Chapter 11
Functional Organization
of Nervous Tissue

Dendrites

Cell body

Axon

Dendrite

Cell body

Axon

Sensory receptors

Cell body

Axon

Axon branches function as a single axon.
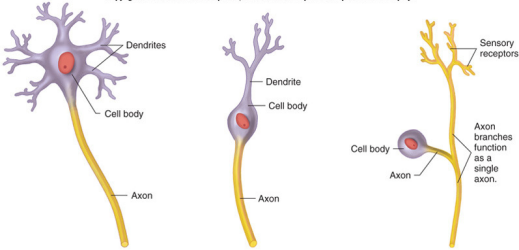
(a) A **multipolar neuron** has many dendrites and an axon.

(b) A **bipolar neuron** has a dendrite and an axon.

(c) A **unipolar neuron** has an axon and no dendrites.

11-1

Functions of the Nervous System

1. <u>Sensory input</u>. Monitor internal and external stimuli

2. <u>Integration</u>. Brain and spinal cord process sensory input and initiate responses

3. <u>Controls of muscles</u> and glands

4. <u>Homeostasis</u>. Regulate and coordinate physiology

5. <u>Mental activity</u>. Consciousness, thinking, memory, emotion

11-2

PNS

- **Sensory receptors**: ending of neurons or separate, specialized cells that <u>detect</u> such things as temperature, pain, touch, pressure, light, sound, odors
- **Nerve**: a bundle of axons and their sheaths that <u>connects</u> 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 <u>neuron cell bodies</u> <u>outside</u> CNS
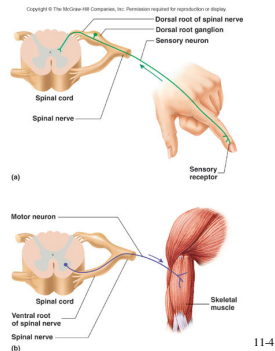- **Plexus**: <u>extensive network</u> of axons, and sometimes neuron cell bodies, located outside CNS

11-3

Divisions of PNS

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

11-4

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.((**ALERT**))
    - **Parasympathetic**. Regulates resting or vegetative functions such as digesting food or emptying of the urinary bladder.((**Housekeeping**))
    - **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.
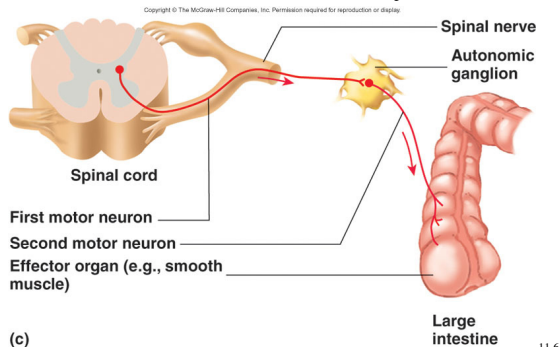
11-5

Autonomic Nervous System

11-6

2

Cells of Nervous System

- **Glial cells** or neuroglia
  - _Support and protect_ neurons
- **Neurons** or nerve cells receive stimuli and _transmit_ action potentials
  - Organization
    - **Cell body** or soma
    - **Dendrites**: input
    - **Axons**: output

11-7

Parts of the Neuron—LAB

- 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
  - Axoplasm
  - Axolemma
  - Presynaptic terminals (terminal boutons)
  - Synaptic vesicles
  - Trigger zone: site where action potentials are generated; axon hillock and part of axon nearest cell body

11-8

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.

11-9

3

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
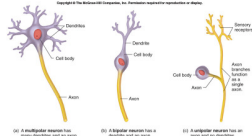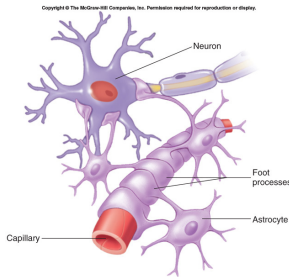

11-10

Glial Cells of the CNS: **Astrocytes**

- 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

11-11

Glial Cells of the CNS: **Ependymal Cells**
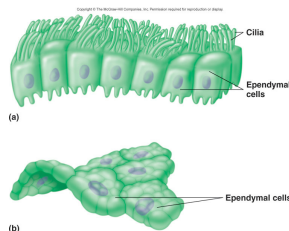
- Line brain ventricles and spinal cord central canal. Specialized versions of ependymal form choroid plexuses.
- **Choroid plexus** within certain regions of ventricles. Secrete cerebrospinal fluid. Cilia help move fluid thru the cavities of the brain. Have long processes on basal surface that extend within the brain tissue, may have astrocyte-like functions.
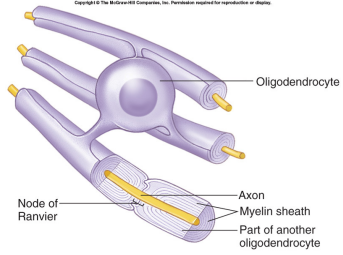
11-12

4

Glial Cells of the CNS:
Microglia and **Oligodendrocytes**

- **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. (In CNS)

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Oligodendrocyte

Node of Ranvier
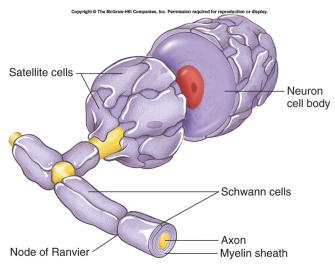
Axon
Myelin sheath
Part of another oligodendrocyte

11-13

Glial Cells 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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Satellite cells

Neuron cell body

Schwann cells

Node of Ranvier

Axon
Myelin sheath

11-14

Myelinated and Unmyelinated Axons

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Extracellular fluid
Na⁺
Cl⁻

K⁺ leak channel (always open)
Gated Na⁺ channel (closed)
Cl⁻ leak channel (always open)
K⁺

Negatively charged protein

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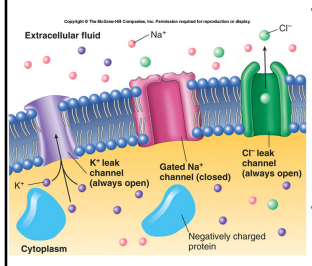
- **Myelinated axons**
  - Myelin protects and insulates axons from one another, speeds transmission, functions in repair of axons.
  - Not continuous
  - **Nodes of Ranvier**
  - Completion of development of myelin sheaths at 1 yr.
  - Degeneration of myelin sheaths occurs in multiple sclerosis and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

11-15

Organization of Nervous Tissue

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

11-16

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

11-17

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 11.1	Representative Concentrations of the Principal Cations and Anions in Extracellular and Intracellular Fluids of Vertebrates	
Ions	Intracellular Fluid (mEq/L)*	Extracellular Fluid (mEq/L)
Cations (Positive)		
Potassium (K⁺)	148	5
Sodium (Na⁺)	10	142
Calcium (Ca²⁺)	<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).

11-18

6

Sodium-Potassium Exchange Pump

11-19
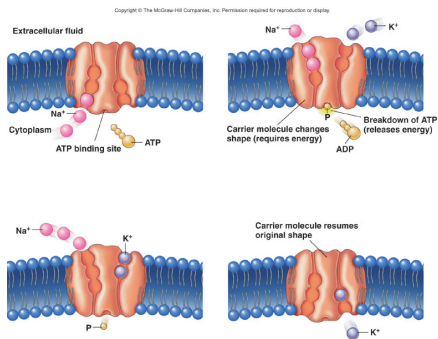
Permeability Characteristics of the Plasma Membrane

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

11-20
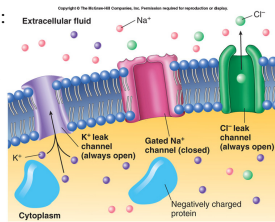
Leak Channels

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

11-21

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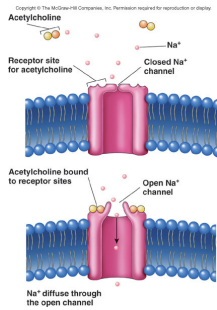
- **Gated ion channels**. Gated ion channels open and close because of some sort of <u>stimulus</u>. When they open, they change the <u>permeability</u> of the cell membrane.
  - **Ligand-gated**: open or close in response to ligand such as <u>ACh</u> binding to receptor protein. Receptor proteins are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

11-22

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 <u>Na^+ and K^+.</u> In cardiac and smooth muscle, <u>Ca^{2+}</u> are important.

11-23

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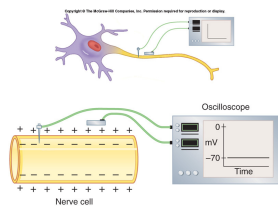
- Number of charged molecules and ions inside and outside cell nearly equal
- Concentration of K^+ higher inside than outside cell, Na^+ higher outside than inside
- **Potential difference**: unequal distribution of charge exists between the immediate inside and immediate outside of the plasma membrane: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

11-24

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 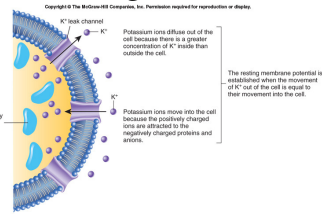of ions is due to attraction to trapped proteins: N.B. leakage channels work in both directions. Movement of ions depends upon concentration gradient.)

- 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

11-25

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Table 11.2	Characteristics Responsible for the Resting Membrane Potential
1.	The number of charged molecules and ions inside and outside the cell is nearly equal.
2.	The concentration of K^+ is higher inside than outside the cell, and the concentration of Na^+ is higher outside than inside the cell.
3.	The plasma membrane is 50–100 times more permeable to K^+ than to other positively charged ions such as Na^+.
4.	The plasma membrane is impermeable to large intracellular negatively charged molecules such as proteins.
5.	K^+ tend to diffuse across the plasma membrane from the inside to the outside of the cell.
6.	Because negatively charged molecules cannot follow the positively charged K^+, a small negative charge develops just inside the plasma membrane.
7.	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.
8.	The charge difference across the plasma membrane at equilibrium is reflected as a difference in potential, which is measured in millivolts (mV).
9.	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^+.
10.	At equilibrium there is very little movement of K^+ or other ions across the plasma membrane.

11-26

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.
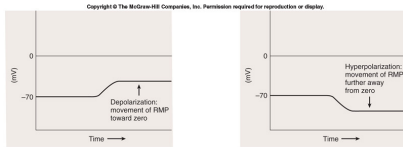
11-27

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

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

11-28

Local Potentials

- 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 <u>strength or frequency</u>
- Can **summate** or <u>**add**</u> 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.
- <u>Can</u> cause generation of action potentials

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(a) Successively stronger stimuli of short duration from 1–4

(b) Two equal stimuli in short succession at 1 and 2

11-29

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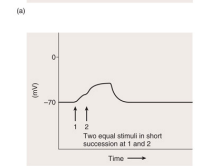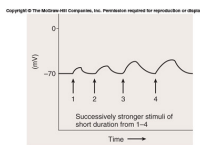
Table 11.3 Characteristics of Local Potentials

1. A stimulus causes ion channels to open, resulting in increased 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. Local potentials are graded; that is, the size of the local potential is proportional to the strength of the stimulus. Local potentials can also summate. Thus, a local potential produced in response to several stimuli is larger than one produced in response to a single stimulus.
4. Local potentials are conducted in a decremental fashion, meaning that their magnitude decreases as they spread over the plasma membrane. Local potentials cannot be measured a few millimeters from the point of stimulation.
5. A depolarizing local potential can cause an action potential.

11-30

Action Potentials

- Depolarization phase followed by repolarization phase.
  - **Depolarization**: more <u>positive</u>
  - **Repolarization**: more <u>negative</u> (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 <u>reach threshold</u>. Then get action potential.
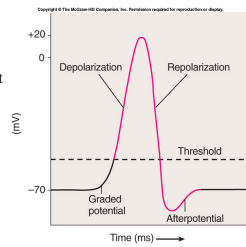- **All-or-none principle.** No matter how strong the stimulus, as long as it **is greater than threshold, then action potential will occur**.

11-31

Table 11.4	Characteristics of the Action Potential

1. Action potentials are produced when a local 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 increased K$^+$ movement out of the cell. The inactivation gates of the voltage-gated Na$^+$ channels close, and the voltage-gated K$^+$ channels open.
5. No action potential is produced by a stimulus, no matter how strong, during the absolute refractory period. 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.

11-32

Operation of Gates: **Action Potential**

- **Resting membrane potential.** Voltage-gated Na$^+$ channels are closed (the activation gates are closed and the inactivation gates are open). Voltage-gated K$^+$ channels are closed

- **Depolarization**. <u>Voltage-gated Na$^+$ channels open</u> because the activation gates open. As soon as the threshold depolarization is reached, many voltage-gated Na$^+$ channels begin to open. Na$^+$ diffuses in and this causes other Na$^+$ channels to open-- <u>positive feedback--</u> until <u>all the Na$^+$ channels are open</u>. Voltage-gated K$^+$ channels start to open. Depolarization results because the inward diffusion of Na$^+$ is much greater than the outward diffusion of K$^+$.

11-33

11

Operation of Gates: Action Potential

- **Repolarization**. Voltage-gated Na$^+$ channels are closed because the inactivation gates close. Voltage-gated K$^+$ channels are now open. Na$^+$diffusion into the cell stops and K$^+$ diffuse out of the cell causing repolarization.
- **End of repolarization and afterpotential**. Voltage-gated Na$^+$ channels are closed. Closure of the activation gates and opening of the inactivation gates reestablish the resting condition for Na$^+$ channels (see step 1). Diffusion of K$^+$ through voltage-gated channels produces the afterpotential.
- **Resting membrane potential**. The resting membrane potential is reestablished after the voltage-gated K$^+$ channels close.

11-34

Refractory Period

- 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

11-35

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.

11-36

12

Propagation of Action Potentials

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Action potential propagation

1. Action potentials propagate in one direction along the axon.

Outside of membrane becomes more negative as positive charges move away from it.

Inside of membrane becomes more positive as positive charges move toward it.

Depolarization of the membrane adjacent to the site of action potential production

2. An action potential (*orange* part of the membrane) generates local currents (*black arrows*) that tend to depolarize the membrane immediately adjacent to the action potential.

3. When depolarization caused by the local currents reaches threshold, a new action potential is produced adjacent to where the original action potential occurred.

4. Action potential propagation occurs in one direction because the absolute refractory period of the previous action potential prevents generation of an action potential in the reverse direction.

Absolute refractory period prevents another action potential.

Site of next action potential

11-37

Saltatory Conduction

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Node of Ranvier   Schwann cell   Internode

1   2   3   4   5

Direction of action potential propagation

11-38

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

11-39

The Synapse

1. Electrical synapses connect cardiac muscle cells.

2. An electrical synapse has gap junctions in which the membranes of two cells are separated by a gap but are connected by proteins called connexons.

3. An action potential (*orange arrow*) in the plasma membrane generates ionic currents (*black arrows*) that flow to adjacent parts of the plasma membrane and through the gap junction.

4. An ionic current stimulates the production of another action potential. Thus, the action potential propagates along the plasma membrane.

5. An ionic current flows through a gap junction and stimulates the production of an action potential in the adjacent cardiac muscle cell. Thus, the action potential propagates to the adjacent cell.

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

11-40

Electrical Synapses

1. Electrical synapses connect cardiac muscle cells.

2. An electrical synapse has gap junctions in which the membranes of two cells are separated by a gap but are connected by proteins called connexons.

3. An action potential (*orange arrow*) in the plasma membrane generates ionic currents (*black arrows*) that flow to adjacent parts of the plasma membrane and through the gap junction.

4. An ionic current stimulates the production of another action potential. Thus, the action potential propagates along the plasma membrane.

5. An ionic current flows through a gap junction and stimulates the production of an action potential in the adjacent cardiac muscle cell. Thus, the action potential propagates to the adjacent cell.

- **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 <u>as if the tissue were one cell</u>.
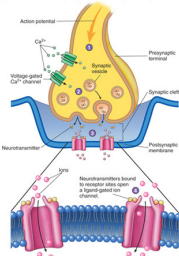- Important where contractile activity among a group of cells important.

11-41

Chemical Synapse

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

11-42

Neurotransmitter Removal

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

11-43

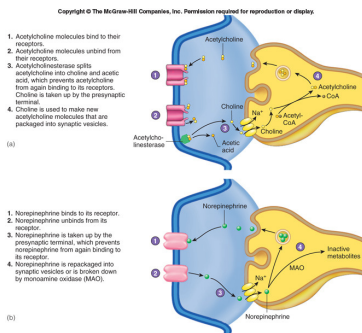## Removal of Neurotransmitter from Synaptic Cleft

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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.

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 is broken down by monoamine oxidase (MAO).

11-44

Receptor Molecules and Neurotransmitters

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

11-45

15

Neuromodulators

- Chemicals produced by neurons that <u>facilitate</u> action potentials. Some of these act by increasing or decreasing the amount of neurotransmitter released by the presynaptic neuron.
- Act in <u>axoaxonic</u> 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.
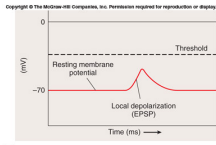
11-46
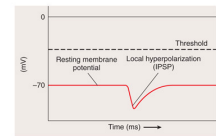
Postsynaptic Potentials

- **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
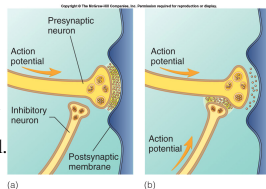 - Decrease action potentials by moving membrane potential farther from threshold

11-47

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. <u>Endorphins</u> can inhibit pain sensation
- **Presynaptic facilitation**: amount of neurotransmitter released from presynaptic terminal increases. <u>Glutamate</u> facilitating <u>nitric oxide</u> production
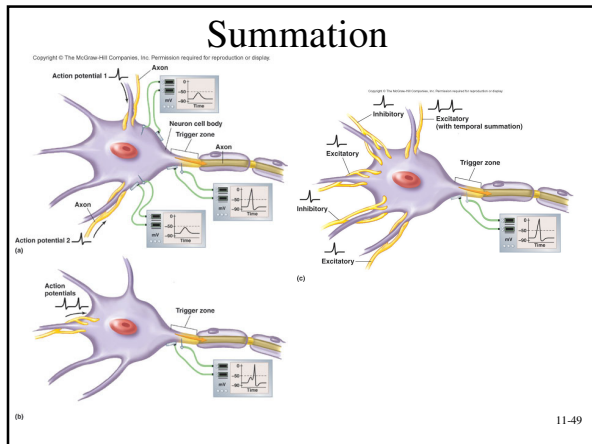

11-48

Summation

11-49

Neuronal Pathways and Circuits

(a) Convergent pathway   (b) Divergent pathway   (c) Oscillating 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.

11-50