

## Bear: Neuroscience: Exploring the Brain 3e

### ◆ Chapter 04: The Action Potential

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## Introduction

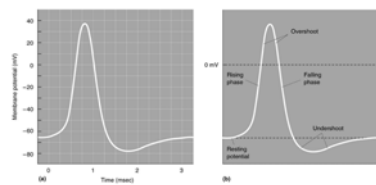
- ◆ Action Potential in the Nervous System
  - ◆ Conveys information over distances
  - ◆ Cytosol has negative charge relative to extracellular space
  - ◆ Neural code - frequency and pattern
  - ◆ Action potential
    - \* Spike
    - \* Nerve impulse
    - \* Discharge

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## Properties of the Action Potential

- ◆ The Ups and Downs of an Action Potential
  - ◆ Oscilloscope to visualize an AP
    - \* Rising phase, overshoot, falling phase, and undershoot



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## Properties of the Action Potential

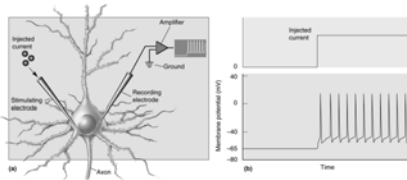
- ◆ The Generation of an Action Potential
  - ◆ "All-or-none": Cross threshold value for action potential
  - ◆ Chain reaction
    - \* e.g., Puncture foot, stretch membrane of nerve fibers
    - \* Opens  $\text{Na}^+$ -permeable channels  $\rightarrow$   $\text{Na}^+$  influx  $\rightarrow$  depolarized membrane  $\rightarrow$  reaches threshold  $\rightarrow$  action potential

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## Properties of the Action Potential

- ◆ The Generation of Multiple Action Potentials
  - ✦ Artificially - inject current into a neuron using a microelectrode

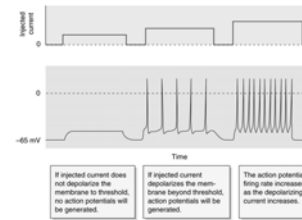


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## Properties of the Action Potential

- ◆ The Generation of Multiple Action Potentials (Cont'd)
  - ✦ Firing frequency reflects the magnitude of the depolarizing current



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## The Action Potential, In Theory

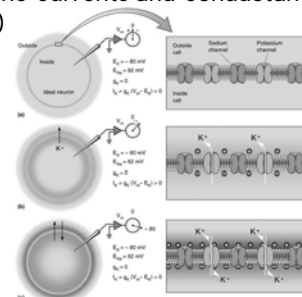
- ◆ Depolarization (influx of  $\text{Na}^+$ ) and repolarization (efflux of  $\text{K}^+$ )
- ◆ Membrane Currents and Conductances
  - ✦ Current
    - ✦ The net movement of  $\text{K}^+$  across membrane
  - ✦ Potassium channel number
    - ✦ Proportional to electrical conductances
  - ✦ Membrane potassium current
    - ✦ Flow and driving force

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## The Action Potential, In Theory

- ◆ Membrane Currents and Conductances (Cont'd)

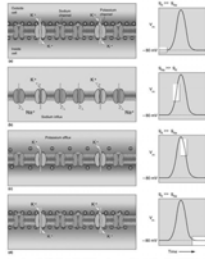


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## The Action Potential, In Theory

### ◆ The Ins and Outs of an Action Potential



- ◆ Rising phase: Inward sodium current
- ◆ Falling phase: Outward potassium current

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## The Action Potential, In Reality

### ◆ The Generation of an Action Potential

#### ◆ Hodgkin and Huxley

- ◆ Voltage Clamp: "Clamp" membrane potential at any chosen value
- ◆ Rising phase → transient increase in  $g_{Na}$ , influx of  $Na^+$  ions
- ◆ Falling phase → increase in  $g_K$ , efflux of  $K^+$  ions
- ◆ Existence of sodium "gates" in the axonal membrane

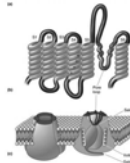
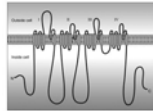
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## The Action Potential, In Reality

### ◆ The Voltage-Gated Sodium Channel

- ◆ Structure - transmembrane domains and ion-selective pore



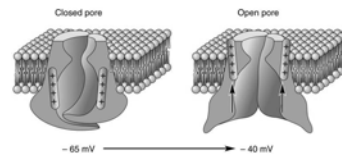
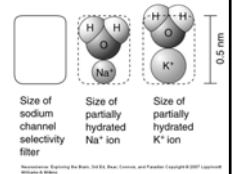
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## The Action Potential, In Reality

### ◆ The Voltage-Gated Sodium Channel (Cont'd)

- ◆ Structure - gating and pore selectivity

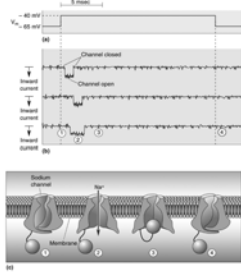


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## The Action Potential, In Reality

- ◆ The Voltage-Gated Sodium Channel
  - ◆ Patch-clamp method (Erwin Neher)



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## The Action Potential, In Reality

- ◆ The Voltage-Gated Sodium Channel (Cont'd)
  - ◆ Functional Properties of the Sodium Channel
    - \* Open with little delay
    - \* Stay open for about 1msec
    - \* Cannot be open again by depolarization
- ◆ Absolute refractory period: Channels are inactivated

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## The Action Potential, In Reality

- ◆ The Voltage-Gated Sodium Channel (Cont'd)
  - ◆ In genetic disease - channelopathies
    - \* E.g., Generalized epilepsy with febrile seizures
  - ◆ Toxins as experimental tools
    - \* Puffer fish: Tetrodotoxin (TTX)- Clogs  $\text{Na}^+$  permeable pore
    - \* Red Tide: Saxitoxin-  $\text{Na}^+$  Channel-blocking toxin

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## The Action Potential, In Reality

- ◆ The Voltage-Gated Sodium Channel (Cont'd)
  - ◆ Varieties of toxins
    - \* Batrachotoxin (frog): Blocks inactivation so channels remain open
    - \* Veratridine (lilies): Inactivates channels
    - \* Aconitine (buttercups): Inactivates channels
  - ◆ Differential toxin binding sites: Clues about 3D structure of channels

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## The Action Potential, In Reality

- ◆ Voltage-Gated Potassium Channels
  - ✦ Potassium vs. sodium gates
    - ✦ Both open in response to depolarization
    - ✦ Potassium gates open later than sodium gates
  - ✦ Delayed rectifier
    - ✦ Potassium conductance serves to rectify or reset membrane potential
  - ✦ Structure: Four separate polypeptide subunits join to form a pore

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## The Action Potential, In Reality

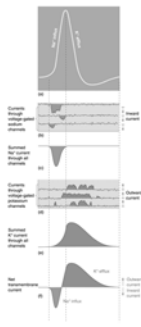
- ◆ Key Properties of the Action Potential
  - ✦ Threshold
  - ✦ Rising phase
  - ✦ Overshoot
  - ✦ Falling phase
  - ✦ Undershoot
  - ✦ Absolute refractory period
  - ✦ Relative refractory period

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## The Action Potential, In Reality

- ◆ Key properties of the action potential (Cont'd)

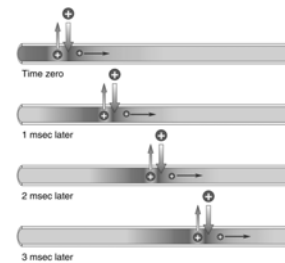


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## Action Potential Conduction

- ◆ Initiation of synaptic transmission



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## Action Potential Conduction

- ◆ Propagation of the action potential
  - ✦ Down axon to the axon terminal
    - \* Orthodromic: Action potential travels in one direction
    - \* Antidromic (experimental): Backward propagation
  - ✦ Typical conduction velocity: 10 m/sec
  - ✦ Length of action potential: 2 msec

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## Action Potential Conduction

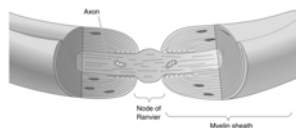
- ◆ Factors Influencing Conduction Velocity
  - ✦ Spread of action potential along membrane
    - \* Dependent upon axon structure
  - ✦ Path of the positive charge
    - \* Inside of the axon (faster)
    - \* Across the axonal membrane (slower)
  - ✦ Axonal excitability
    - \* Axonal diameter (bigger = faster)
    - \* Number of voltage-gated channels

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## Action Potential Conduction

- ◆ Factors Influencing Conduction Velocity
  - ✦ Myelin: Facilitates current flow
  - ✦ Layers of myelin sheath
    - \* Myelinating cells
      - \* Schwann cells in the PNS
      - \* Oligodendroglia in CNS

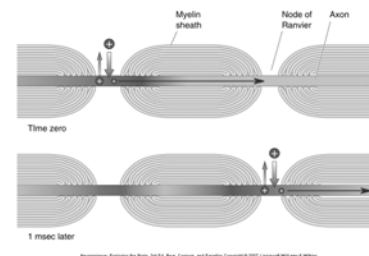


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## Action Potential Conduction

- ◆ Factors Influencing Conduction Velocity
  - ✦ Saltatory conduction

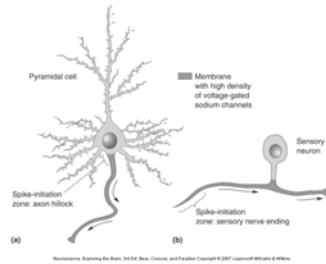


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## Action Potentials, Axons, and Dendrites

- ◆ Spike-initiation zone
  - ◆ Sensory nerve endings
  - ◆ Axon hillock



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## Concluding Remarks

- ◆ Neuronal signal transmitted as the generation and regeneration of APs
  - ◆ E.g.,: Puncture the skin → nerves stretch →  $\text{Na}^+$ -channels open → AP initiated and propagated → information is “communicated” to next neuron across the membrane (synaptic transmission)
  - ◆ Emerging picture: The brain as an interconnected mesh of membranes
- ◆ Next: Synaptic transmission-information transfer

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