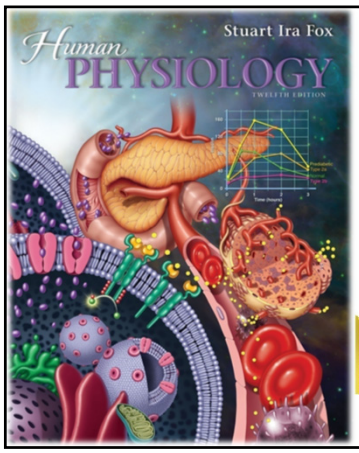
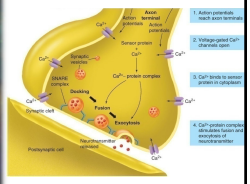


CHAPTER 7

The Nervous System: Neurons and Synapses



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Chapter 7 Outline

- Neurons and Supporting Cells
- Electrical Activity in Axons
- The Synapse
- Acetylcholine as a Neurotransmitter
- Monoamines as Neurotransmitters
- Other Neurotransmitters
- Synaptic Integration

2

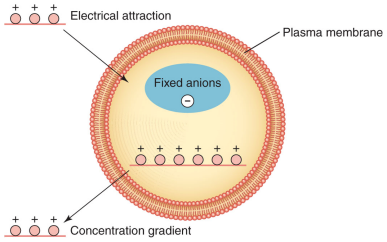
Portions from Chapter 6 Membrane Potential

3

Membrane Potential

Is difference in charge across membranes

- Results in part from presence of large anions being trapped inside cell
  - Diffusable cations such as K^+ are attracted into cell by anions
- Na^+ is not permeable and is actively transported out



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Resting Membrane Potential (RMP)

- Is membrane voltage of cell not producing impulses
- RMP of most cells is –65 to –85 mV
- RMP depends on concentrations of ions inside and out
  - And on permeability of each ion
    - Affected most by K^+ because it is most permeable

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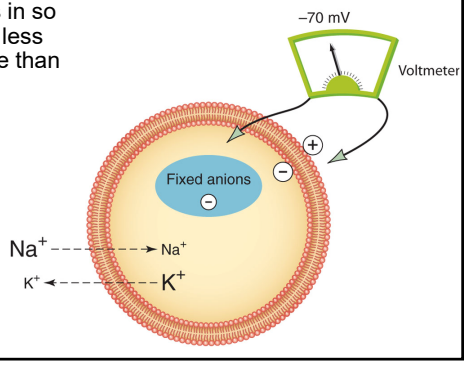
Resting Membrane Potential (RMP)

- Some Na^+ diffuses in so RMP is less negative than E_{K+}



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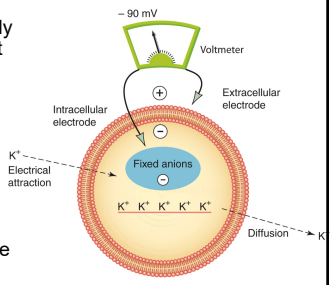
Equilibrium Potential

- **Describes voltage across cell membrane if only 1 ion could diffuse**
- If membrane permeable only to K^+, it would diffuse until it reaches its equilibrium potential (E_k)
  - K+ is attracted inside by trapped anions but also driven out by its concentration gradient
  - At K+ equilibrium, electrical and diffusion forces are = and opposite
  - Inside of cell has a negative charge of about -90mV



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Equilibrium Potential

8

Role of Na+/K+ Pumps in RMP

- Because 3 Na+ are pumped out for every 2 K+ taken in, pump is electrogenic
  - It adds about
  –3mV to RMP

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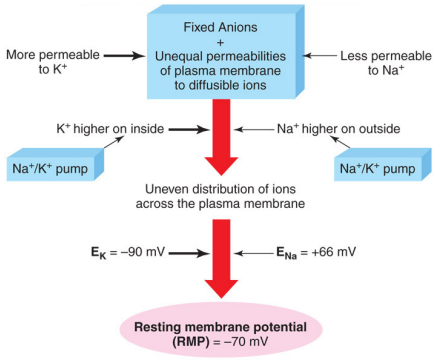
Summary of Processes that Affect the Resting Membrane Potential



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Neurons and Supporting Cells

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Nervous System (NS)

- **Divisions of the Nervous System**
  - Central nervous system (CNS)
    - = brain and spinal cord
  - Peripheral nervous system (PNS)
    - = cranial and spinal nerves
- **2 kinds of cell types in the NS:**
  - Neurons and supporting cells (= glial cells)
    - Neurons are functional units of NS
    - Glial cells maintain homeostasis
      - Are 5X more common than neurons

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Neurons

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Neurons

- Gather and transmit information by:
  - Responding to stimuli
  - Producing and sending electrochemical impulses
  - Releasing chemical messages

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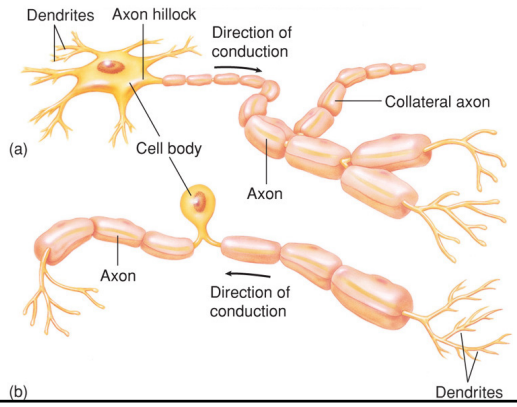
Neurons



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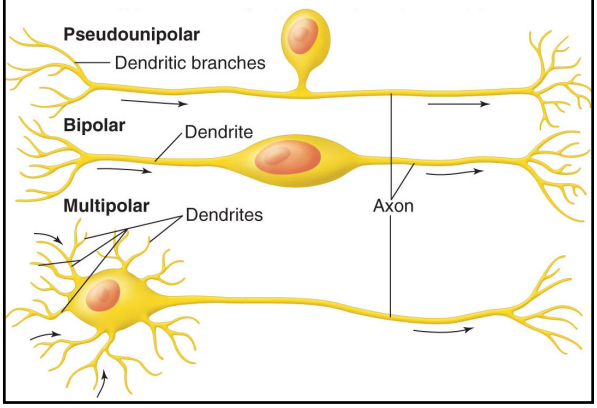
Anatomical Classification of Neurons



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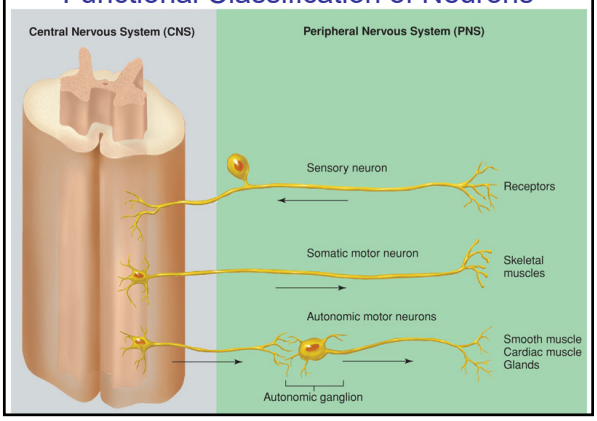
Functional Classification of Neurons



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Supporting/Glial Cells

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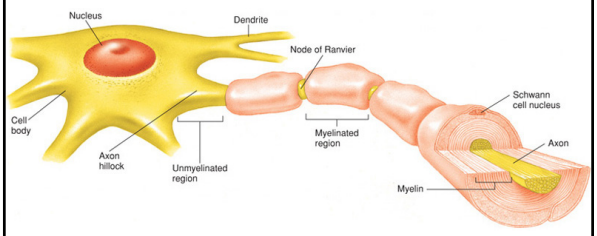
Supporting/Glial Cells

- PNS has Schwann and satellite cells
  - Schwann cells myelinate PNS axons



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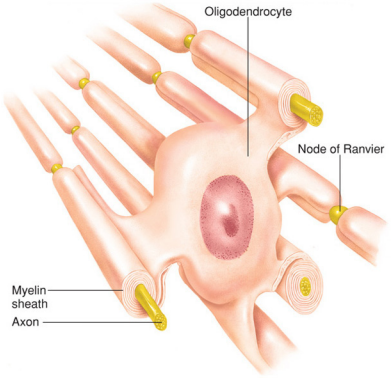
Supporting/Glial Cells



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Electrical Activity in Axons

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Resting Membrane Potential (RMP)

- At rest, all cells have a negative internal charge and unequal distribution of ions:
  - Results from:
    - Large cations being trapped inside cell
    - Na+/K+ pump and limited permeability keep Na+ high outside cell
    - K+ is very permeable and is high inside cell
      - Attracted by negative charges inside

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Excitability

- Excitable cells can discharge their RMP quickly (Produce an Action Potential)
  - By rapid changes in permeability to ions
  - Neurons and muscles do this to generate and conduct impulses

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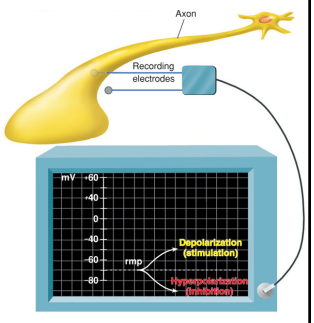
Membrane Potential (MP) Changes

- Measured by placing 1 electrode inside cell and 1 outside
- Depolarization occurs when MP becomes more positive
- Hyperpolarization: MP becomes more negative than RMP
- Repolarization: MP returns to RMP



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Membrane Ion Channels

- MP changes occur by ion flow through membrane channels
  - Some channels are normally open; some closed
    - Leakage channels are always open
  - Closed channels have molecular gates that can be opened
    - Voltage-gated (VG) channels are opened by depolarization
    - **VG Na^+, K^+** and **Ca^+** channels are closed in resting cells

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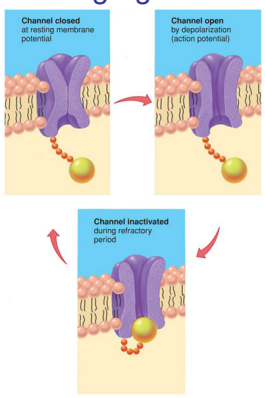
Model of a Voltage-gated Ion Channel



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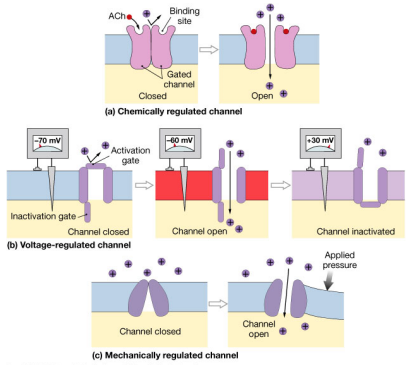
Gated Channels



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Action Potential

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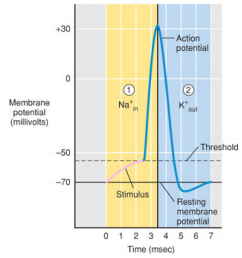
The Action Potential (AP)

- Is a wave of MP change that sweeps along the axon from soma to synapse
- Wave is formed by rapid depolarization of the membrane by Na^+ influx; followed by rapid repolarization by K^+ efflux



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Mechanism of Action Potential

- Depolarization:
  - At threshold, VG Na^+ channels open
  - Na+ driven inward by its electrochemical gradient
  - This adds to depolarization, opens more channels
    - Termed a positive feedback loop
  - Causes a rapid change in MP from –70 to +30 mV
- Repolarization:
  - VG Na^+ channels close; VG K^+ channels open
  - Electrochemical gradient drives K^+ outward
  - Repolarizes axon back to RMP
- Depolarization and repolarization occur via diffusion
  - Do not require active transport
  - After an AP, Na^+/K^+ pump extrudes Na^+, recovers K^+

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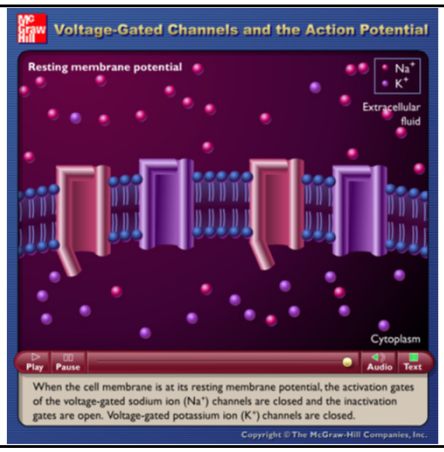

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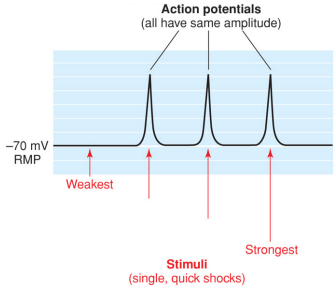
APs Are All-or-None

- When MP reaches threshold an AP is irreversibly fired
  - Because positive feedback opens more and more Na^+ channels
  - Shortly after opening, Na^+ channels close
    - and become inactivated until repolarization



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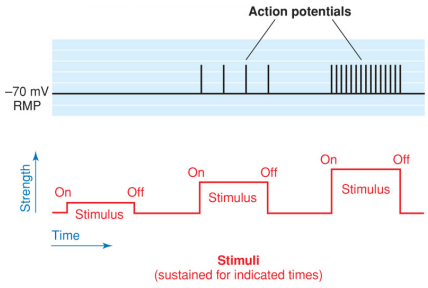
How Stimulus Intensity is Coded

- Increased stimulus intensity causes more APs to be fired
  - Size of APs remains constant



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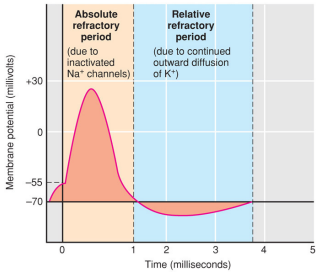
Refractory Periods

- Absolute refractory period:
  - Membrane cannot produce another AP because Na^+ channels are inactivated
- Relative refractory period occurs when VG K^+ channels are open, making it harder to depolarize to threshold



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Axonal Conduction

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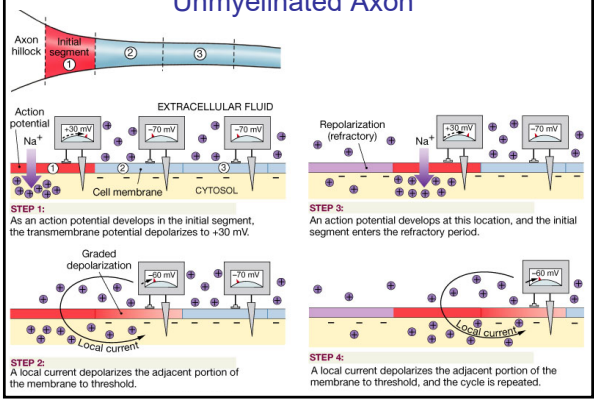
Propagation of an Action Potential along an Unmyelinated Axon



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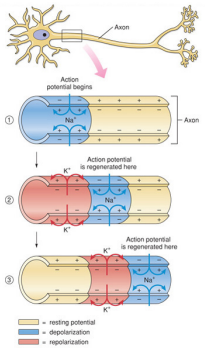
Conduction in an Unmyelinated Axon

- After axon hillock reaches threshold and fires AP, its Na^+ influx depolarizes adjacent regions to threshold
  - Generating a new AP
    - Process repeats all along axon
    - So AP amplitude is always same
  - Conduction is slow



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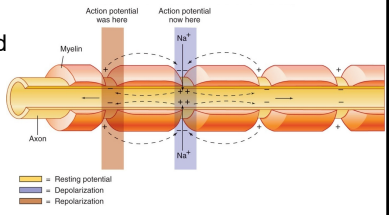
Conduction in Myelinated Axon

- Ions can't flow across myelinated membrane
  - Thus no APs occur under myelin
  - and no current leaks
    - This increases current spread



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Synaptic Transmission

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Synapse

- A connection between a neuron (presynaptic) and another cell (postsynaptic)
- There are **chemical** and **electrical synapses**
  - Synaptic transmission at chemical synapses is via neurotransmitters (NT)
  - Electrical synapses are rare in NS

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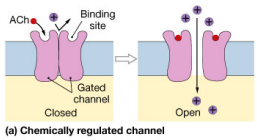
Graded Potentials

- Graded Potentials = are produced when a ligand (stimulus) opens a ligand-regulated channel and causes a voltage which dissipate with distance from stimulus.
  - **Synaptic Potentials/Post Synaptic Potential (PSP)** - which occur at a synapse between a neuron and another cell
  - **Generator Potentials** - occur when a sensory receptor is stimulated



(a) Chemically regulated channel

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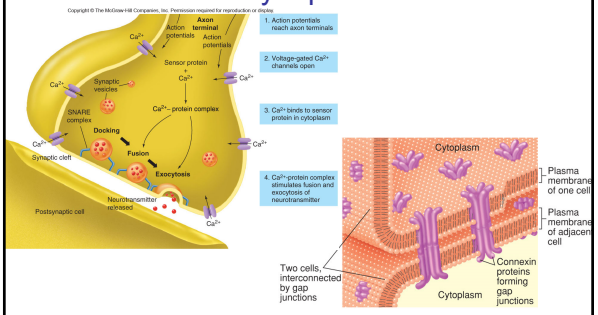
Synapse



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Synaptic Transmission

- Process by which a neuron communicates with a cell across a synapse.

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Synaptic Transmission (Neurotransmitter Release)

- Action potentials reach the axon terminal
- Ca^{2+} enters axon terminal via voltage gated channels
- Ca^{2+} binds to sensor protein in cytoplasm
- Ca^{2+} -protein complex stimulates fusion and exocytosis of neurotransmitter
  - Neurotransmitter is released from the vesicles into synapse

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Synaptic Transmission (Post Synaptic Potential)

- Neurotranmitter diffuses across cleft
- Binds to receptor proteins on postsynaptic membrane
- Opening ligand/chemically-regulated ion channels
- **Post Synaptic Potential (PSP)** is produced as ions diffuse across the membrane through the ligand-regulated ion channel.
  - Depolarizing channels cause EPSPs (excitatory postsynaptic potentials)
  - Hyperpolarizing channels cause IPSPs (inhibitory postsynaptic potentials)
  - These affect VG channels in postsynaptic cell

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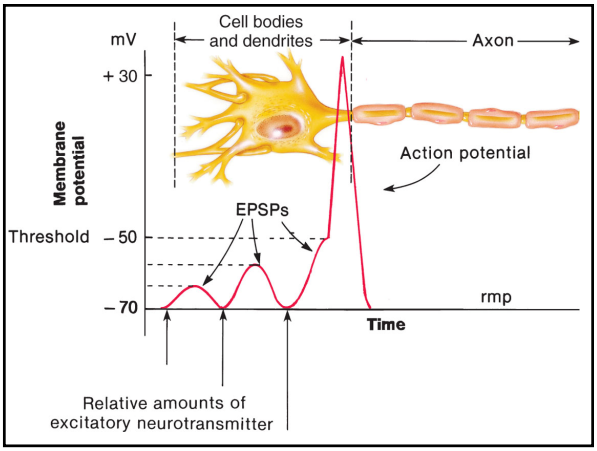

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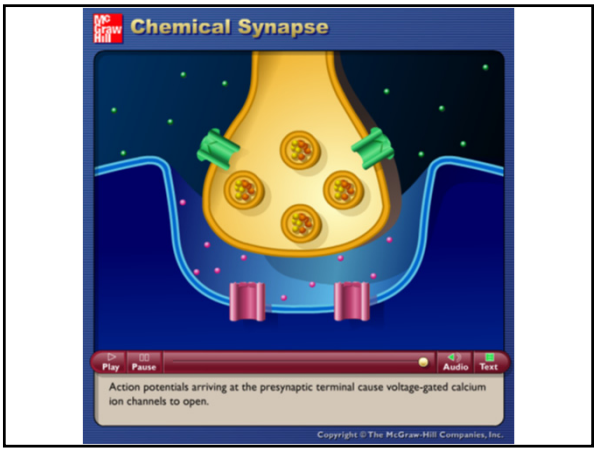

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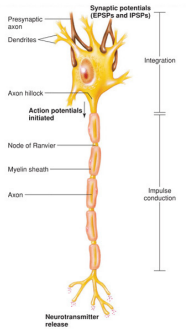
Synaptic Transmission

- EPSPs and IPSPs summate
- If MP in postsynaptic cell reaches threshold at the axon hillock, a new AP is generated
  - axon hillock has many VG channels and is site where APs are normally initiated



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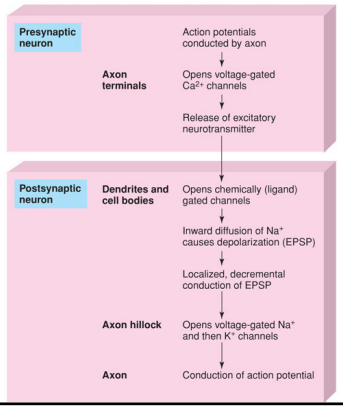
Synaptic Transmission



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Comparison of EPSPs and Action Potentials

Table 7.4 | Comparison of Action Potentials and Excitatory Postsynaptic Potentials (EPSPs)

Characteristic	Action Potential	Excitatory Postsynaptic Potential
Stimulus for opening of ionic gates	Depolarization	Acetylcholine (ACh) or other excitatory neurotransmitter
Initial effect of stimulus	Na^+ channels open	Common channels for Na^+ and K^+ open
Cause of repolarization	Opening of K^+ gates	Loss of intracellular positive charges with time and distance
Conduction distance	Regenerated over length of the axon	1–2 mm; a localized potential
Positive feedback between depolarization and opening of Na^+ gates	Yes	No
Maximum depolarization	+ 40 mV	Close to zero
Summation	No summation—all-or-none event	Summation of EPSPs, producing graded depolarizations
Refractory period	Yes	No
Effect of drugs	ACh effects inhibited by tetrodotoxin, not by curare	ACh effects inhibited by curare, not by tetrodotoxin

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Neurotransmitters

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Acetylcholine (ACh)

- Most widely used NT
  - Used in brain and ANS; used at all neuromuscular junctions
- Has nicotinic and muscarinic receptor subtypes
  - These can be excitatory or inhibitory

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Ligand-Gated Channels

- Contain both a NT receptor site and an ion channel
- Open when ligand (NT) binds

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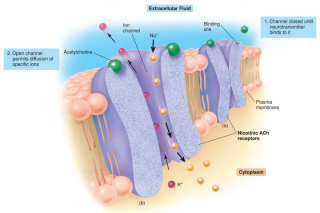
Nicotinic ACh Channel

- Formed by 5 polypeptide subunits
- 2 subunits contain ACh binding sites
  - Opens when 2 AChs bind
  - Permits diffusion of Na^+ into and K^+ out of postsynaptic cell
  - Inward flow of Na^+ dominates
  - Produces EPSPs



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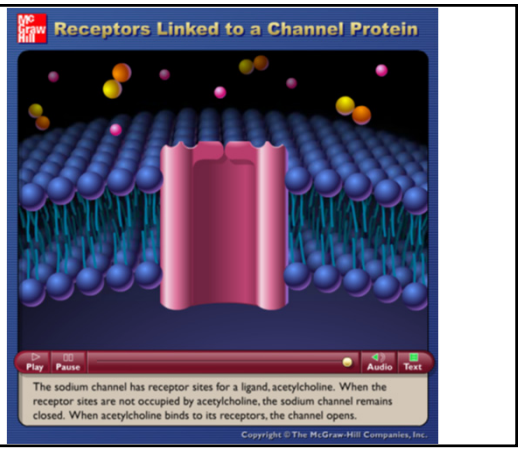

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G Protein-Coupled Channels

- NT receptor is not part of the ion channel
  - Is a 1 subunit membrane polypeptide
  - Activates ion channel indirectly through G-proteins

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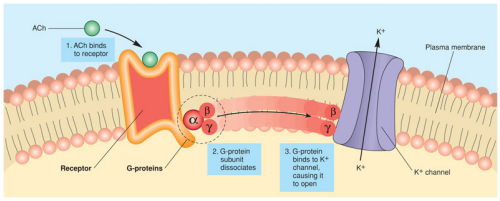
Muscarinic ACh Channel

- Binding of 1 ACh activates G-protein cascade which affects gated K+ channels
  - Opens some, causing hyperpolarization
  - Closes others, causing depolarization



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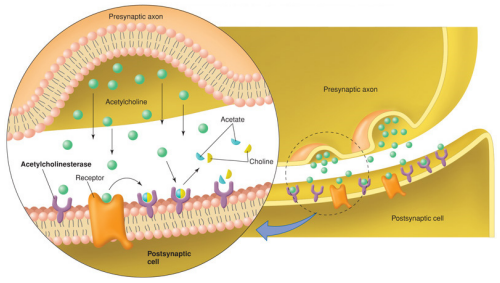
Acetylcholinesterase (AChE)

- Inactivates ACh, terminating its action; located in cleft



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Acetylcholine in the PNS

- Cholinergic neurons use acetylcholine as NT
- The large synapses on skeletal muscle are termed end plates or neuromuscular junctions (NMJ)
  - Produce large EPSPs called end-plate potentials
    - Open VG channels beneath end plate
    - Cause muscle contraction
  - **Curare blocks ACh** action at Neuromuscular Junction

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Monoamine NTs

- Include **serotonin, norepinephrine** and **dopamine**
- **Serotonin** is derived from **tryptophan**
- **Norepinephrine** and **dopamine** are derived from **tyrosine (**called catecholamines**)**

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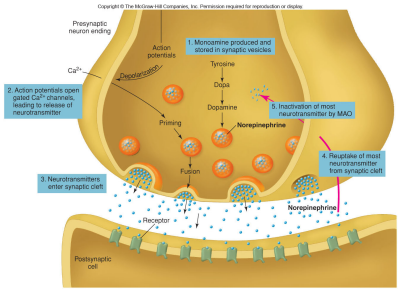
Monoamine NTs



MAO inhibitors are antidepressants

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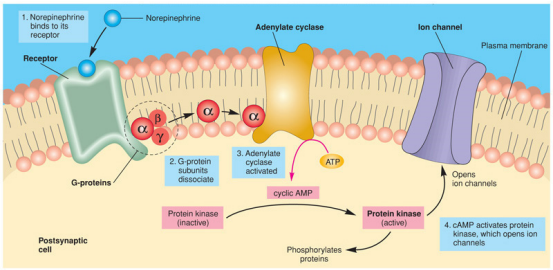
Monoamine NTs

- Their receptors activate G-protein cascade to affect ion channels



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Serotonin

- Involved in regulation of mood, behavior, appetite and cerebral circulation
- LSD is structurally similar
- SSRIs (serotonin-specific reuptake inhibitors) are antidepressants
  - e.g., Prozac, Zoloft, Paxil, Luvox
  - Block reuptake of serotonin, prolonging its action

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Dopamine

- There are 2 major dopamine systems in brain
  - **Nigrostriatal dopamine system** originates in the substantia nigra and is involved in motor control
    - Degeneration of this system causes Parkinson's disease

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Norepinephrine (NE)

- Used in PNS and CNS
- In PNS is a sympathetic NT
- In CNS affects general level of excitation
  - Amphetamines stimulate NE pathways

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Gaseous NTs

- NO and CO are gaseous NTs
  - Act through cGMP second messenger system
  - NO causes smooth muscle relaxation
    - Viagra increases NO
    - In some cases it may act as a retrograde NT

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Synaptic Integration

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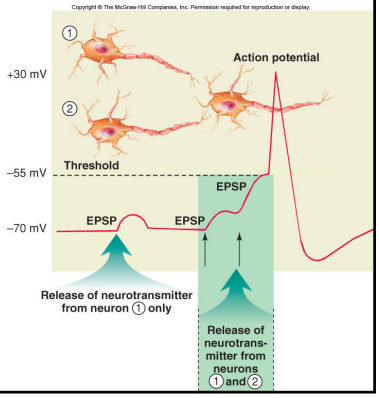
EPSPs

- Graded in magnitude
- Have no threshold
- Cause depolarization
- Summate
- Have no refractory period



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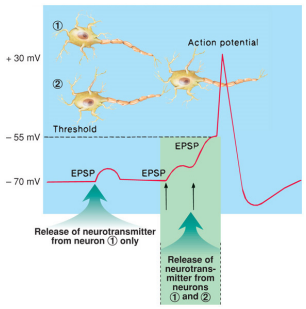
Spatial Summation

- Cable properties cause EPSPs to fade quickly over time and distance
- Spatial summation takes place when EPSPs from different synapses occur in postsynaptic cell at same time



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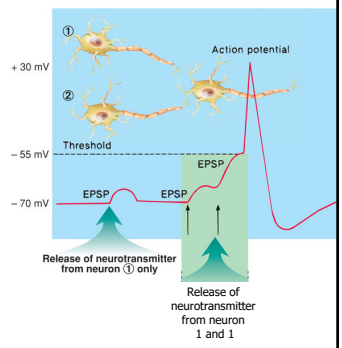
Temporal Summation

- Temporal summation occurs because EPSPs that occur closely in time can sum before they fade



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Synaptic Plasticity

- Repeated use of a synapse can increase or decrease its ease of transmission
  - = synaptic facilitation or synaptic depression
  - High frequency stimulation often causes enhanced excitability
    - Called long-term potentiation (LTP)
      - Believed to underlie learning

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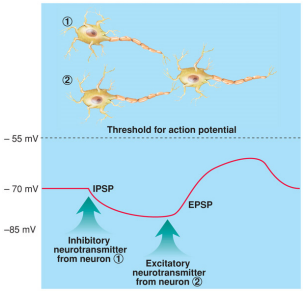
Synaptic Inhibition

- Postsynaptic inhibition
  - GABA and glycine produce IPSPs
    - IPSPs dampen EPSPs
    - Making it harder to reach threshold
- Presynaptic inhibition:
  - Occurs when 1 neuron synapses onto axon or bouton of another neuron, inhibiting release of its NT



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