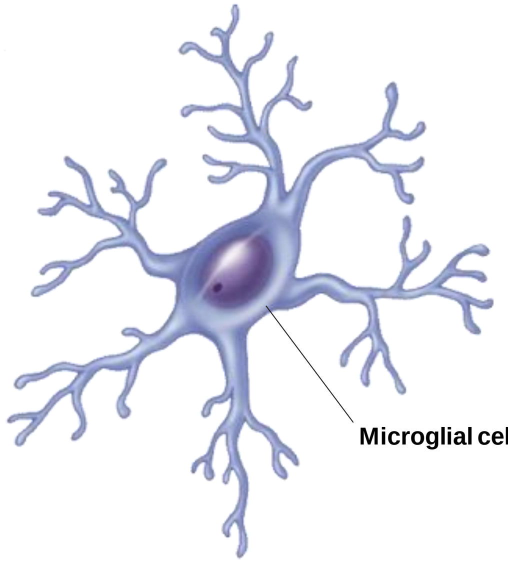
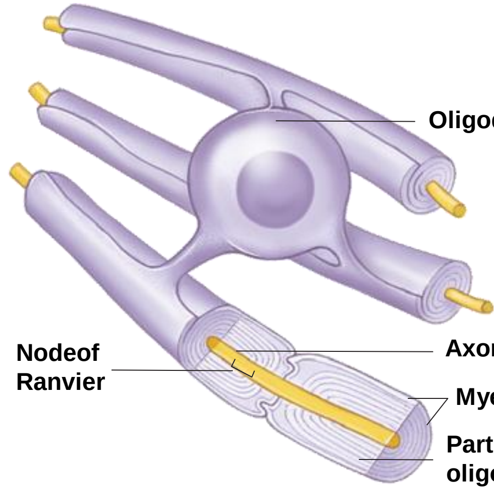
- **Microglia**: specialized macrophages. Respond to inflammation, phagocytize necrotic tissue, microorganisms, and foreign substances that invade the CNS.
- **Oligodendrocytes**: form myelin sheaths if surrounding axon. Single oligodendrocytes can form myelin sheaths around portions of several axons.





Neuroglia of the PNS

- **Schwann cells** or **neurolemmocytes**: wrap around portion of only one axon to form myelin sheath. Wrap around many times. During development, as cells grow around axon, cytoplasm is squeezed out and multiple layers of cell membrane wrap the axon. Cell membrane primarily phospholipid.
- **Satellite cells**: surround neuron cell bodies in sensory ganglia, provide support and nutrients

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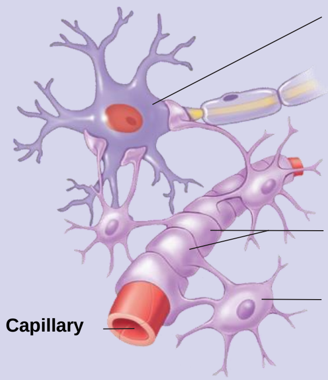
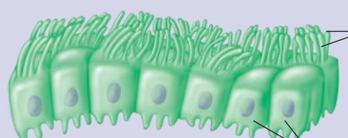
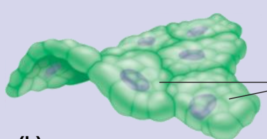
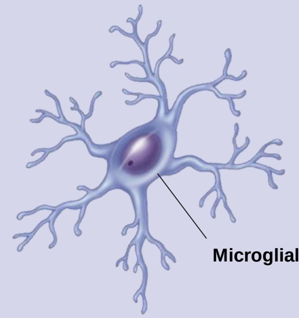
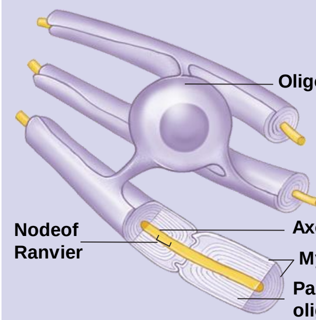
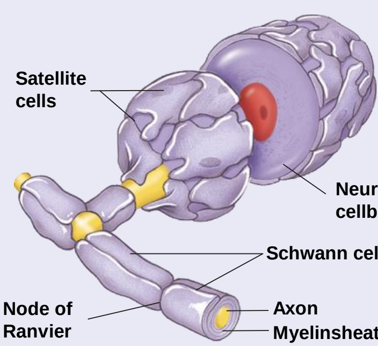
TABLE 11.1 Types of Neuroglial Cells APR

Neuroglial Cells	Function
CNS	
Astrocytes 	Astrocyte foot Processes cover the surfaces of neurons, blood vessels, and the pia mater membrane of the brain and spinal cord.The astrocytes provide structural support and play a role in regulating what substances from the blood reach the neurons.
Ependymal cells  	(*a*) Ciliatedependymal cells lining the ventricles of the brain and the central canal of the spinal cord help move cerebro spinal fluid. (*b*) Ependymal cells on the surface of the choroid plexus secrete cerebro spinal fluid.
Microglia 	Microglia are phagocytic cells within the CNS.
Oligodendrocytes 	Extensions from oligodendrocytes form part of the myelin sheaths of several axons within the CNS.
PNS	
Schwann cells and satellite cells 	Neuron cell bodies within ganglia are surrounded by satellite cells.Schwann cells form the myelin sheath of an axon within the PNS.

Myelinated and Unmyelinated Axons

- **Myelinated axons**
  - Myelin protects and insulates axons from one another, speeds transmission, functions in repair of axons.
  - Not continuous
  - **Nodes of Ranvier**
  - Completion of development of myelin sheaths at 1 yr.
  - Degeneration of myelin sheaths occurs in multiple sclerosis and some cases of diabetes mellitus.
- **Unmyelinated axons**: rest in invaginations of Schwann cells or oligodendrocytes. Not wrapped around the axon; gray matter.

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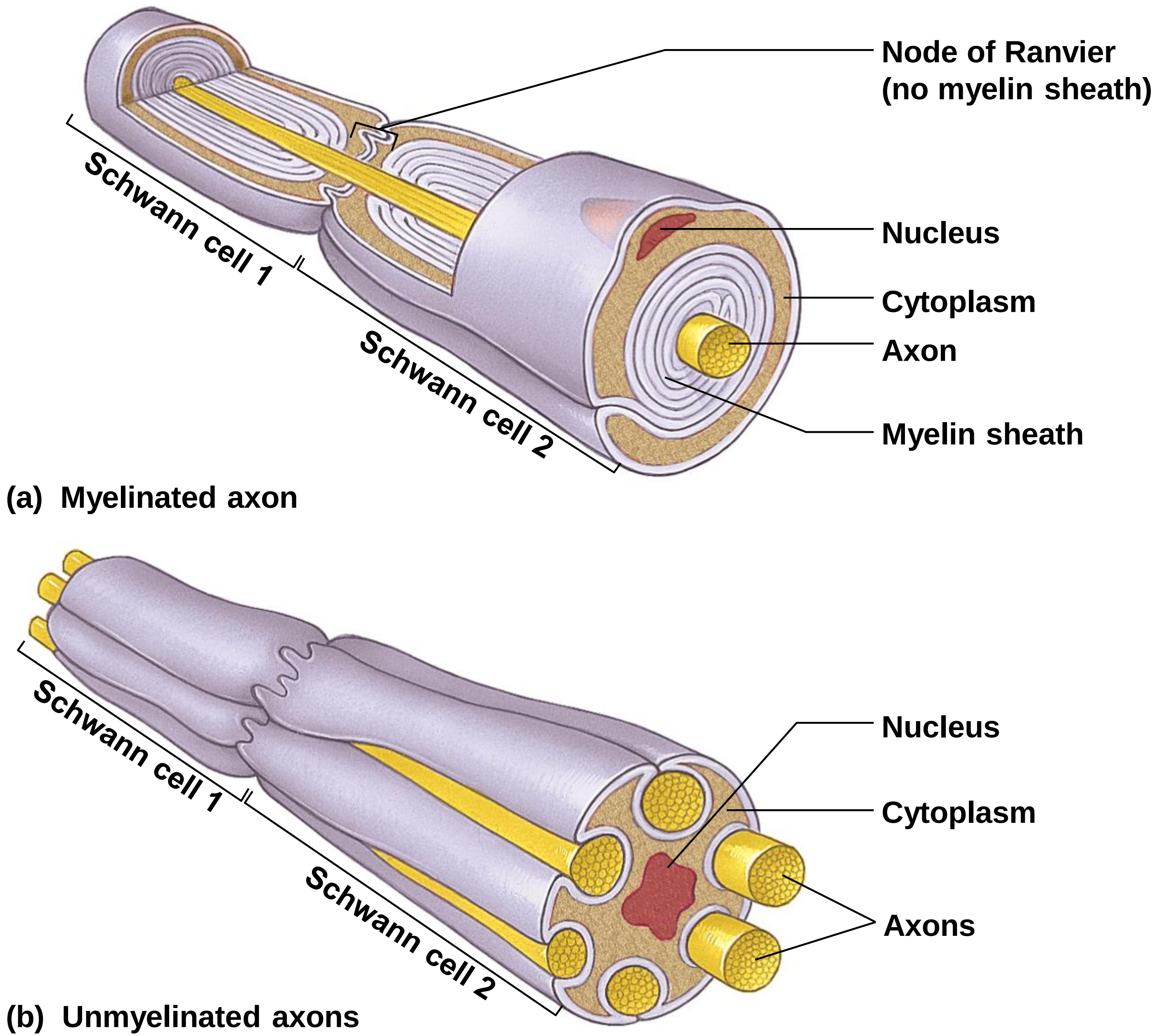

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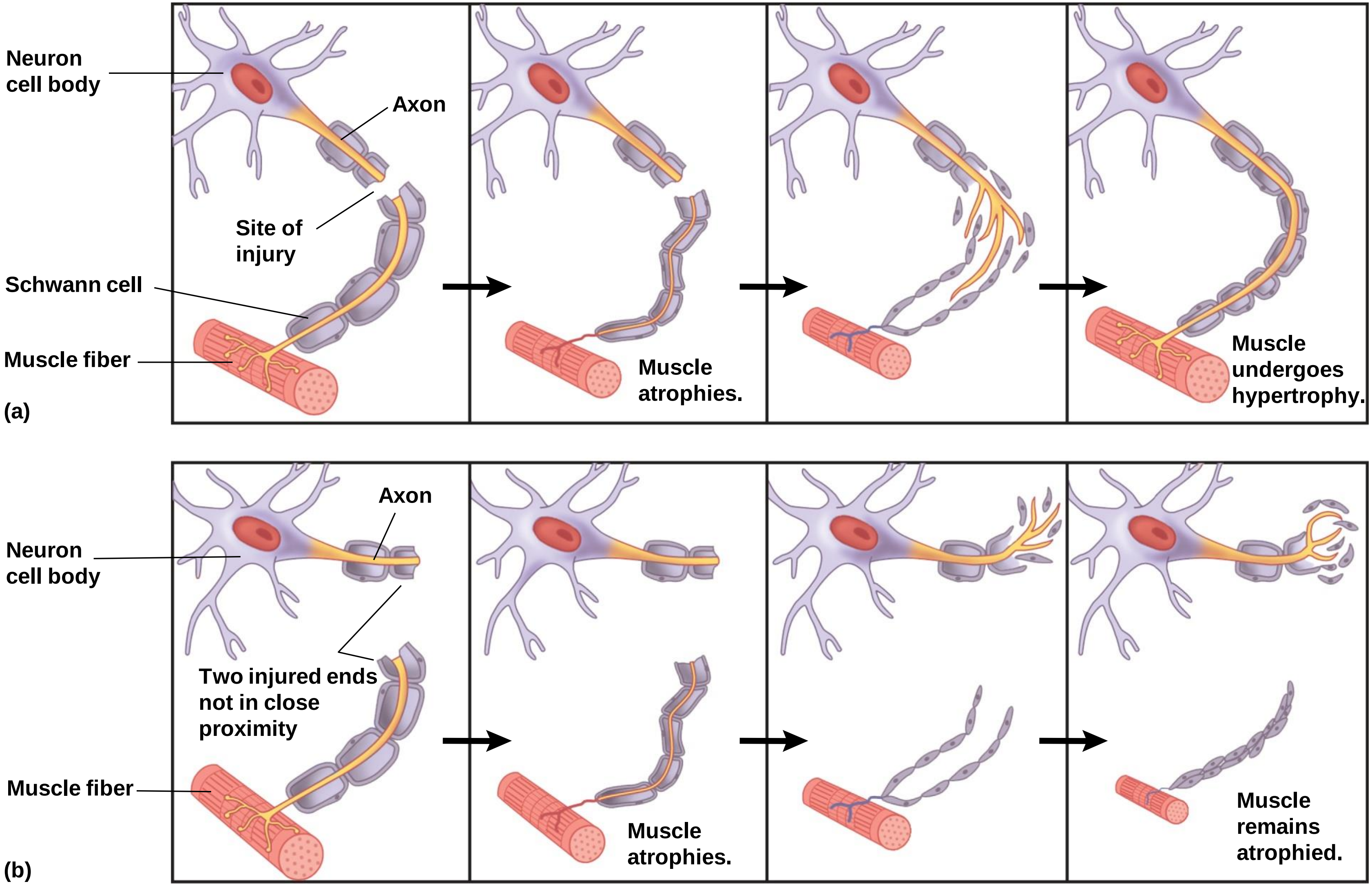

11.4 Organization of Nervous Tissue

- **Gray matter**: unmyelinated axons, cell bodies, dendrites, neuroglia. Integrative functions
- **White matter**: myelinated axons. Nerve tracts propagate actin potentials from one area in the CNS to another
- In brain: gray is outer cortex as well as inner nuclei; white is deeper.
- In spinal cord: white is outer, gray is deeper.
- PNS gray matter is groups of cell bodies called **ganglia**

11.5 Electrical Signals

- Cells produce electrical signals called **action potentials**
- Transfer of information from one part of body to another
- Electrical properties result from ionic concentration differences across plasma membrane and permeability of membrane

Concentration Differences Across the Plasma Membrane

- These ion concentrations are a result of two processes: the Na/K pump and membrane permeability. Note high concentration of Na and Cl ions outside and high concentration of K and proteins on inside. Note steep concentration gradient of Na and K, but in opposite directions.

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TABLE 11.2 Representative Concentrations of the Principal Cations and Anions in Extracellular and Intracellular Fluids in the Human Body

Ions	Intracellular Fluid (mEq/L)*	Extracellular Fluid (mEq/L)
Cations (Positive)		
Potassium (K^+)	148	5
Sodium (Na^+)	10	142
Calcium (Ca^{2+})	<1	5
Others	41	3
TOTAL	200	155
Anions (Negative)		
Proteins	56	16
Chloride (Cl^-)	4	103
Others	140	36
TOTAL	200	155

* See appendix C for an explanation of milliequivalents (mEq).

Permeability Characteristics of the Plasma Membrane

- Proteins: synthesized inside cell: Large, don't dissolve in phospholipids of membrane. Proteins are negatively charged.
- Cl^- are repelled by proteins and they exit thru always-open nongated Cl^- channels.
- Gated ion channels open and close because of some sort of stimulus. When they open, they change the permeability of the cell membrane.
  - Ligand-gated: molecule that binds to a receptor; protein or glycoprotein

Leak Channels

- Many more of these for K^+ and Cl^- than for Na^+. So, at rest, more K^+ and Cl^- are moving than Na^+. How are they moving? Protein repels Cl^-, they move out. K^+ are in higher concentration on inside than out, they move out.
  - Always open and responsible for permeability when membrane is at rest.
  - Specific for one type of ion although not absolute.

Leak Channels

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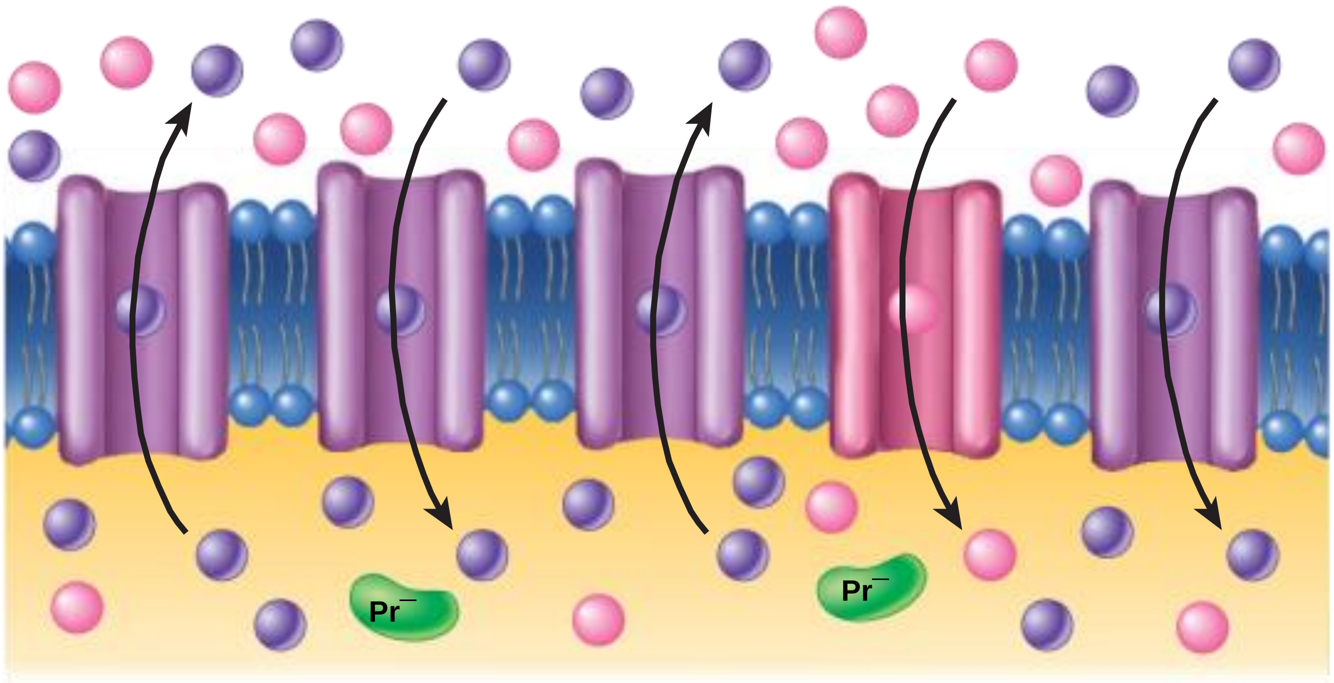

2 There are more K^+ leak channels than Na^+ leak channels. In the resting cell, only the leak channels are opened; the gated channels (not shown) are closed. Because of the ion concentration differences across the membrane, K^+ diffuses out of the cell down its concentration gradient and Na^+ diffuses into the cell down its concentration gradient. The tendency for K^+ to diffuse out of the cell is opposed by the tendency of the positively charged K^+ to be attracted back into the cell by the negatively charged proteins.

Gated Ion Channels

- **Gated ion channels**. Gated ion channels open and close because of some sort of stimulus. When they open, they change the permeability of the cell membrane.
  - **Ligand-gated**: open or close in response to ligand such as ACh binding to receptor protein. Receptor proteins are usually glycoproteins. E.g., acetylcholine binds to acetylcholine receptor on a Na^+ channel. Channel opens, Na^+ enters the cell.

Voltage Gated Ion Channels

- **Voltage-gated**: open or close in response to small voltage changes across the cell membrane.
- At rest, membrane is negative on the inside relative to the outside.
- When cell is stimulated, that relative charge changes and voltage-gated ion channels either open or close. Most common voltage gated are Na^+ and K^+. In cardiac and smooth muscle, Ca^{2+} are important.

Other Gated Ion Channels

- Touch receptors: respond to mechanical stimulation of the skin
- Temperature receptors: respond to temperature changes in the skin

Establishing the Resting Membrane Potential

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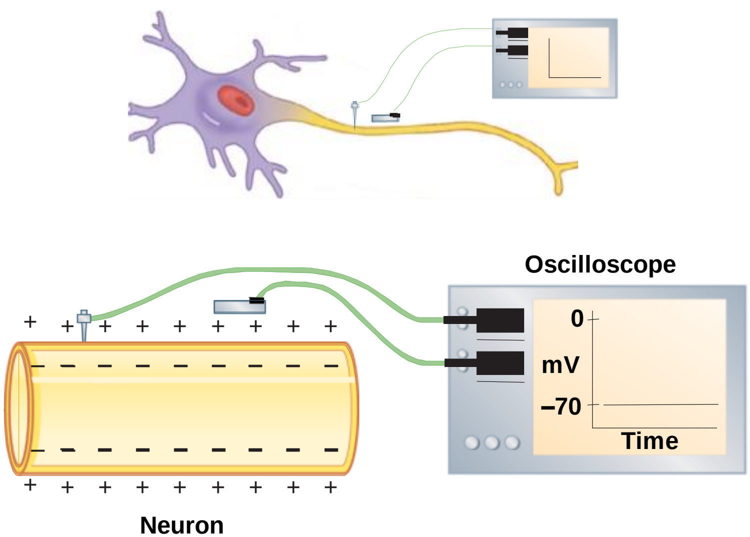

(b)

- Number of charged molecules and ions inside and outside cell nearly equal
- Concentration of K^+ higher inside than outside cell, Na^+ higher outside than inside
- **Potential difference**: unequal distribution of charge exists between the immediate inside and immediate outside of the plasma membrane: -70 to -90 mV
- The **resting membrane potential**

Establishing the Resting Potential

- At equilibrium there is very little movement of K^+ or other ions across plasma membrane (Movement of K out through leakage channels = movement of ions is due to attraction to trapped proteins: N.B. leakage channels work in both directions. Movement of ions depends upon concentration gradient.)
- Na^+, Cl^-, and Ca^{2+} do not have a great affect on resting potential since there are very few leakage channels for these ions.
- If leakage channels alone were responsible for resting membrane potential, in time Na^+ and K^+ ion concentrations would eventually equalize.
- But they are maintained by the Na/K pump. For each ATP that is consumed, three Na moved out, two K^+ moved in. Outside of plasma membrane slightly positive

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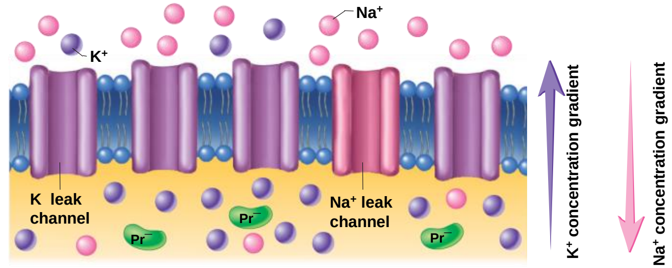
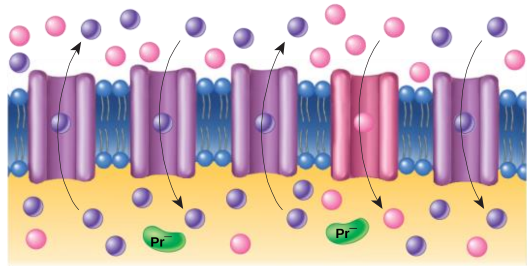
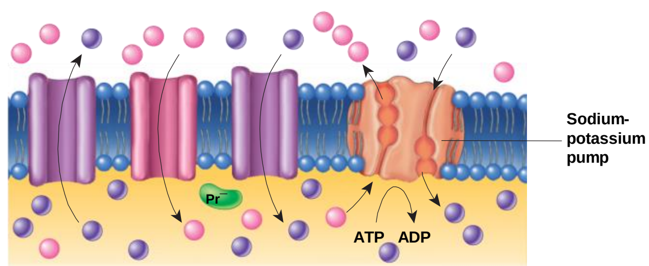


1 In a resting cell, there is a higher concentration of K^+ (*purple circles*) inside the cell membrane and a higher concentration of Na^+ (*pink circles*) outside the cell membrane. Because the membrane is not permeable to negatively charged proteins (*green*) they are isolated to inside of the cell membrane.



2 There are more K^+ leak channels than Na^+ leak channels. In the resting cell, only the leak channels are opened; the gated channels (not shown) are closed. Because of the ion concentration differences across the membrane, K^+ diffuses out of the cell down its concentration gradient and Na^+ diffuses into the cell down its concentration gradient. The tendency for K^+ to diffuse out of the cell is opposed by the tendency of the positively charged K^+ to be attracted back into the cell by the negatively charged proteins.



3 The sodium-potassium pump helps maintain the differential levels of Na+ and K^+ by pumping three Na^+ out of the cell in exchange for two K^+ into the cell. The pump is driven by ATP hydrolysis. The resting membrane potential is established when the movement of K^+ out of the cell is equal to the movement of K^+ into the cell.

(a)

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TABLE 11.3 Characteristics Responsible for the Resting Membrane Potential

1.	The concentration of K^+ is higher inside the cell than outside, and the concentration of Na^+ is higher outside the cell than inside.
2.	Due to the K^+ leak channels, the plasma membrane is 50–100 times more permeable to K^+ than to other positively charged ions, such as Na^+.
3.	The plasma membrane is impermeable to large, intracellular, negatively charged molecules, such as proteins. In other words, these anions are "trapped" inside the cell.
4.	Potassium ions tend to diffuse across the plasma membrane from the inside to the outside of the cell.
5.	Because negatively charged molecules cannot follow the positively charged K^+, a small negative charge develops inside the plasma membrane.
6.	The negative charge inside the cell attracts positively charged K^+. When the negative charge inside the cell is great enough to prevent additional K^+ from diffusing out of the cell through the plasma membrane, an equilibrium is established.
7.	The charge difference across the plasma membrane at equilibrium is reflected as a difference in potential, which is measured in millivolts (mV).
8.	The resting membrane potential is proportional to the potential for K^+ to diffuse out of the cell but not to the actual rate of flow for K^+.
9.	At equilibrium, very little movement of K^+ or other ions takes place across the plasma membrane.

Changing the Resting Membrane Potential: K^+

- **Depolarization**: Potential difference becomes smaller or less polar
- **Hyperpolarization**: Potential difference becomes greater or more polar
- K^+ concentration gradient alterations
  - If extracellular concentration of K^+ increases: less gradient between inside and outside. **Depolarization**
  - If extracellular ion concentration decreases: steeper gradient between inside and outside. **Hyperpolarization**
- K^+ membrane permeability changes. In resting membrane, K^+ in and out is equal through the leakage channels. But there are also gated K^+ channels in the membrane. If they open, more K^+ diffuses out but this is opposed by the negative charge that starts to develop as the K^+ diffuses out.

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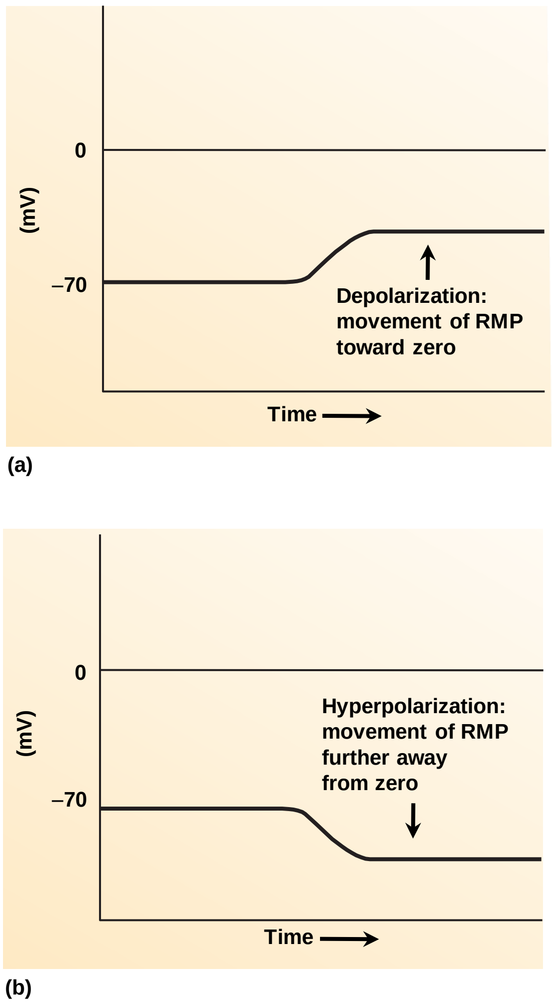

Changes in Resting Membrane Potential: Na^+

- Na^+ membrane permeability.
- Change the concentration of Na^+ inside or outside the cell, little effect because gates remain closed.
- But open gates (like when ACh attaches to receptors), Na^+ diffuses in, depolarizing the membrane.

Changes in Resting Membrane Potential: Ca^{2+}

- Voltage-gated Na^+ channels sensitive to changes in extracellular Ca^{2+} concentrations
  - If extracellular Ca^{2+} concentration decreases- Na^+ gates open and membrane depolarizes.
  - If extracellular concentration of Ca^{2+} increases- gates close and membrane repolarizes or becomes hyperpolarized.

Graded Potentials

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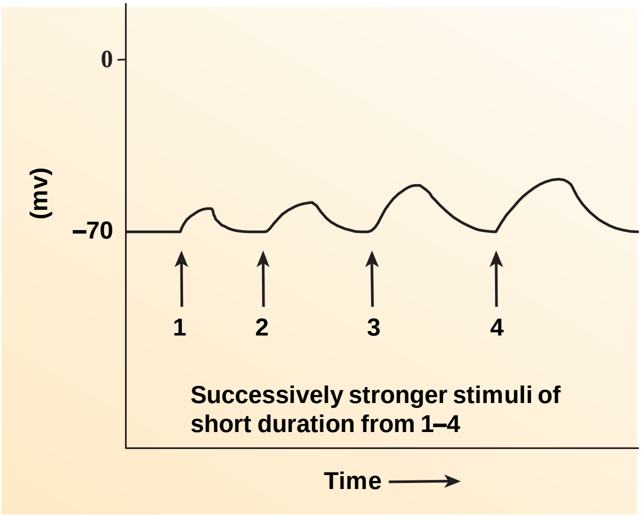
- Result from
  - Ligands binding to receptors
  - Changes in charge across membrane
  - Mechanical stimulation
  - Temperature changes
  - Spontaneous change in permeability
- **Graded**
  - Magnitude varies from small to large depending on stimulus strength or frequency
- Can **summate** or add onto each other
- Spread (are conducted) over the plasma membrane in a decremental fashion: rapidly decrease in magnitude as they spread over the surface of the plasma membrane.
- Can cause generation of action potentials



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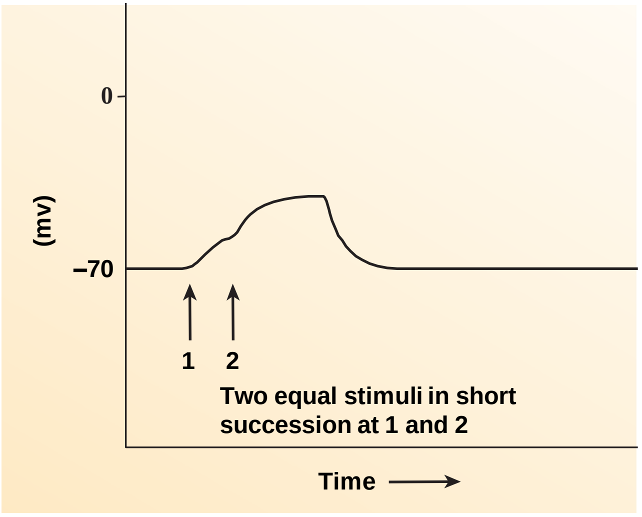

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TABLE 11.4 Characteristics of Graded Potentials

1. A stimulus causes ion channels to open, increasing the permeability of the membrane to Na^+, K^+, or Cl^-.
2. Increased permeability of the membrane to Na^+ results in depolarization. Increased permeability of the membrane to K^+ or Cl^- results in hyperpolarization.
3. The size of the graded potential is proportional to the strength of the stimulus. Graded potentials can also summate. Thus, a graded potential produced in response to several stimuli is larger than one produced in response to a single stimulus.
4. Graded potentials are conducted in a *decremental* fashion, meaning that their magnitude decreases as they spread over the plasma membrane. Graded potentials cannot be measured a few millimeters from the point of stimulation.
5. A depolarizing graded potential can cause an action potential.

Action Potentials

- Depolarization phase followed by repolarization phase.
  - **Depolarization**: more positive
  - **Repolarization**: more negative (may get afterpotential [slight hyperpolarization])
- Series of permeability changes when a graded potential causes depolarization of membrane. A large enough graded potential may cause the membrane to reach threshold. Then get action potential.
- **All-or-none principle.** No matter how strong the stimulus, as long as it is greater than threshold, then action potential will occur.

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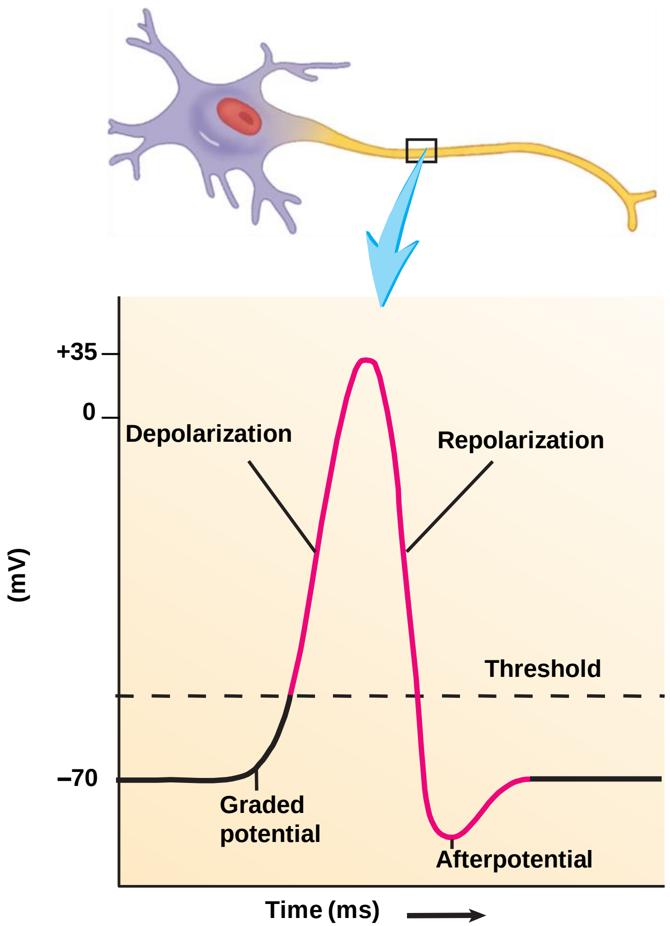

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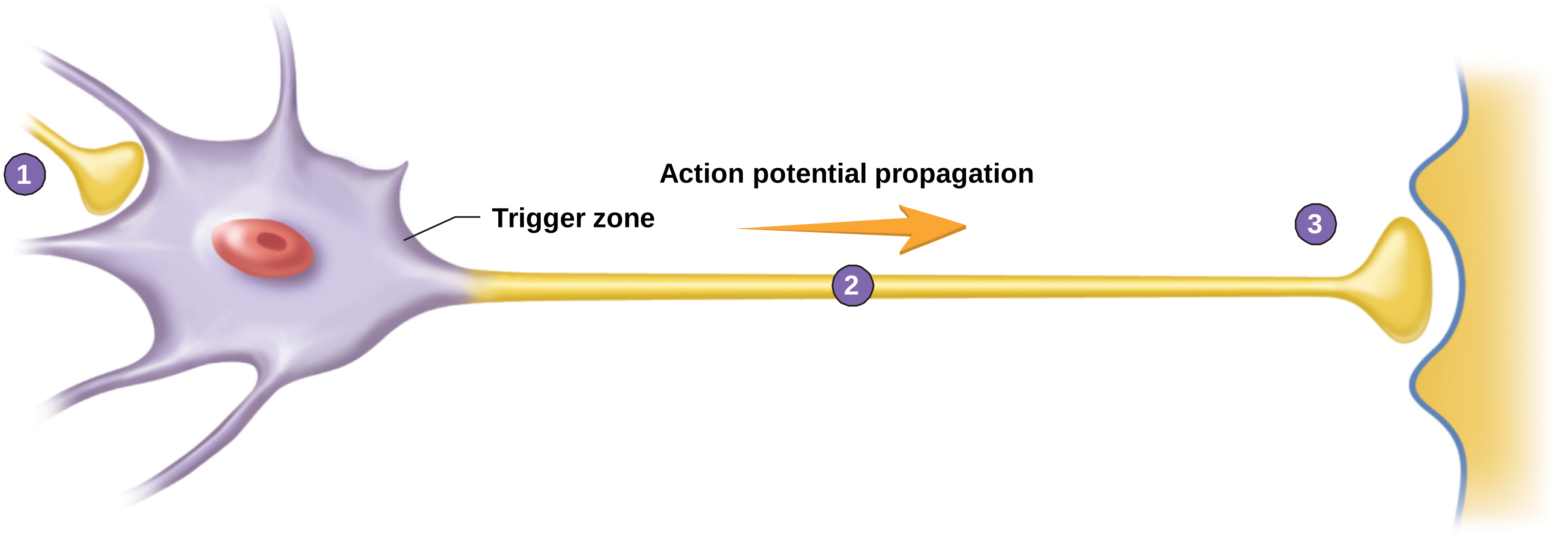

1 Action potentials in the communicating neuron stimulate graded potentials in a receiving neuron that can summate at the trigger zone.

2 Action potentials are propagated down the axon to the axon terminal.

3 Action potentials result in communication of the neuron with its target.

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TABLE 11.5 Characteristics of Action Potentials

1. Action potentials are produced when a graded potential reaches threshold.
2. Action potentials are all-or-none.
3. Depolarization is a result of increased membrane permeability to Na^+ and movement of Na^+ into the cell. Activation gates of the voltage-gated Na^+ channels open.
4. Repolarization is a result of decreased membrane permeability to Na^+ and increased membrane permeability to K^+, which stops Na^+ movement into the cell and increases K^+ movement out of the cell. The inactivation gates of the voltage-gated Na^+ channels close, and the voltage-gated K^+ channels open.
5. During the absolute refractory period, no action potential is produced by a stimulus, no matter how strong. During the relative refractory period, a stronger-than-threshold stimulus can produce an action potential.
6. Action potentials are propagated and, for a given axon or muscle fiber, the magnitude of the action potential is constant.
7. Stimulus strength determines the frequency of action potentials.

Operation of Gates: Action Potential

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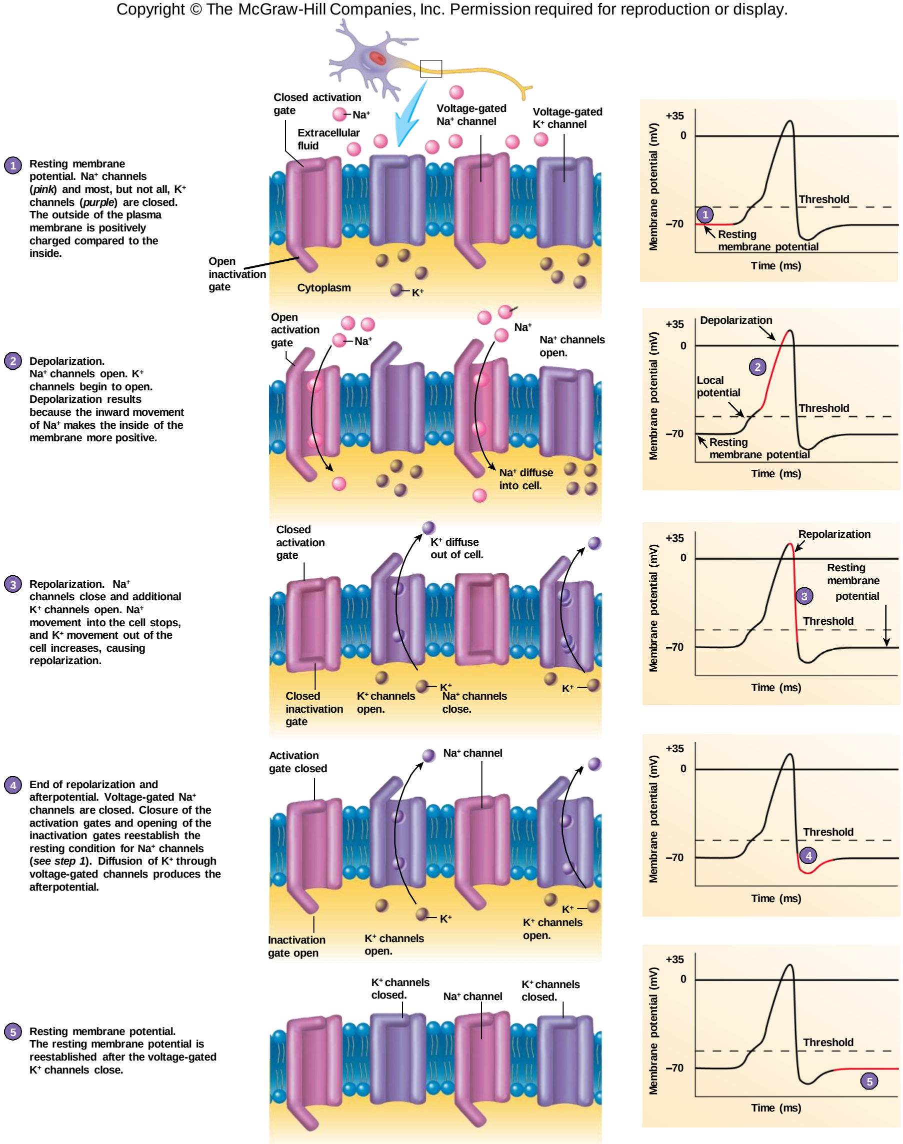

Refractory Period

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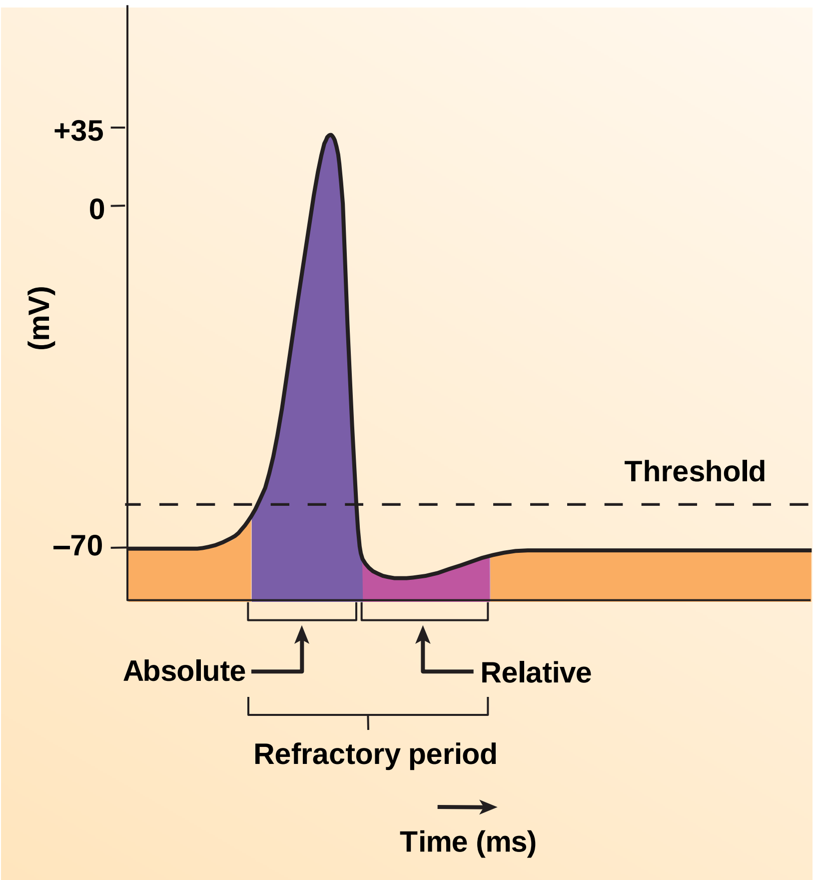

- Sensitivity of area to further stimulation decreases for a time
- Parts
  - **Absolute**
    - Complete insensitivity exists to another stimulus
    - From beginning of action potential until near end of repolarization. No matter how large the stimulus, a second action potential cannot be produced. Has consequences for function of muscle, particularly how often a.p.s can be produced.
  - **Relative**
    - A stronger-than-threshold stimulus can initiate another action potential

Action Potential Frequency

- Number of potentials produced per unit of time to a stimulus
  - **Threshold stimulus**: causes a graded potential that is great enough to initiate an action potential.
  - **Subthreshold stimulus**: does not cause a graded potential that is great enough to initiate an action potential.
  - **Maximal stimulus**: just strong enough to produce a maximum frequency of action potentials.
  - **Submaximal stimulus**: all stimuli between threshold and the maximal stimulus strength.
  - **Supramaximal stimulus**: any stimulus stronger than a maximal stimulus. These stimuli cannot produce a greater frequency of action potentials than a maximal stimulus.

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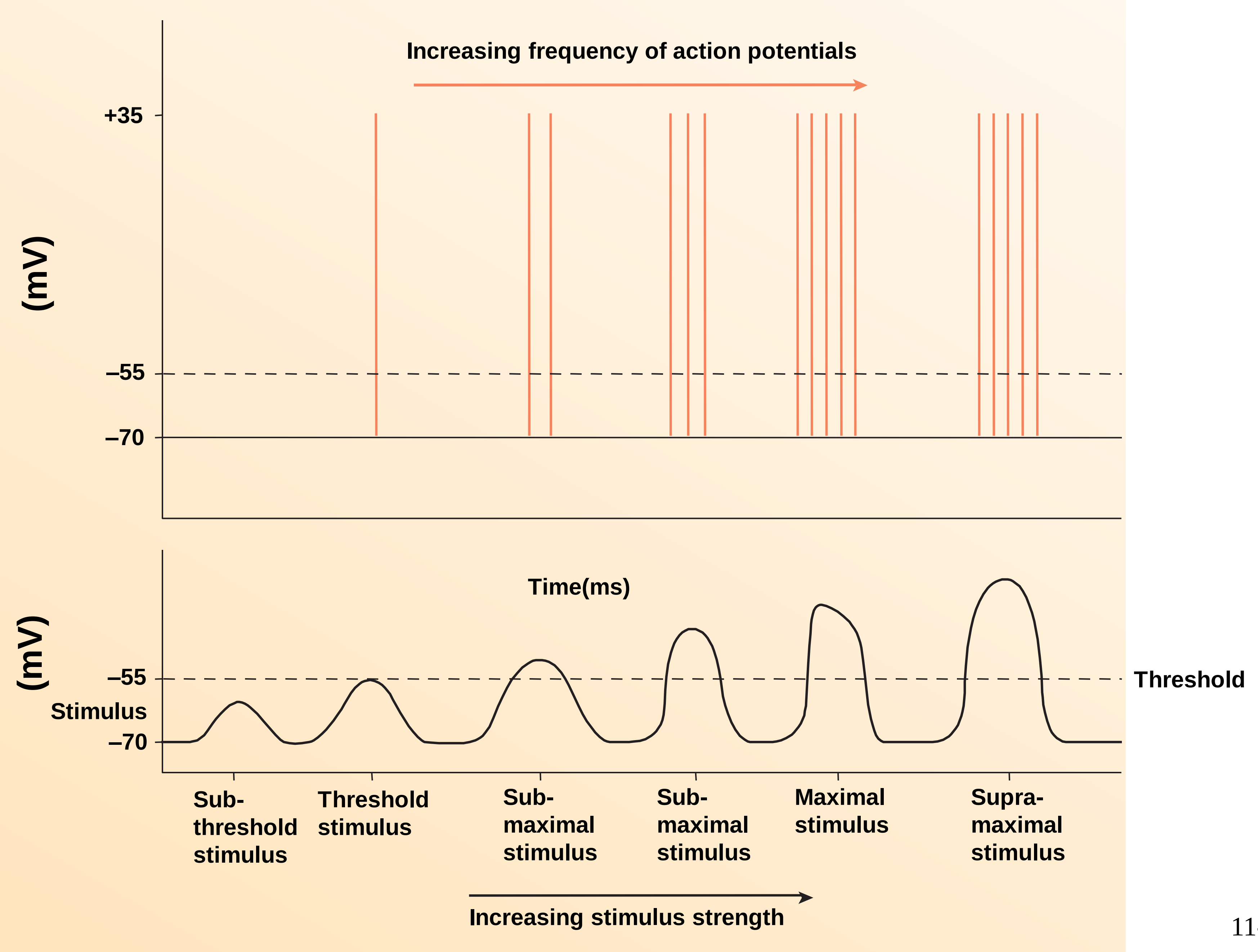

Propagation of Action Potentials

- In an unmyelinated axon
- Threshold graded current at trigger zone causes action potential
- Action potential in one site causes action potential at the next location. Cannot go backwards because initial action potential site is depolarized yielding one-way conduction of impulse.

Propagation of Action Potentials

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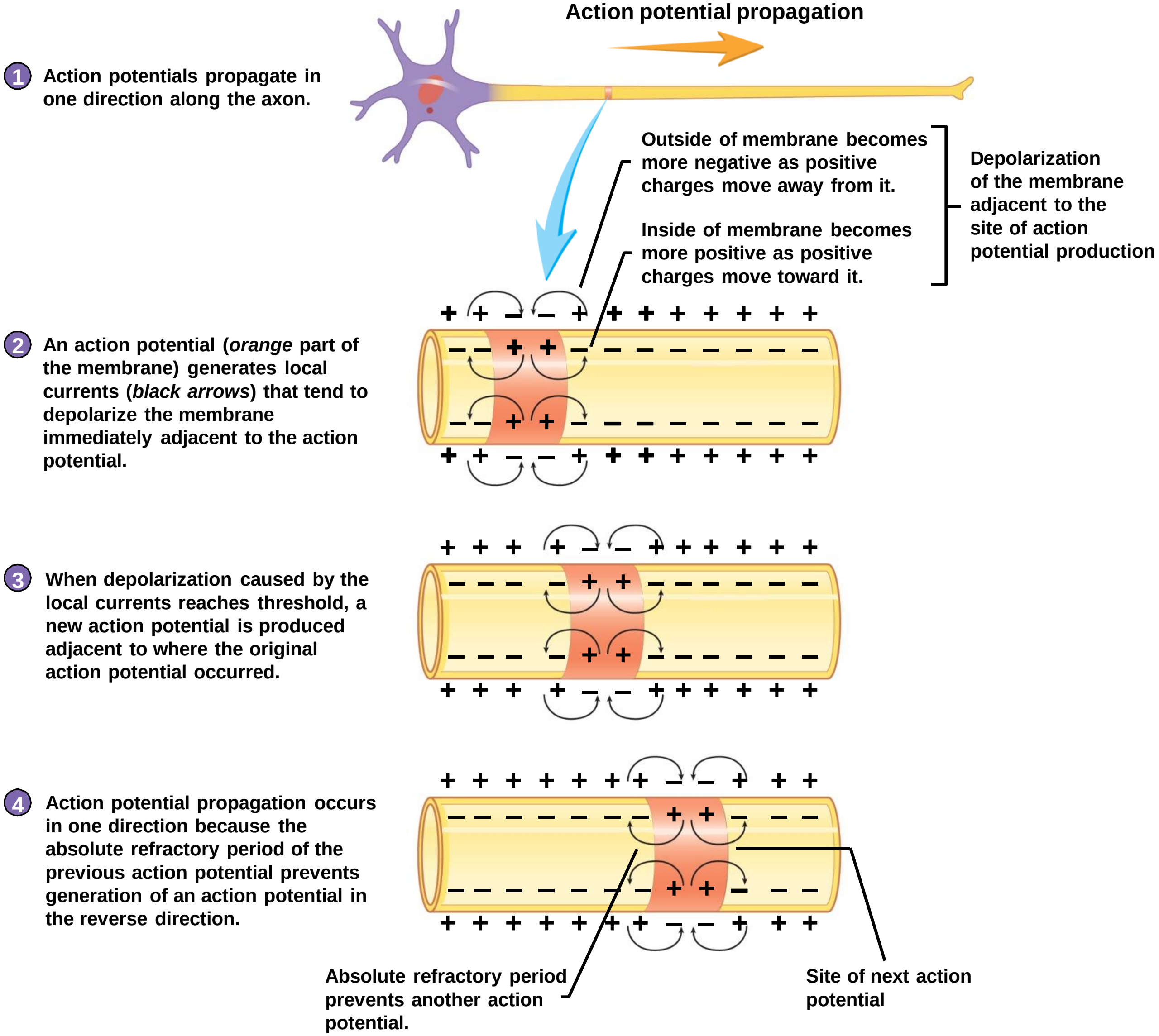

Saltatory Conduction

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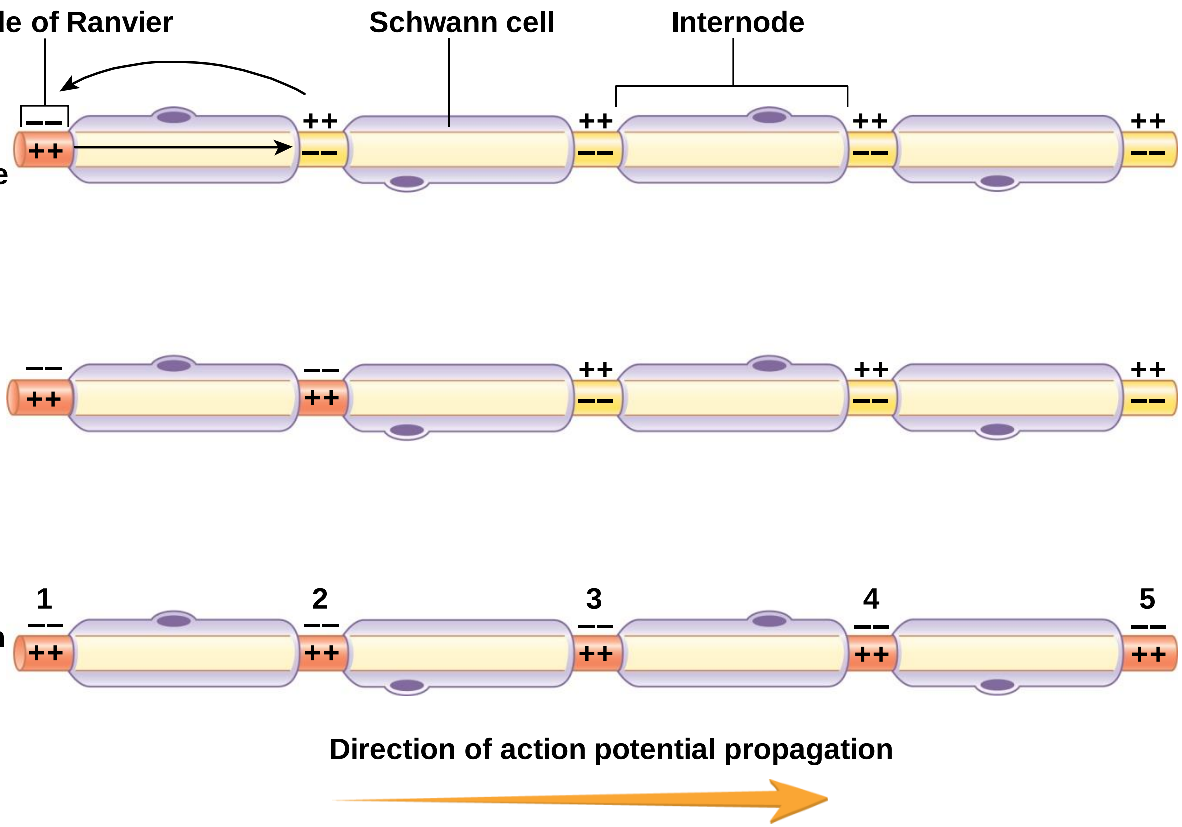
1. An action potential (*orange*) at a node of Ranvier generates local currents (*black arrows*). The local currents flow to the next node of Ranvier because the myelin sheath of the Schwann cell insulates the axon of the internode.

2. When the depolarization caused by the local currents reaches threshold at the next node of Ranvier, a new action potential is produced (*orange*).

3. Action potential propagation is rapid in myelinated axons because the action potentials are produced at successive nodes of Ranvier (*1–5*) instead of at every part of the membrane along the axon.



Speed of Conduction

- Faster in myelinated than in non-myelinated
- In myelinated axons, lipids act as insulation forcing ionic currents to jump from node to node
- In myelinated, speed is affected by thickness of myelin sheath
- Diameter of axons: large-diameter conduct more rapidly than small-diameter. Large have greater surface area and more voltage-gated Na^+ channels

Nerve Fiber Types

- **Type A**: large-diameter, myelinated. Conduct at 15-120 m/s. Motor neurons supplying skeletal and most sensory neurons
- **Type B**: medium-diameter, lightly myelinated. Conduct at 3-15 m/s. Part of ANS
- **Type C**: small-diameter, unmyelinated. Conduct at 2 m/s or less. Part of ANS

11.6 The Synapse

- Junction between two cells
- Site where action potentials in one cell cause action potentials in another cell
- Types of cells in synapse
  - **Presynaptic**
  - **Postsynaptic**

Electrical Synapses

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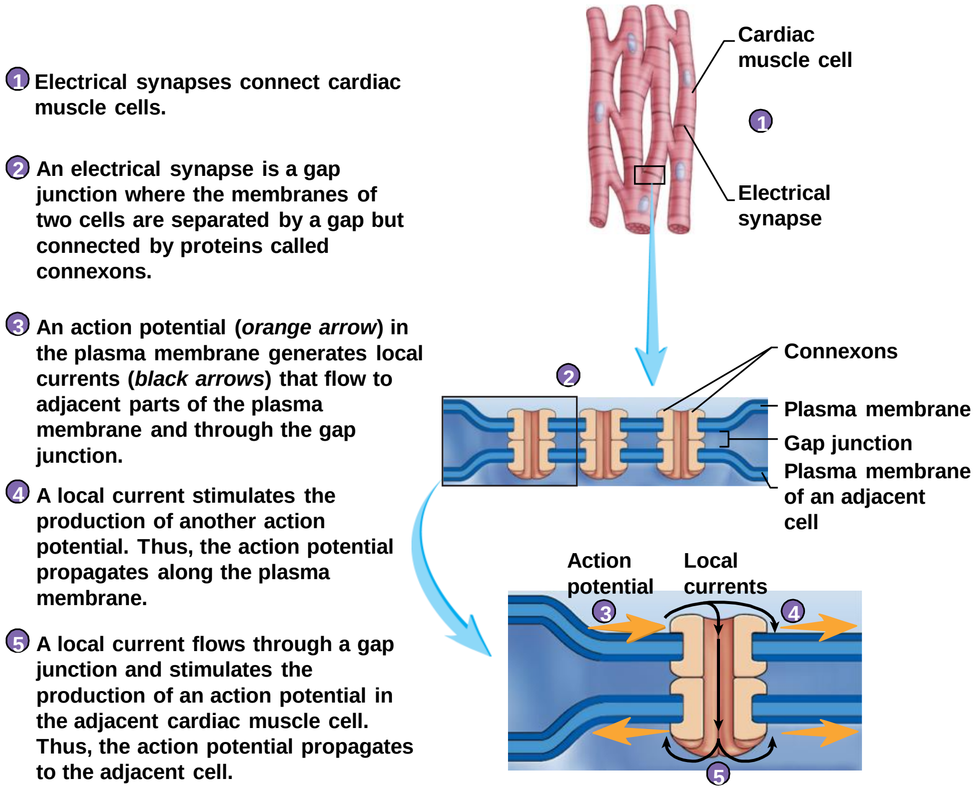

- **Gap junctions** that allow graded current to flow between adjacent cells. **Connexons**: protein tubes in cell membrane.
- Found in cardiac muscle and many types of smooth muscle. Action potential of one cell causes action potential in next cell, almost as if the tissue were one cell.
- Important where contractile activity among a group of cells important.

Chemical Synapses

- Components
  - **Presynaptic terminal**
  - **Synaptic cleft**
  - **Postsynaptic membrane**
- Neurotransmitters released by action potentials in presynaptic terminal
  - **Synaptic vesicles**: action potential causes Ca^{2+} to enter cell that causes neurotransmitter to be released from vesicles
  - Diffusion of neurotransmitter across synapse
  - Postsynaptic membrane: when ACh binds to receptor, ligand-gated Na^{+} channels open. If enough Na^{+} diffuses into postsynaptic cell, it fires.

Chemical Synapse

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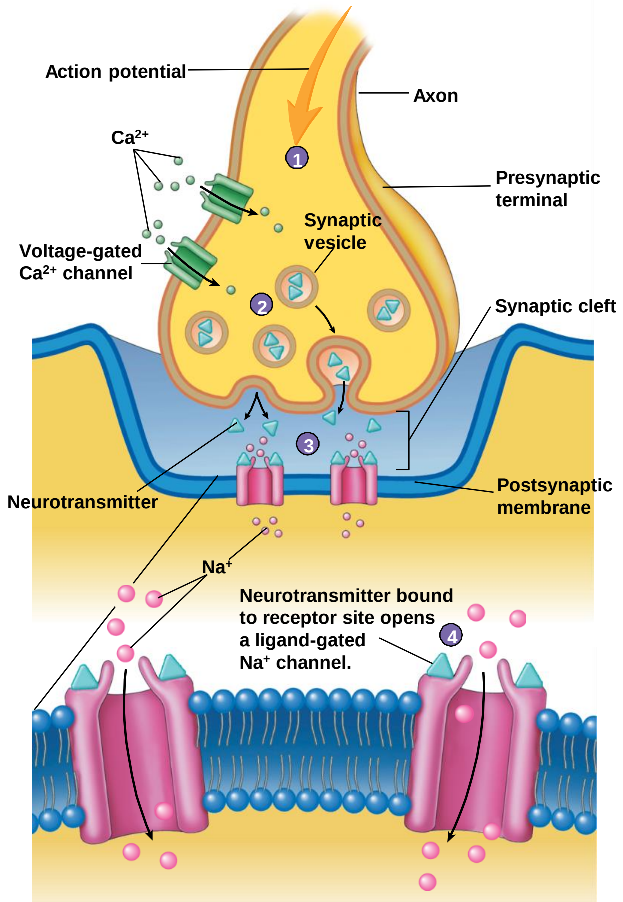

1. Action potentials arriving at the presynaptic terminal cause voltage-gated Ca^{2+} channels to open.
2. Ca^{2+} diffuse into the cell and cause synaptic vesicles to release neurotransmitter molecules.
3. Neurotransmitter molecules diffuse from the presynaptic terminal across the synaptic cleft.
4. Neurotransmitter molecules combine with their receptor sites and cause ligand-gated Na^+ channels to open. Na^+ diffuse into the cell (*shown in illustration*) or out of the cell (*not shown*) and cause a change in membrane potential.

Neurotransmitter Removal

- Method depends on neurotransmitter/synapse.
- ACh: acetylcholinesterase splits ACh into acetic acid and choline. Choline recycled within presynaptic neuron.
- Norepinephrine: recycled within presynaptic neuron or diffuses away from synapse. Enzyme monoamine oxidase (MAO). Absorbed into circulation, broken down in liver.

Removal of Neurotransmitter from Synaptic Cleft

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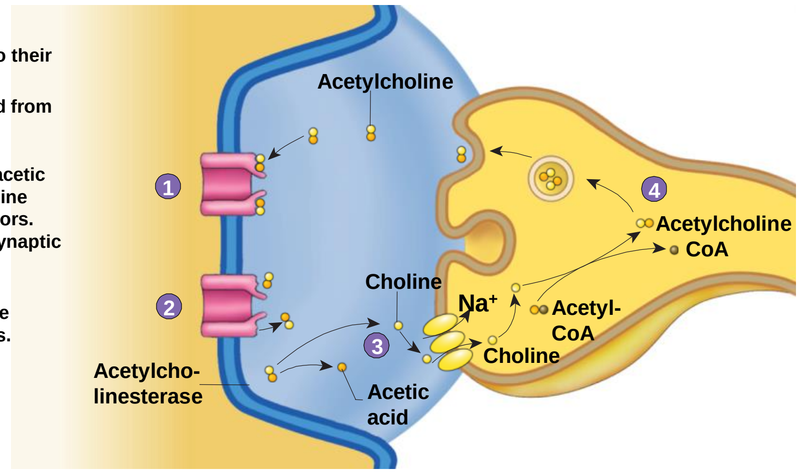
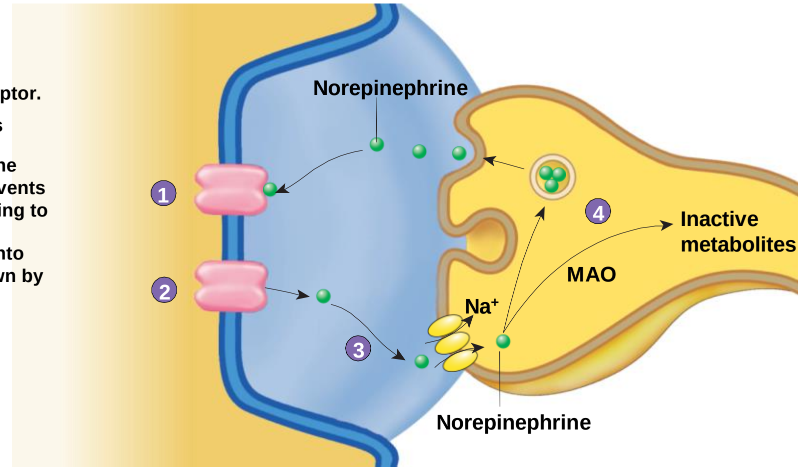
1. Acetylcholine molecules bind to their receptors.
2. Acetylcholine molecules unbind from their receptors.
3. Acetylcholinesterase splits acetylcholine into choline and acetic acid, which prevents acetylcholine from again binding to its receptors. Choline is taken up by the presynaptic terminal.
4. Choline is used to make new acetylcholine molecules that are packaged into synaptic vesicles.



(a)

1. Norepinephrine binds to its receptor.
2. Norepinephrine unbinds from its receptor.
3. Norepinephrine is taken up by the presynaptic terminal, which prevents norepinephrine from again binding to its receptor.
4. Norepinephrine is repackaged into synaptic vesicles or broken down by monoamine oxidase (MAO).



(b)

Receptor Molecules in Synapses

- Neurotransmitter only "fits" in one receptor.
- Not all cells have receptors.
- Neurotransmitters are excitatory in some cells and inhibitory in others.
- Some neurotransmitters (norepinephrine) attach to the presynaptic terminal as well as postsynaptic and then inhibit the release of more neurotransmitter.

Neuromodulators

- Chemicals produced by neurons that facilitate action potentials. Some of these act by increasing or decreasing the amount of neurotransmitter released by the presynaptic neuron.
- Act in axoaxonic synapses. Axon of one neuron synapses with axon of second neuron. Second neuron is actually presynaptic. This type of connection leads to release of neuromodulators in the synapse that can alter the amount of neurotransmitter produced by the second neuron.

Postsynaptic Potentials

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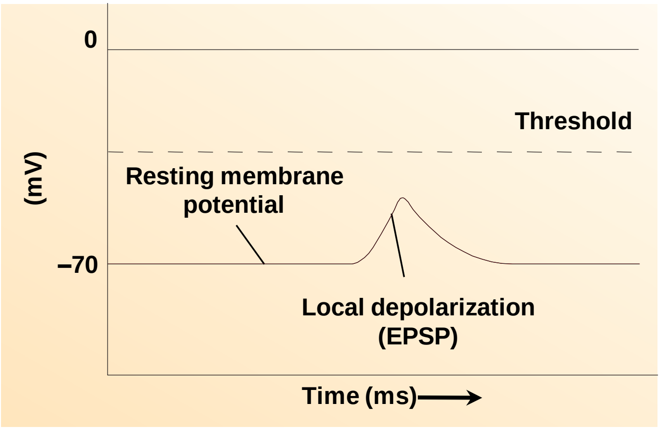
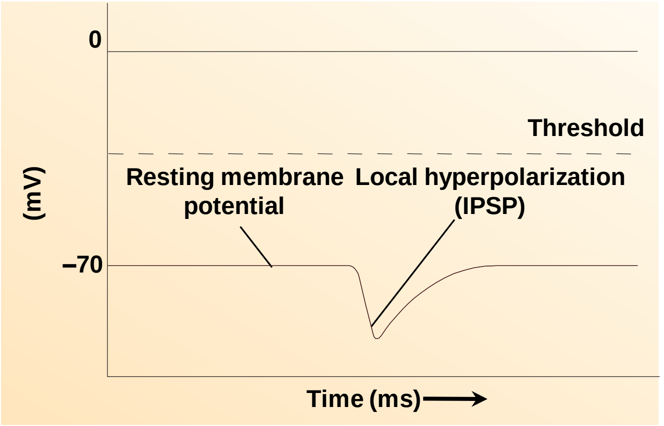


(a) Excitatory postsynaptic potential (EPSP)



(b) Inhibitory postsynaptic potential (IPSP)

- **Excitatory postsynaptic potential** (EPSP)
  - Depolarization occurs and response stimulatory
  - Depolarization might reach threshold producing an action potential and cell response
- **Inhibitory postsynaptic potential** (IPSP)
  - Hyperpolarization and response inhibitory
  - Decrease action potentials by moving membrane potential farther from threshold

Presynaptic Inhibition and Facilitation

- **Axoaxonic synapses**: axon of one neuron synapses with the presynaptic terminal (axon) of another. Many of the synapses of CNS
- **Presynaptic inhibition**: reduction in amount of neurotransmitter released from presynaptic terminal. Endorphins can inhibit pain sensation
- **Presynaptic facilitation**: amount of neurotransmitter released from presynaptic terminal increases. Glutamate facilitating nitric oxide production

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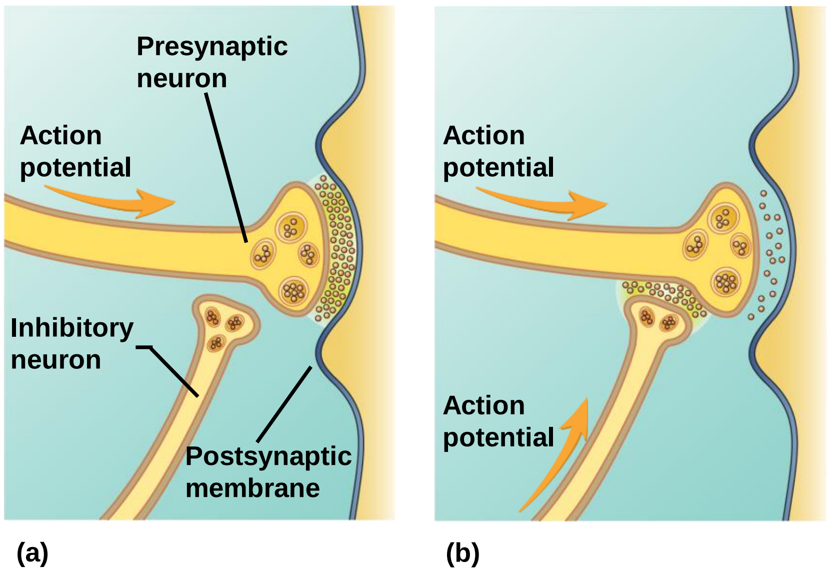

Spatial Summation

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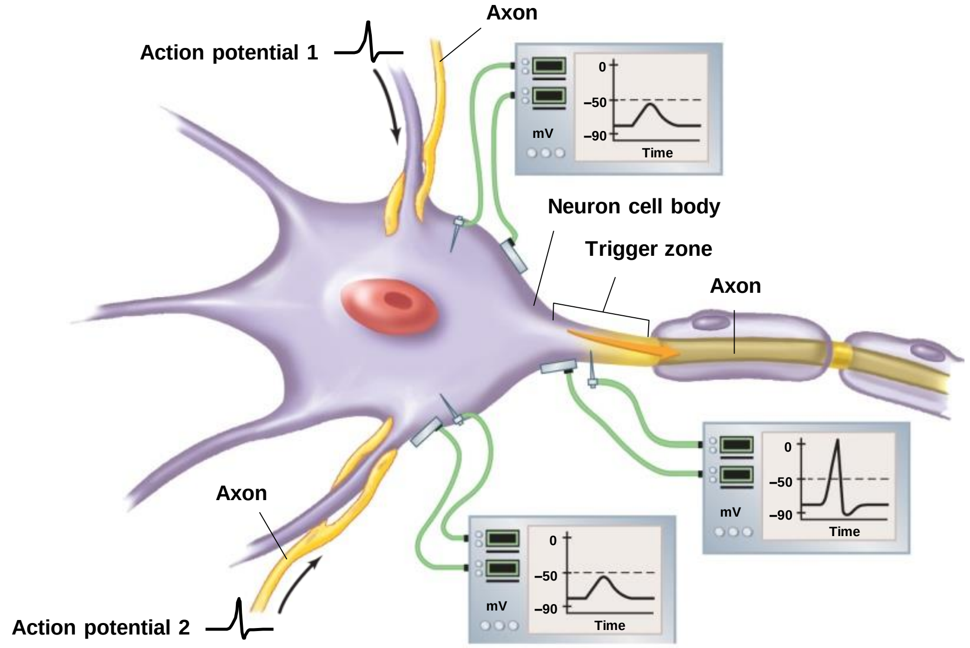
(a) Spatial summation. Action potentials 1 and 2 cause the production of graded potentials at two different dendrites. These graded potentials summate at the trigger zone to produce a graded potential that exceeds threshold, resulting in an action potential.



Temporal Summation

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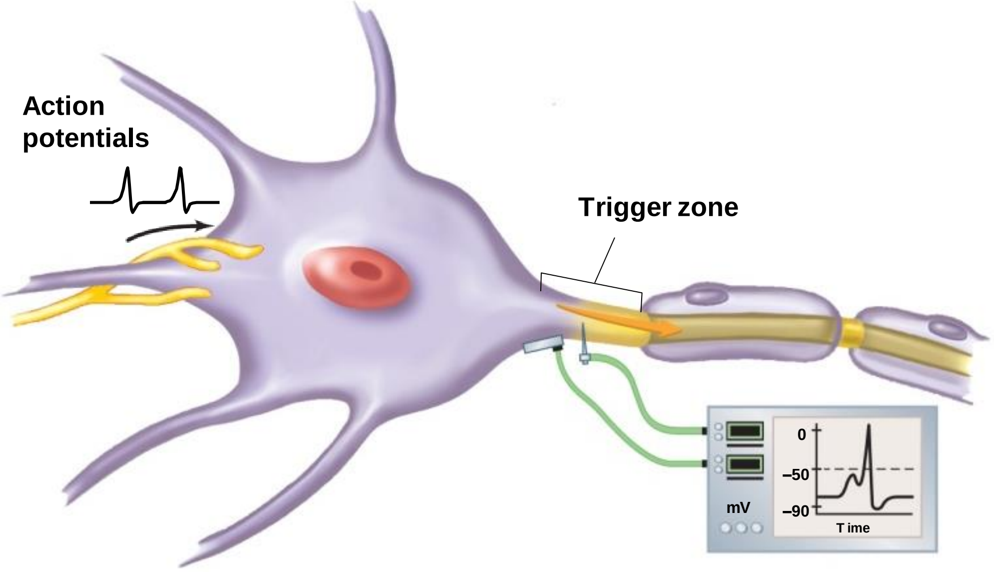
(b) Temporal summation. Two action potentials arrive in close succession at the presynaptic membrane. The first action potential causes the production of a graded potential that does not reach threshold at the trigger zone. The second action potential results in the production of a second graded potential that summates with the first to reach threshold, resulting in the production of an action potential.



Combined Summation

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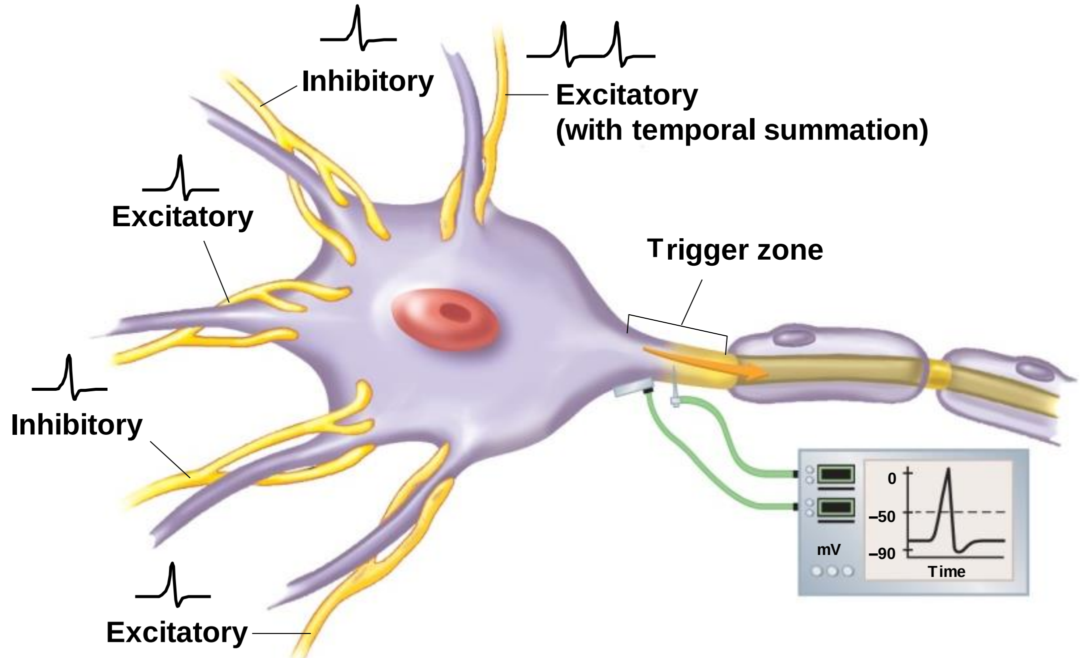

(c) Combined spatial and temporal summation with both excitatory postsynaptic potentials (EPSPs) and inhibitory postsynaptic potentials (IPSPs). An action potential is produced at the trigger zone when the graded potentials produced as a result of the EPSPs and IPSPs summate to reach

11.7 Neuronal Pathways and Circuits

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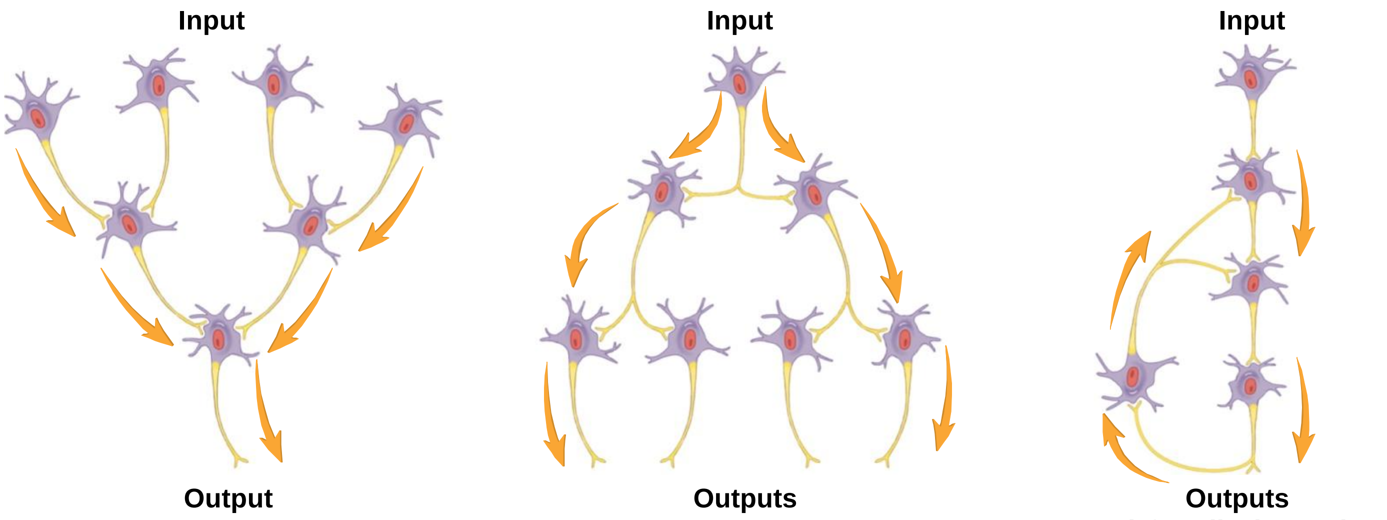

(a) Convergent pathway (b) Divergent pathway (c) Reverberating circuit

- Organization of neurons in CNS varies in complexity
  - **Convergent pathways**: many converge and synapse with smaller number of neurons. E.g., synthesis of data in brain.
  - **Divergent pathways**: small number of presynaptic neurons synapse with large number of postsynaptic neurons. E.g., important information can be transmitted to many parts of the brain.
  - **Oscillating circuit:** outputs cause reciprocal activation.