

Voltage-Gated Ion Channels and the Action Potential

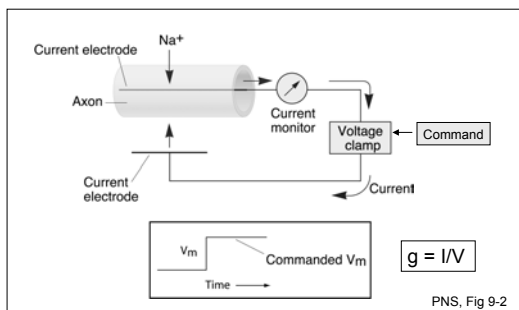
jdk3

Principles of Neural Science, chaps 8&9

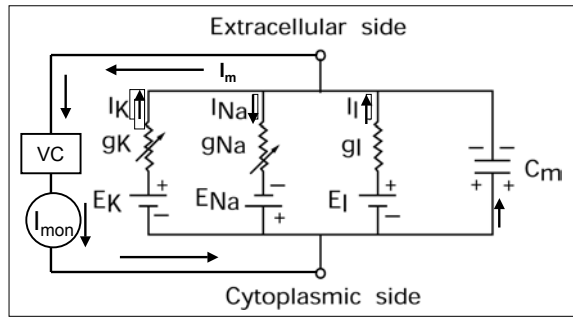
Voltage-Gated Ion Channels and the Action Potential

- The Action Potential
 - Generation
 - Conduction
- Voltage-Gated Ion Channels
 - Diversity
 - Evolutionary Relationships

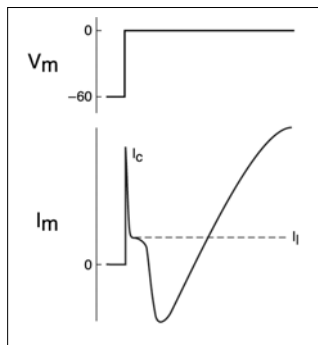
Electronically Generated Current Counterbalances the Na⁺ Membrane Current



Equivalent Circuit of the Membrane Connected to the Voltage Clamp

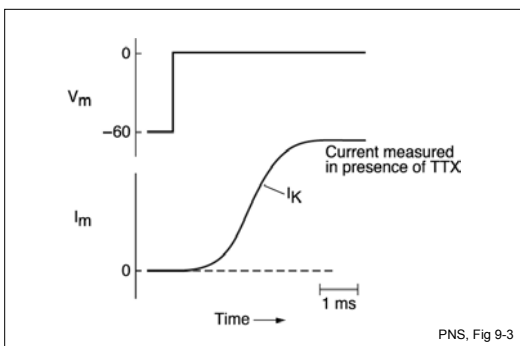


For Large Depolarizations, Both I_{Na} and I_K Are Activated



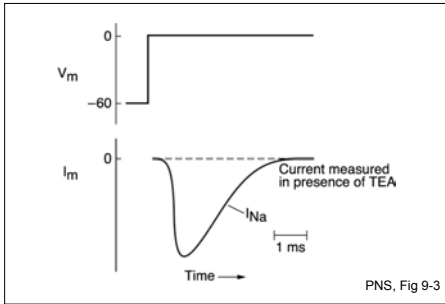
PNS, Fig 9-3

I_K is Isolated By Blocking I_{Na}

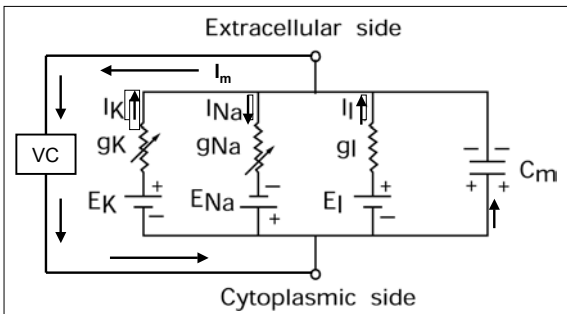


PNS, Fig 9-3

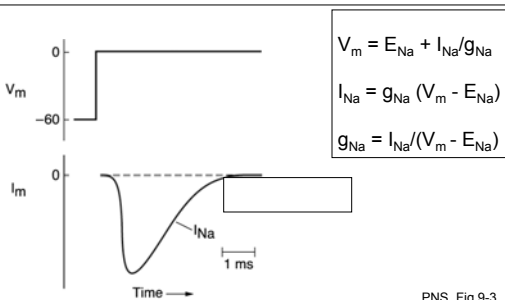
I_{Na} is Isolated By Blocking I_K



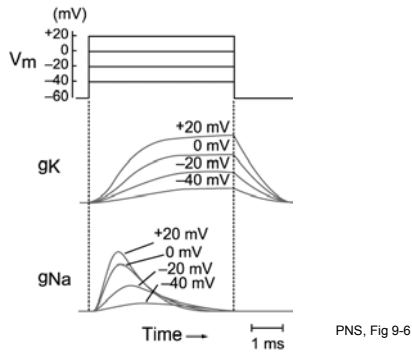
V_m = the Value of the Na Battery Plus the Voltage Drop Across g_{Na}



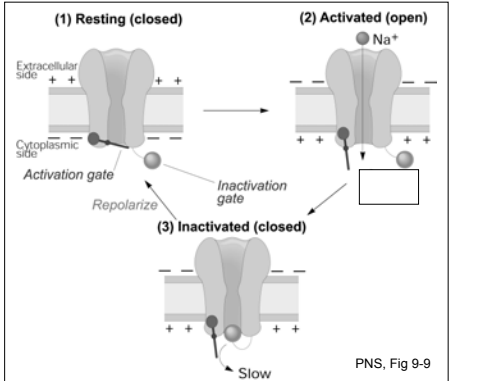
Calculation of g_{Na}



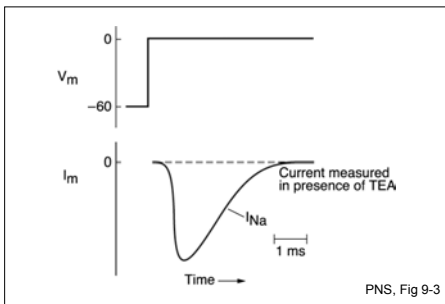
g_{Na} and g_K Have Two Similarities and Two Differences



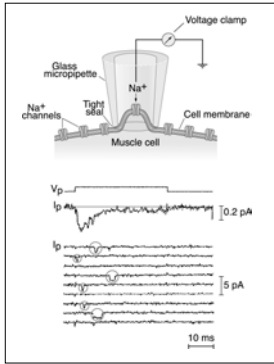
Voltage-Gated Na^+ Channels Have Three States



Total I_{Na} is a Population Phenomenon

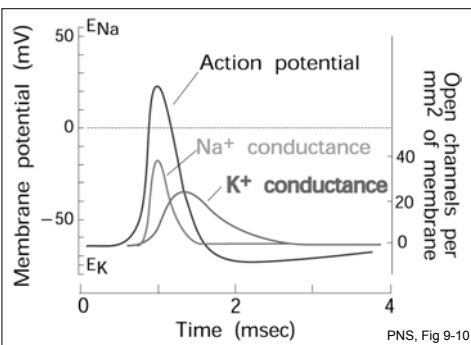


Na⁺ Channels Open in an All-or-None Fashion



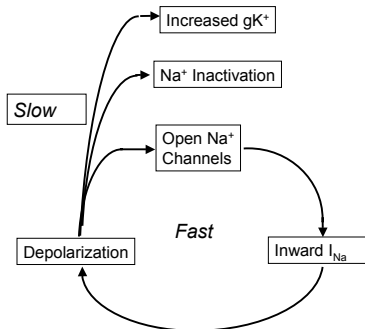
PNS, Fig 9-12

The Action Potential is Generated by Sequential Activation of g_{Na} and g_K

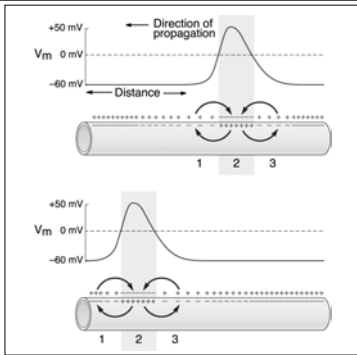


PNS, Fig 9-10

Negative Feedback Cycle Underlies Falling Phase of the Action Potential

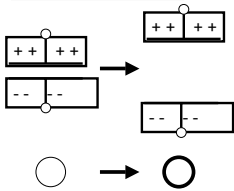
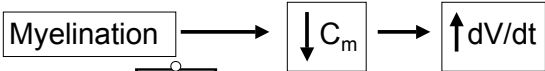
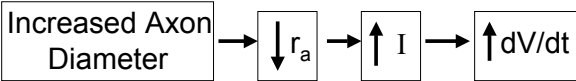


Local Circuit Flow of Current Contributes to Action Potential Propagation



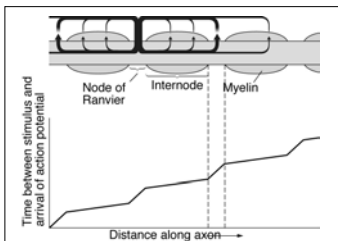
PNS, Fig 8-6

Conduction Velocity Can be Increased by Increased Axon Diameter and by Myelination



$$\Delta V = \Delta Q / C$$

Myelin Speeds Up Action Potential Conduction



PNS, Fig 8-8

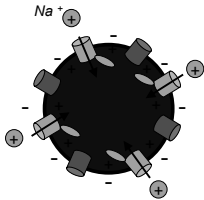
Voltage-Gated Ion Channels and the Action Potential

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Opening of Na^+ and K^+ Channels is Sufficient to Generate the Action Potential

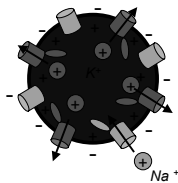
Rising Phase

Na^+ Channels Open

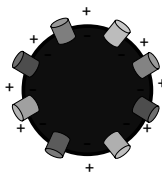


Falling Phase

Na^+ Channels Close;
 K^+ Channels Open



However, a Typical Neuron Has Several Types of Voltage-Gated Ion Channels



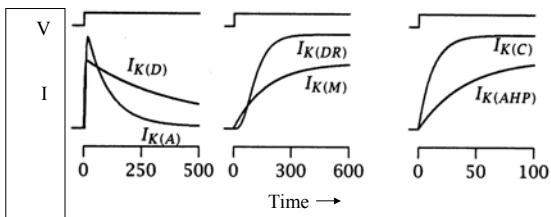
Functional Properties of Voltage-Gated Ion Channels Vary Widely

- Selective permeability
- Kinetics of activation
- Voltage range of activation
- Physiological modulators

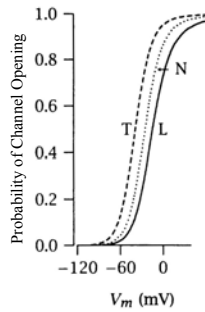
Voltage-Gated Ion Channels Differ in their Selective Permeability Properties

Cation Permeable	Anion Permeable
Na ⁺	Cl ⁻
K ⁺	
Ca ⁺⁺	
Na ⁺ , Ca ⁺⁺ , K ⁺	

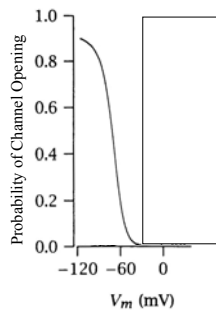
Voltage-Gated K⁺ Channels Differ Widely in Their Kinetics of Activation and Inactivation



Voltage-Gated Ca^{++} Channels Differ in Their Voltage Ranges of Activation



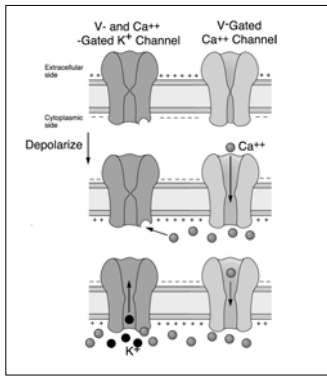
The Inward Rectifier K^+ Channels and HCN Channels Are Activated by Hyperpolarization



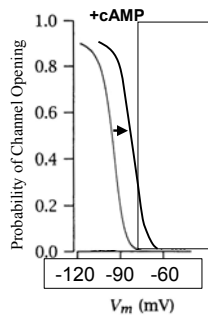
Functional properties of Voltage-Gated Ion Channels Vary Widely

- Selective permeability
- Kinetics of activation
- Voltage range of activation
- Physiological modulators: e.g., phosphorylation, binding of intracellular Ca^{++} or cyclic nucleotides, etc.

Physiological Modulation



HCN Channels That Are Opened by Hyperpolarization Are Also Modulated by cAMP

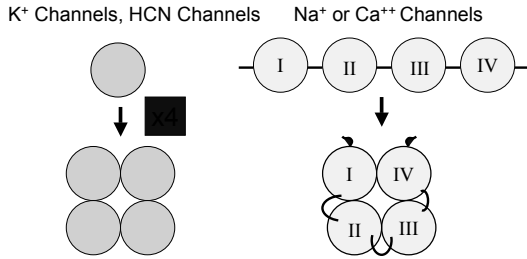


Voltage-Gated Ion Channels Belong to Two Major Gene Superfamilies

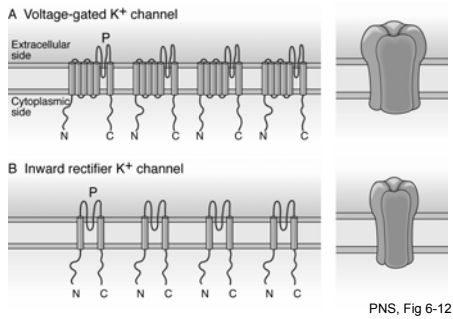
I. Cation Permeant

II. Anion Permeant

Four-Fold Symmetry of Voltage-Gated Channels Arises in Two Ways

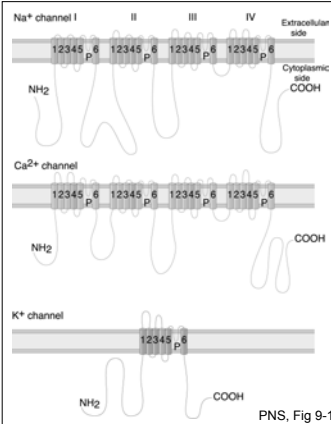


Inward Rectifier K⁺ Channels Have Only Two of the Six Alpha-Helices per Subunit



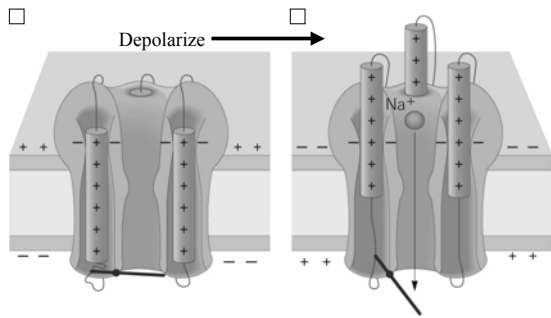
PNS, Fig 6-12

Voltage-Gated Cation-Permeant Channels Use the Same Structural Elements for Gating and for Ion Selectivity



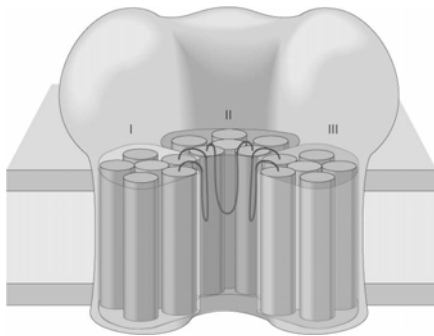
PNS, Fig 9-14

Gating of Voltage-Gated Cation-Permeant Channels is Caused by Movement of S4 α -Helices in Response to a Change in V_m



PNS, Fig 9-16

P-Loops Form the Selectivity Filter of Voltage-Gated Cation-Permeant Channels



PNS, Fig 9-15

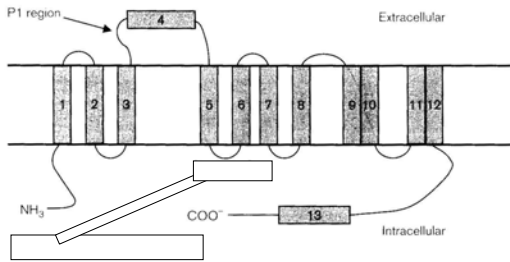
Voltage-Gated Ion Channel Gene Superfamilies

II) "CLC" Family of Cl⁻-Permeant Channels (dimeric structure):

Gated by:

- Voltage
- Cell Swelling
- pH

Voltage-Gated Cl⁻ Channels Differ in Sequence and Structure from Cation-Permeant Channels



Voltage-Gated Cl⁻ Channels are Dimers

