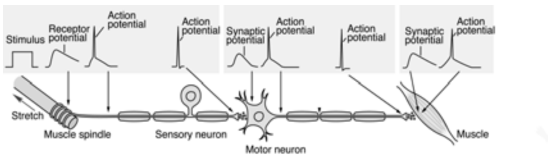
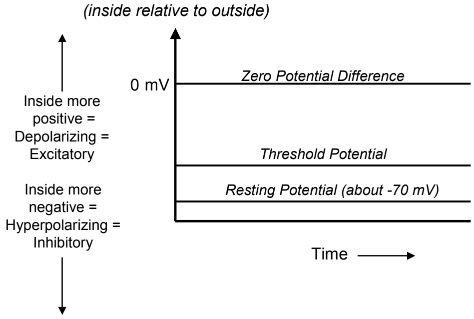
Generator Potentials, Synaptic Potentials and Action Potentials All Can Be Described by the Equivalent Circuit Model of the Membrane

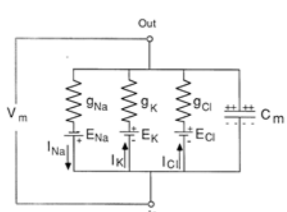


PNS, Fig 2-11

Nomenclature



Equivalent Circuit Model of the Neuron

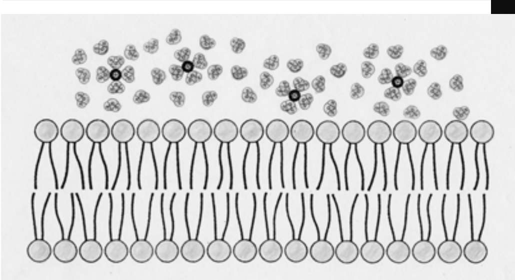


[redacted]

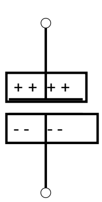
Equivalent Circuit of the Membrane and Passive Electrical Properties

- Equivalent Circuit of the Membrane
  - What Gives Rise to C, R, and V?
  - Model of the Resting Membrane
- Passive Electrical Properties
  - Time Constant and Length Constant
  - Effects on Synaptic Integration
- Voltage-Clamp Analysis of the Action Potential

Ions Cannot Diffuse Across the Hydrophobic Barrier of the Lipid Bilayer



The Lipid Bilayer Acts Like a Capacitor

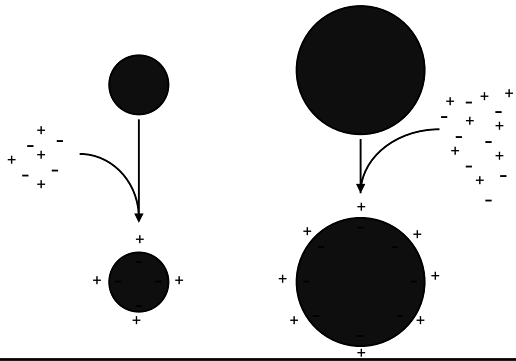


$V_m = Q/C$

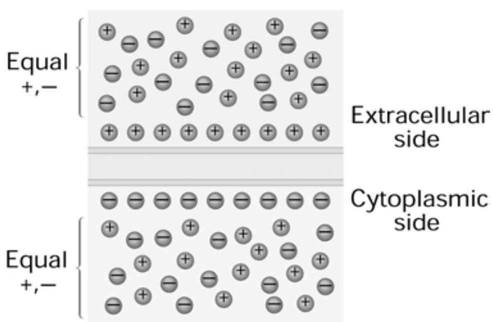
$\Delta V_m = \Delta Q/C$

ΔQ must change before
ΔV_m can change

Capacitance is Proportional to Membrane Area

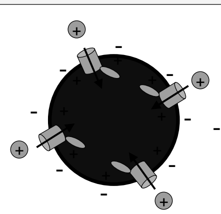


The Bulk Solution Remains Electroneutral



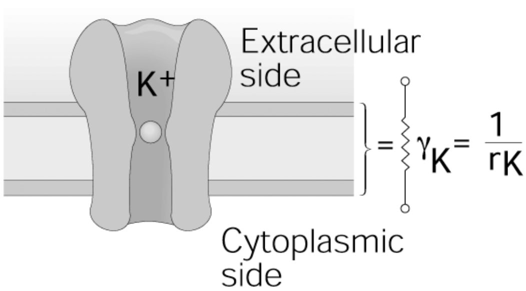
PNS, Fig 7-1

Electrical Signaling in the Nervous System is Caused by the Opening or Closing of Ion Channels



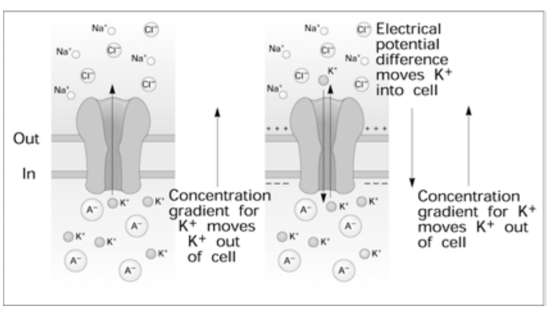
The Resultant Flow of Charge into the Cell
Drives the Membrane Potential Away From its Resting Value

Each K^+ Channel Acts as a Conductor (Resistance)



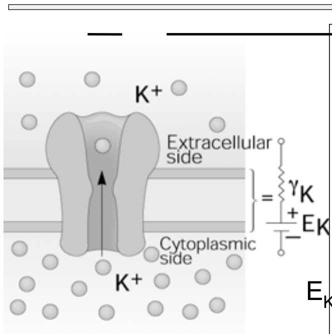
PNS, Fig 7-5

Ion Channel Selectivity and Ionic Concentration Gradient Result in an Electromotive Force



PNS, Fig 7-3

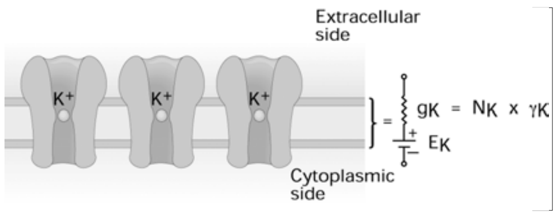
An Ion Channel Acts Both as a Conductor and as a Battery



$$E_K = \frac{RT}{zF} \cdot \ln \frac{[K^+]_o}{[K^+]_i}$$

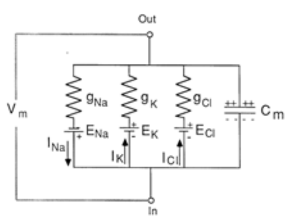
PNS, Fig 7-6

All the K^+ Channels Can be Lumped into One Equivalent Structure



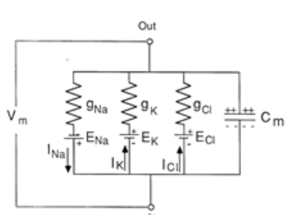
PNS, Fig 7-7

An Ionic Battery Contributes to V_M in Proportion to the Membrane Conductance for That Ion



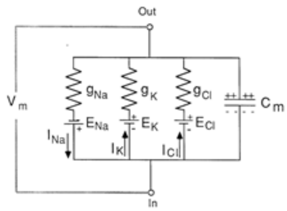
$$V_m = \frac{g_K \cdot E_K + g_{Cl} \cdot E_{Cl} + g_{Na} \cdot E_{Na}}{g_K + g_{Cl} + g_{Na}}$$

When g_K is Very High, $g_K \cdot E_K$ Predominates



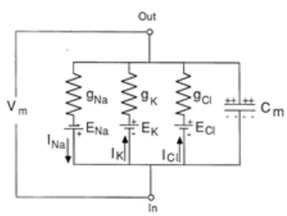
$$V_m = \frac{g_K \cdot E_K + \cancel{g_{Cl} \cdot E_{Cl}} + \cancel{g_{Na} \cdot E_{Na}}}{g_K + \cancel{g_{Cl}} + \cancel{g_{Na}}}$$

The K+ Battery Predominates at Resting Potential



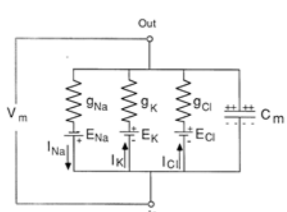
$$V_m \approx \frac{g_K \cdot E_K}{g_K}$$

The K+ Battery Predominates at Resting Potential



$$V_m \approx \frac{\cancel{g_K} \cdot E_K}{\cancel{g_K}}$$

This Equation is Qualitatively Similar to the Goldman Equation

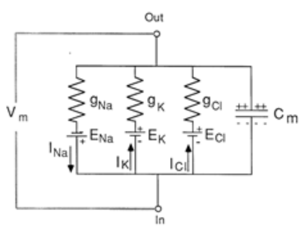


$$V_m = \frac{g_K \cdot E_K + g_{Cl} \cdot E_{Cl} + g_{Na} \cdot E_{Na}}{g_K + g_{Cl} + g_{Na}}$$

The Goldman Equation

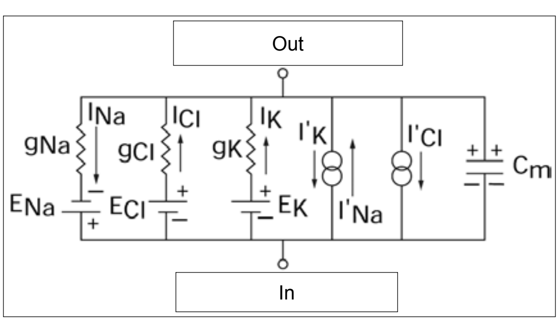
[redacted] $\frac{RT}{zF}$ [redacted] $\frac{(P_K\{K^+\}_o + P_{Na}\{Na^+\}_o + P_{Cl}\{Cl^-\}_i)}{(P_K\{K^+\}_i + P_{Na}\{Na^+\}_i + P_{Cl}\{Cl^-\}_o)}$

Ions Leak Across the Membrane at Resting Potential



[redacted]

At Resting Potential The Cell is in a Steady-State

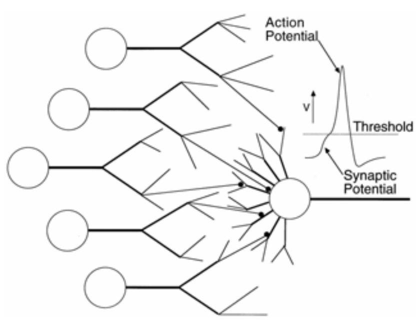


PNS, Fig 7-10

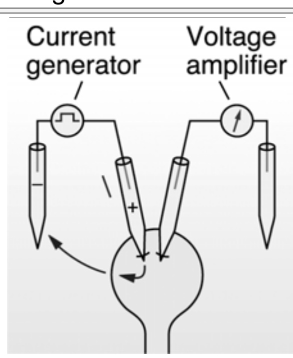
Equivalent Circuit of the Membrane and Passive Electrical Properties

- Equivalent Circuit of the Membrane
  - What Gives Rise to C, R, and V?
  - Model of the Resting Membrane
- Passive Electrical Properties
  - Time Constant and Length Constant
  - Effects on Synaptic Integration
- Voltage-Clamp Analysis of the Action Potential

Passive Properties Affect Synaptic Integration

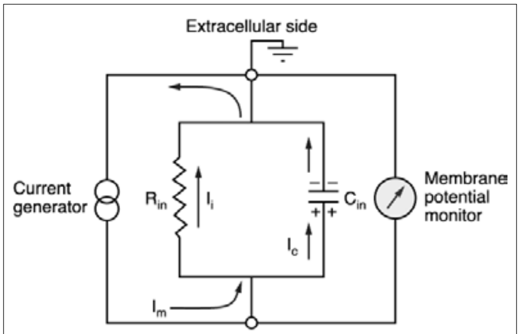


Experimental Set-up for Injecting Current into a Neuron



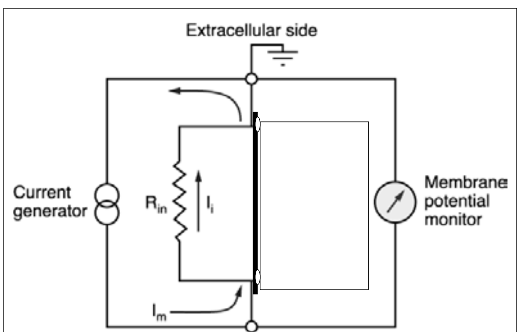
PNS, Fig 7-2

Equivalent Circuit for Injecting Current into Cell



PNS, Fig 8-2

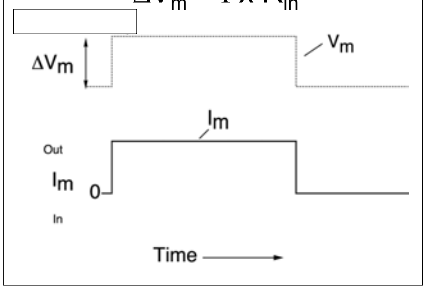
If the Cell Had Only Resistive Properties



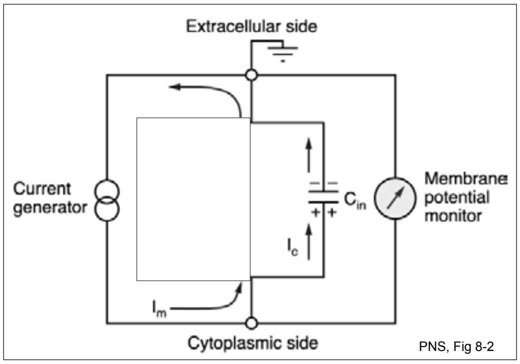
PNS, Fig 8-2

If the Cell Had Only Resistive Properties

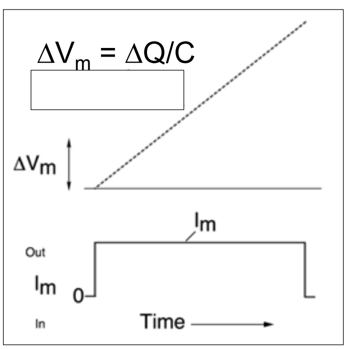
$$\Delta V_m = I \times R_{in}$$



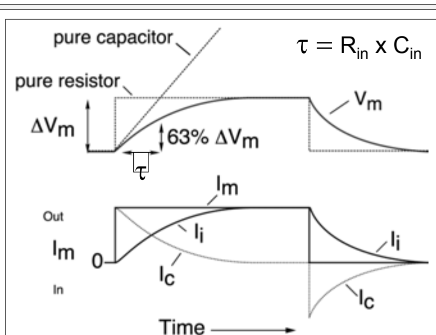
If the Cell Had Only Capacitive Properties



If the Cell Had Only Capacitive Properties

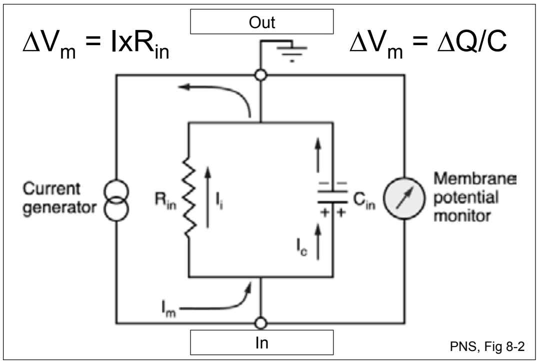


Because of Membrane Capacitance, Voltage Always Lags Current Flow



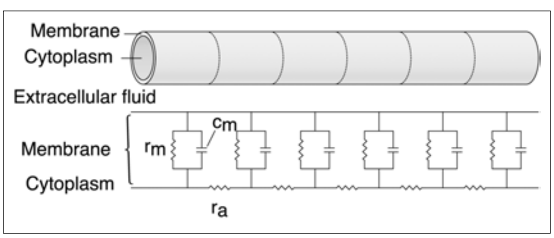
PNS, Fig 8-3

Equivalent Circuit for Injecting Current into Cell



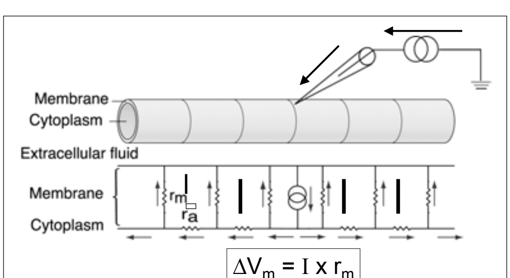
PNS, Fig 8-2

The Axon or Dendrite Can be Represented by a Collection of Identical Circuit Elements

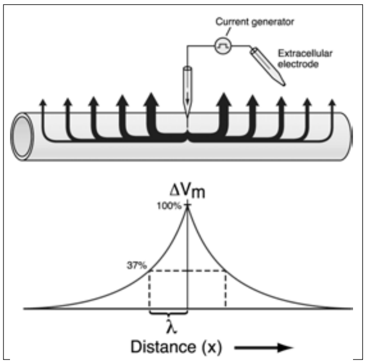


PNS, Fig 8-4

Spread of Injected Current is Affected by r_a and r_m

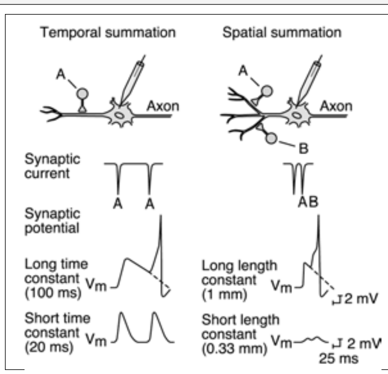


Length Constant $\lambda = \sqrt{r_m/r_a}$



PNS, Fig 8-5

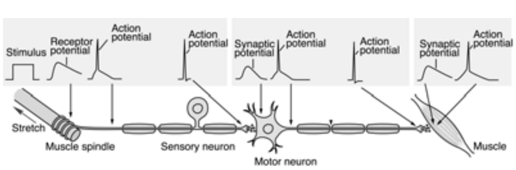
Synaptic Integration



PNS, Fig 12-13

Receptor Potentials and Synaptic Potentials Convey Signals over <u>Short</u> Distances

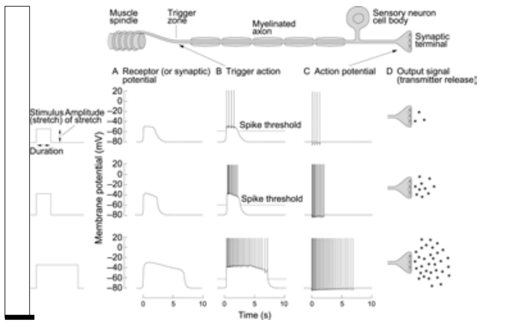
Action Potentials Convey Signals over <u>Long</u> Distances



PNS, Fig 2-11

The Action Potential

1) Has a threshold, is all-or-none, and is conducted without decrement
2) Carries information from one end of the neuron to the other in a pulse-code



PNS, Fig 2-10

Equivalent Circuit of the Membrane and Passive Electrical Properties

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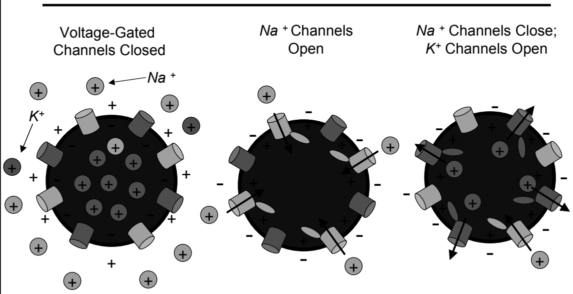
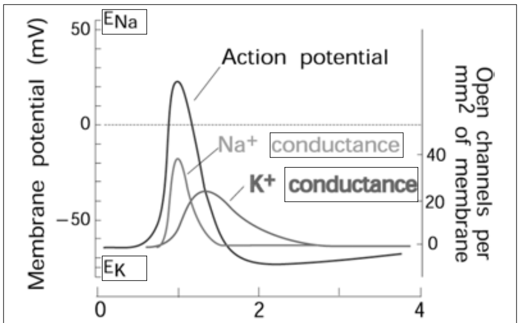
Sequential Opening of Na^+ and K^+ Channels Generate the Action Potential

Rest	Rising Phase of Action Potential	Falling Phase of Action Potential

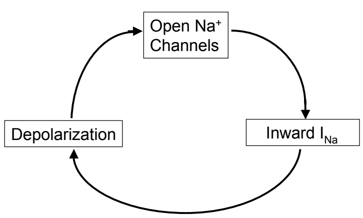


The Action Potential is Generated by Sequential Activation of Sodium and Potassium Channels

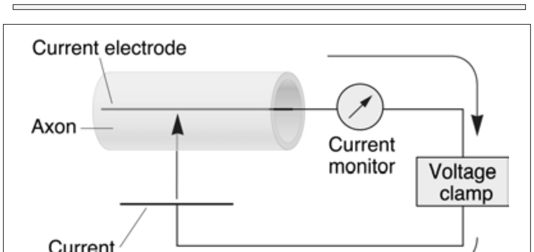


PNS, Fig 9-10

A Positive Feedback Cycle Generates the Rising Phase of the Action Potential



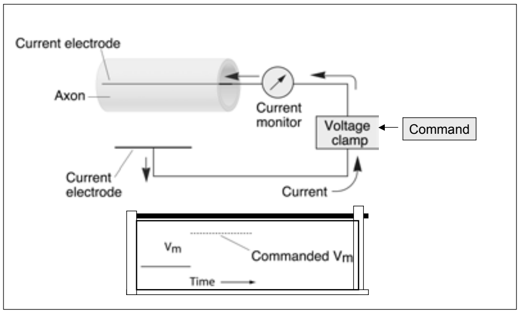
Voltage Clamp Circuit



Voltage Clamp:
1) Steps
2) Clamps

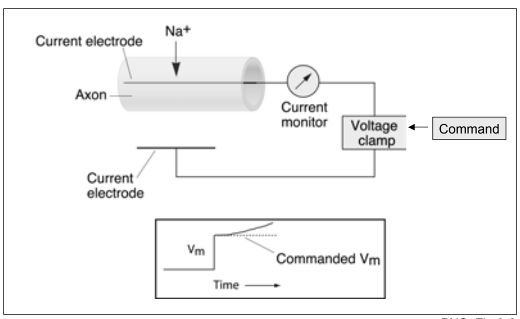
PNS, Fig 9-2

The Voltage Clamp Generates a Depolarizing Step by Injecting Positive Charge into the Axon



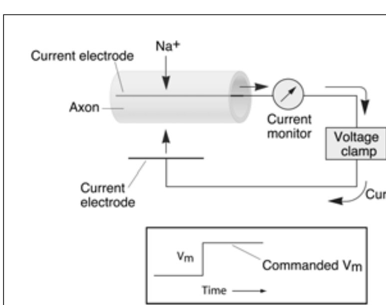
PNS, Fig 9-2

Opening of Na^+ Channels Gives Rise to Na^+ Influx That Tends to Cause V_m to Deviate from Its Commanded Value



PNS, Fig 9-2

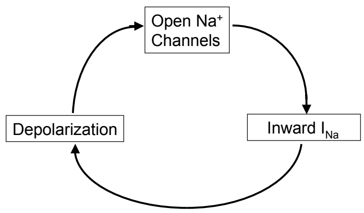
Electronically Generated Current Counterbalances the Na^+ Membrane Current



$g = I/V$

PNS, Fig 9-2

Where Does the Voltage Clamp Interrupt the Positive Feedback Cycle?



The Voltage Clamp Interrupts the Positive Feedback Cycle Here