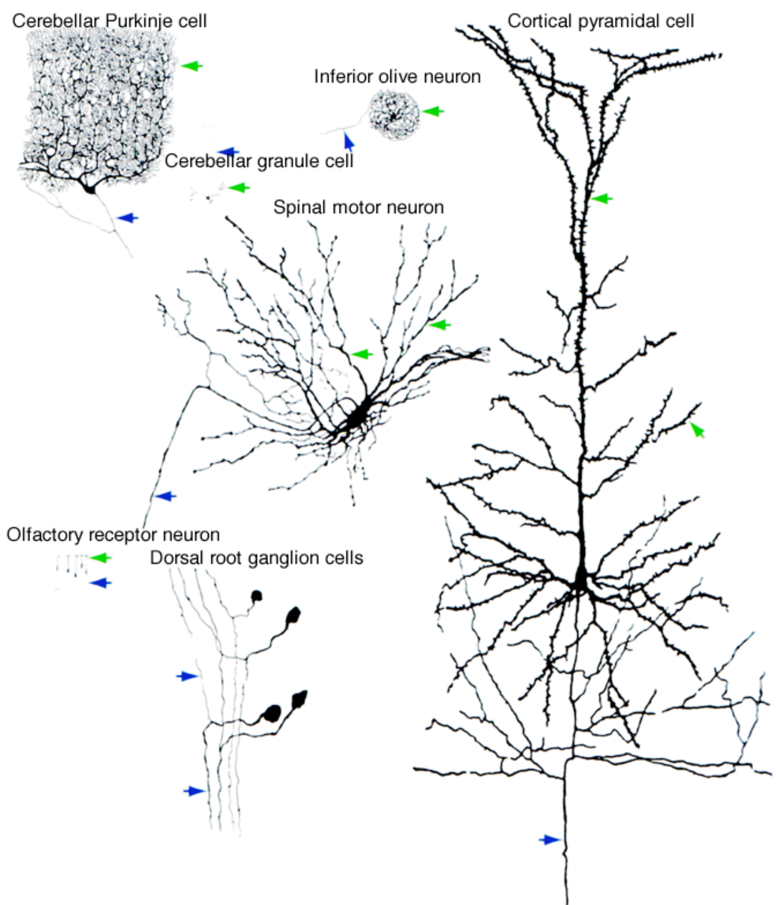
BME 665/565 Lecture 2 1/11/2007

Part A: Biophysical models of Single Neurons. (7 classes)
Using the simulation package NEURON, we will explore the effects of membrane currents and neuron morphology on the responses of neurons to stimuli.

NEURON
for computer simulations of neurons and neural networks

http://www.neuron.yale.edu
http://neuron.duke.edu/

01_singleNeurons.psd



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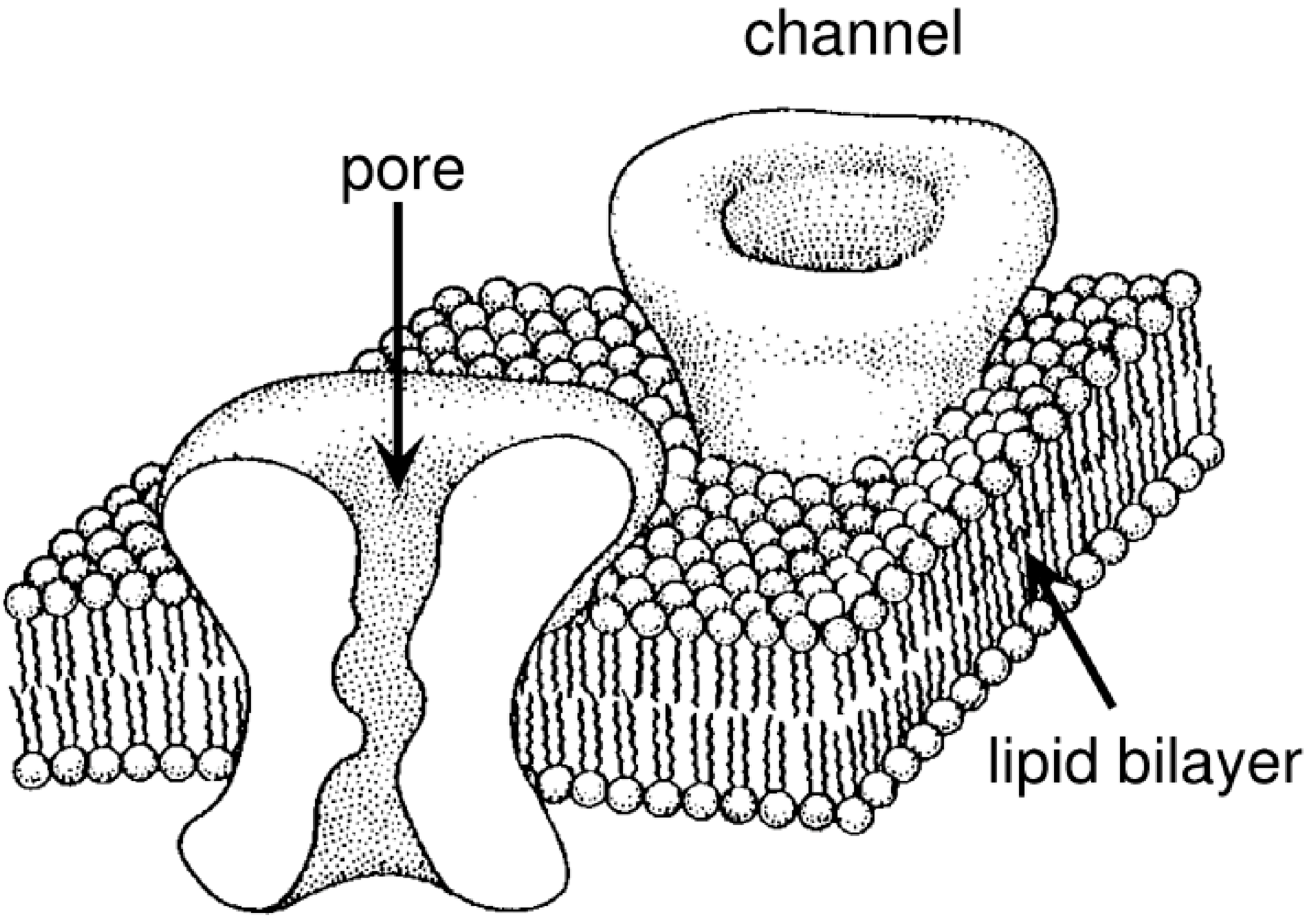
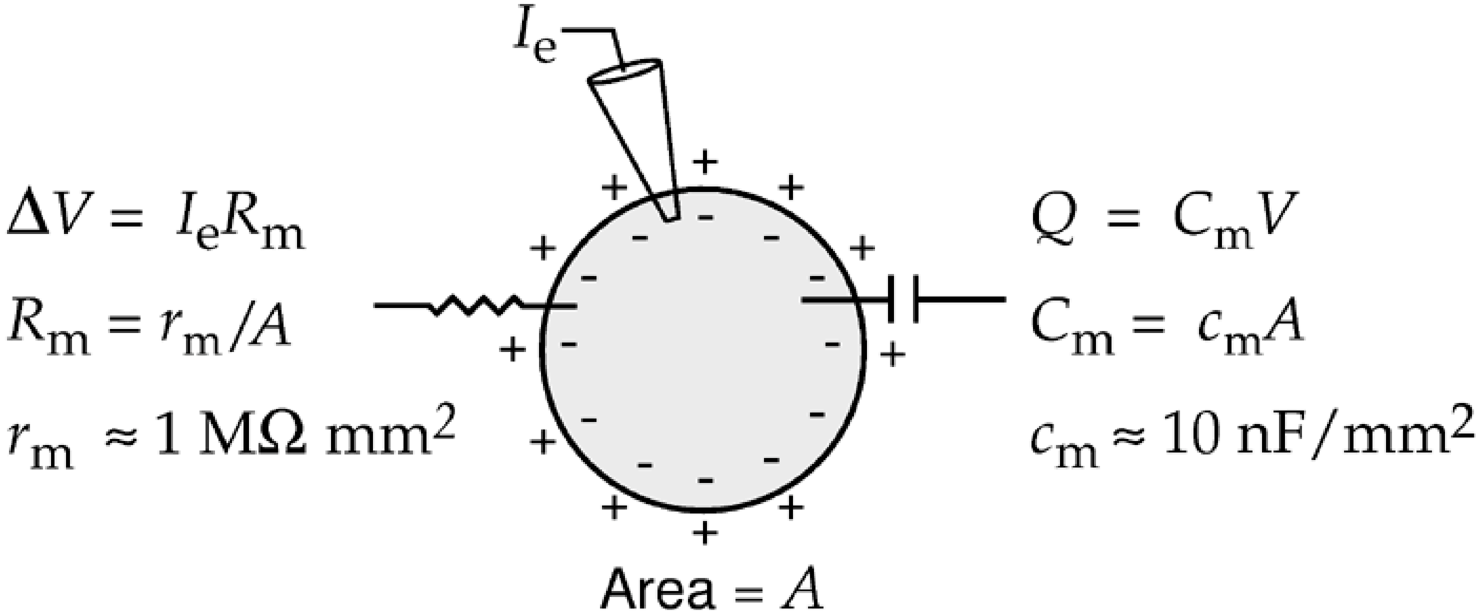
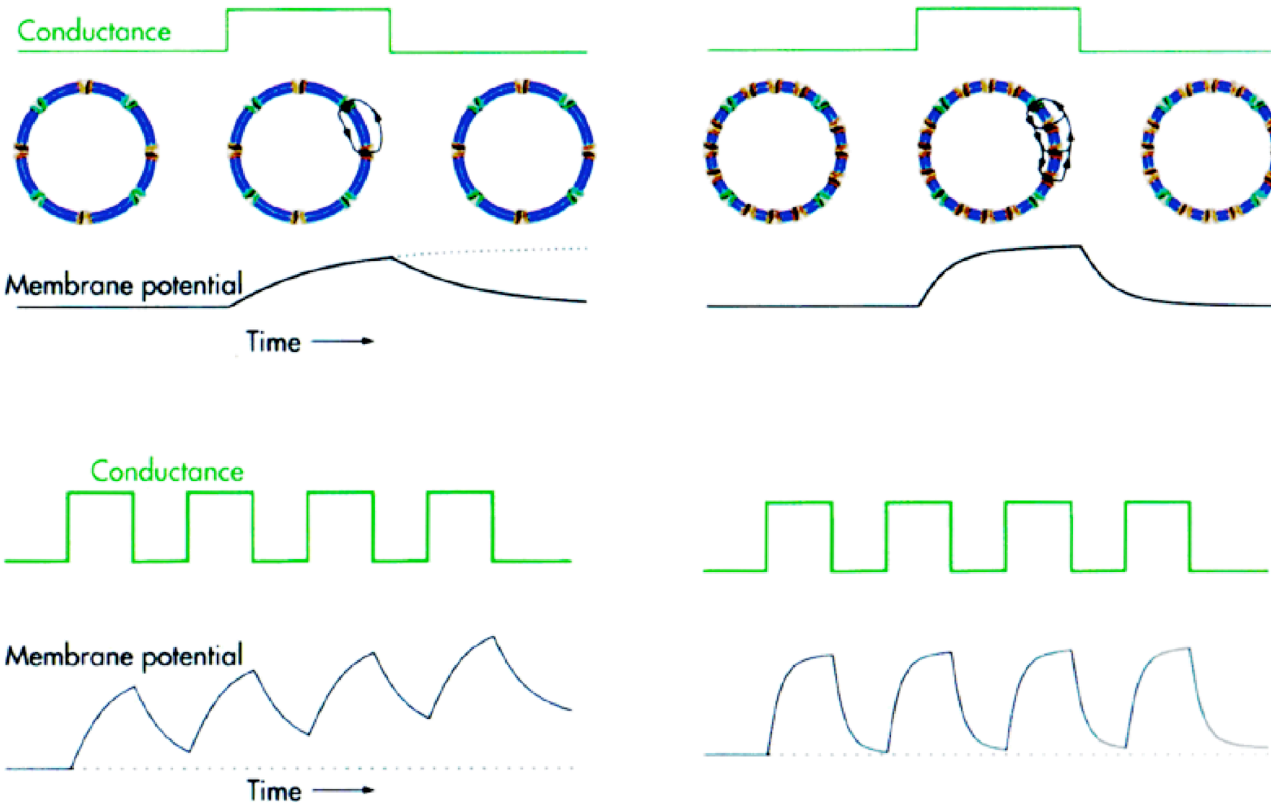
02_typesMorph.psd



03_ch5fig1.png



04_ch5fig3.png



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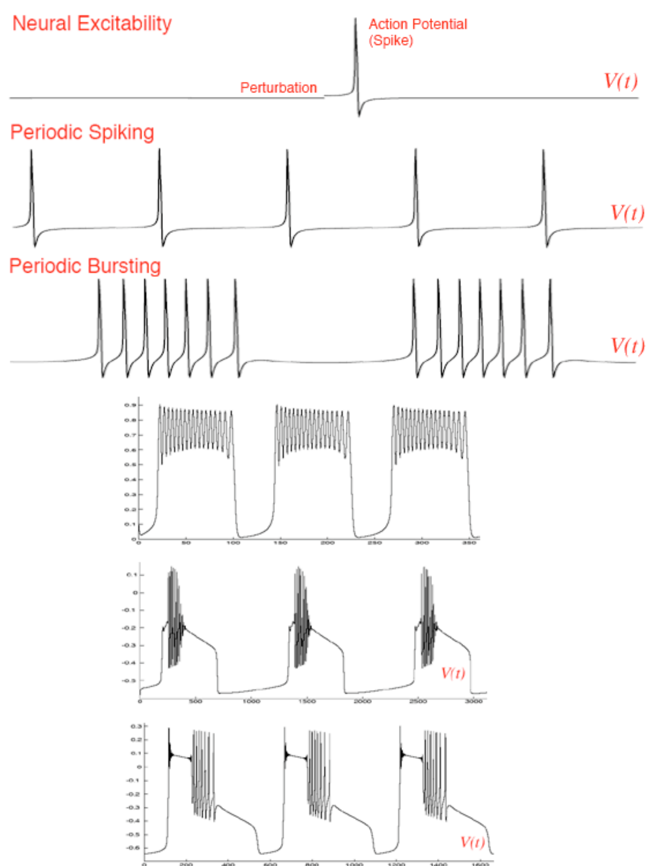
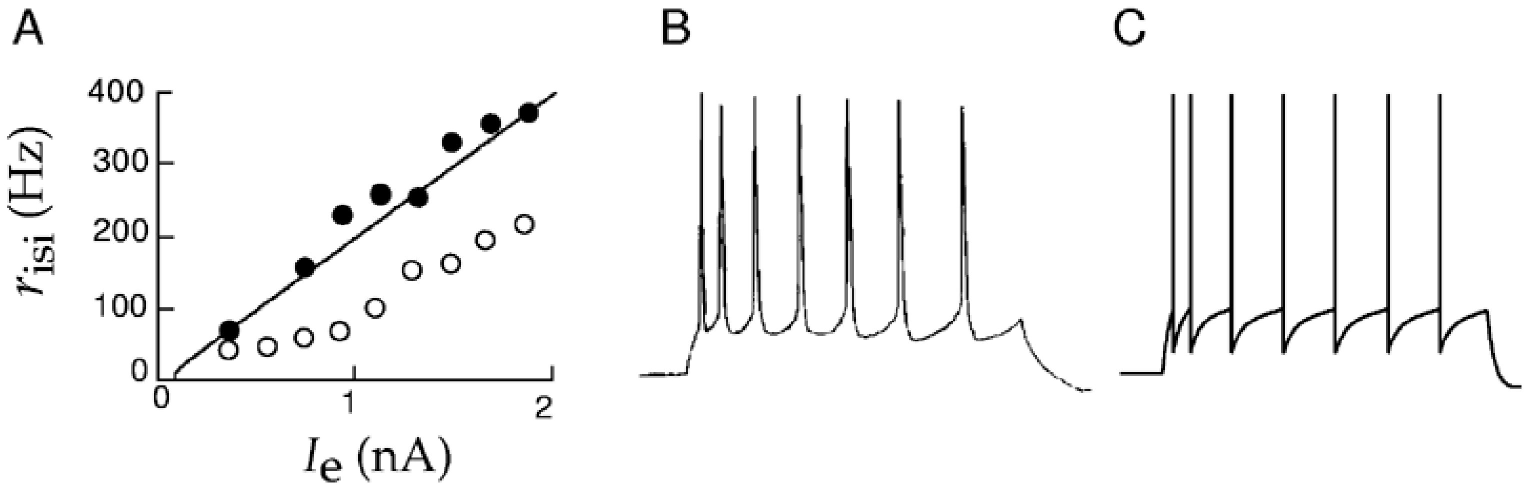
05_leakyMembrane.psd

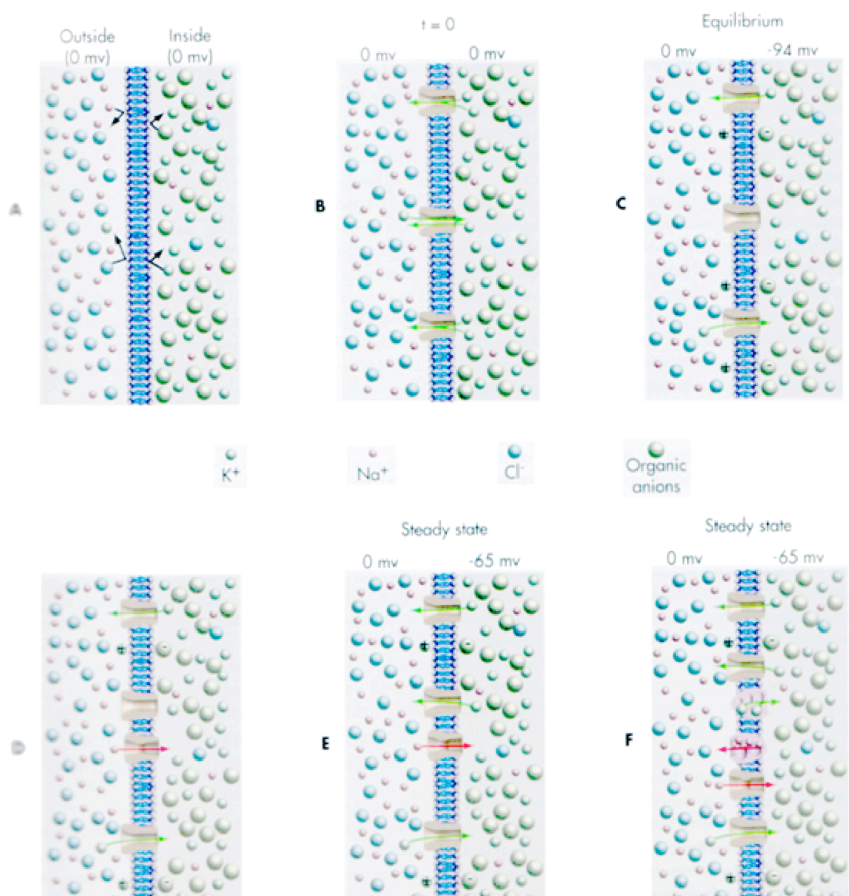


E.M. Izhikevich, Neural Excitability, Spiking, and Bursting
Int. J. Bifurcation and Chaos (2000), 10:1171--1266.

06_typesElectric.psd



07_ch5fig6.png



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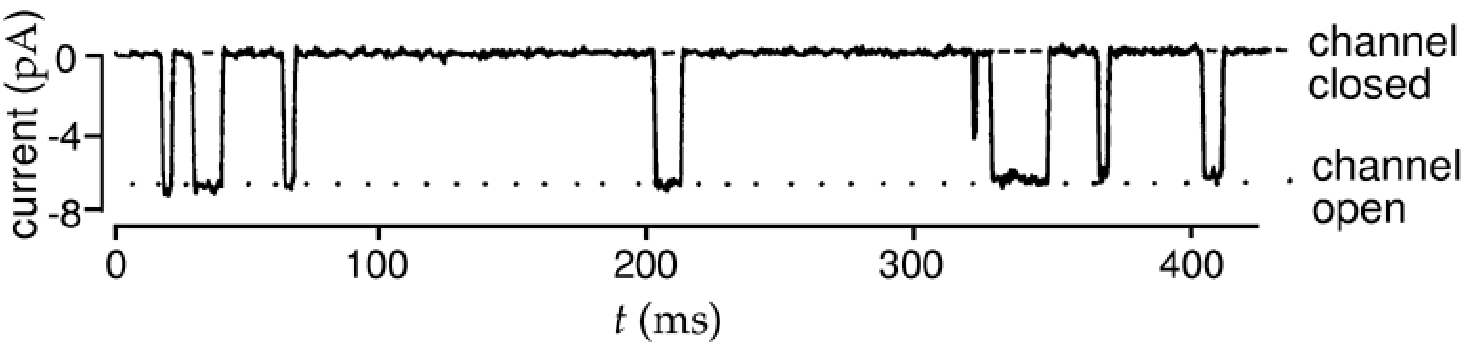
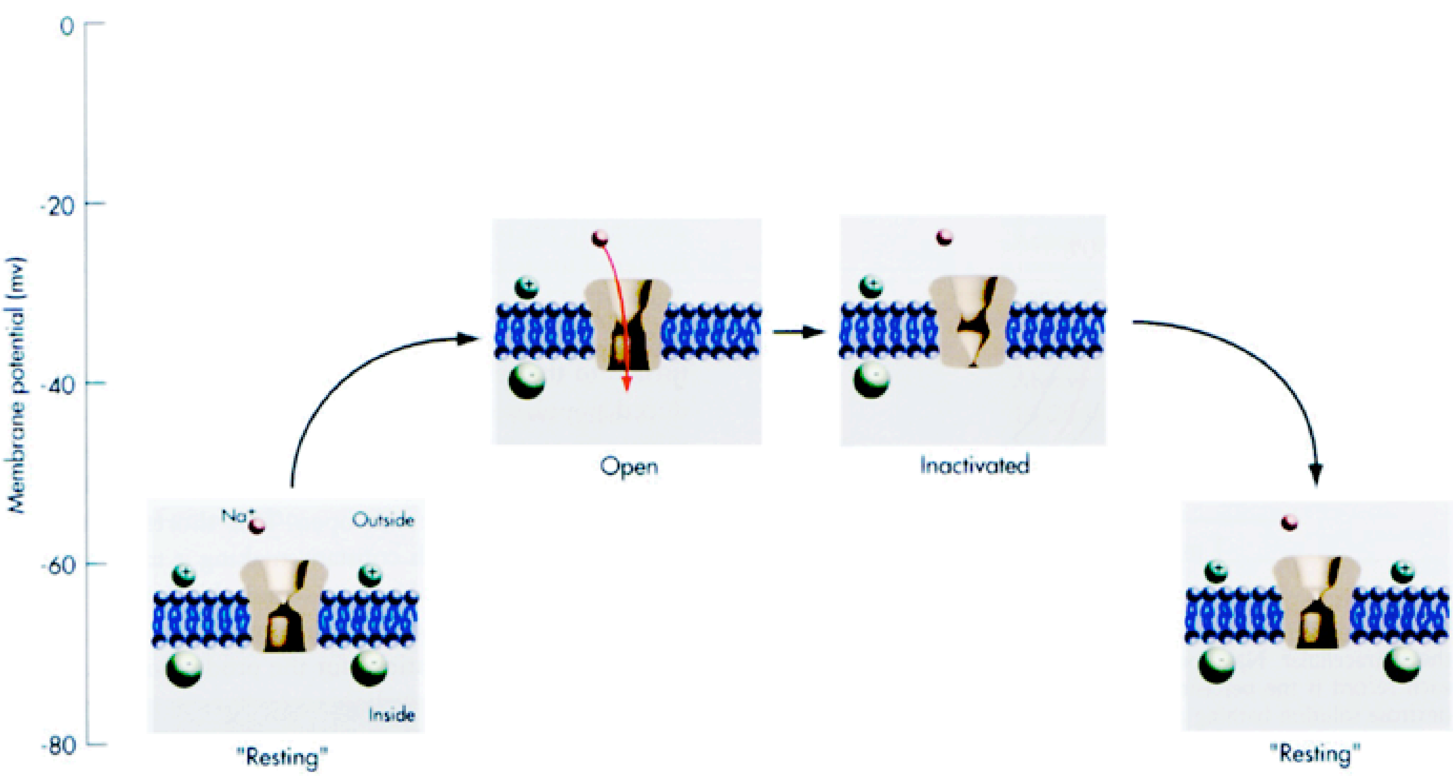
08_memPot.psd



09_ch5fig7.png



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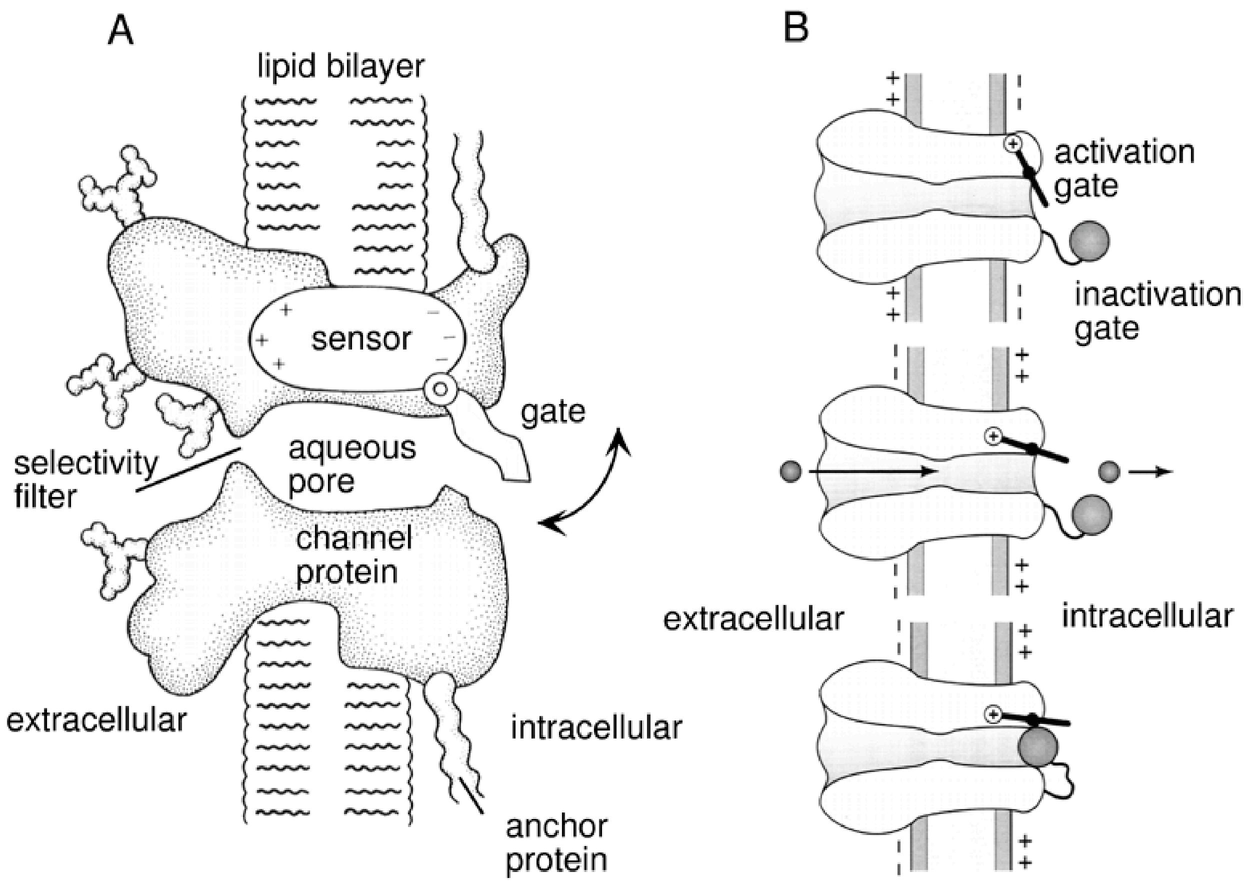
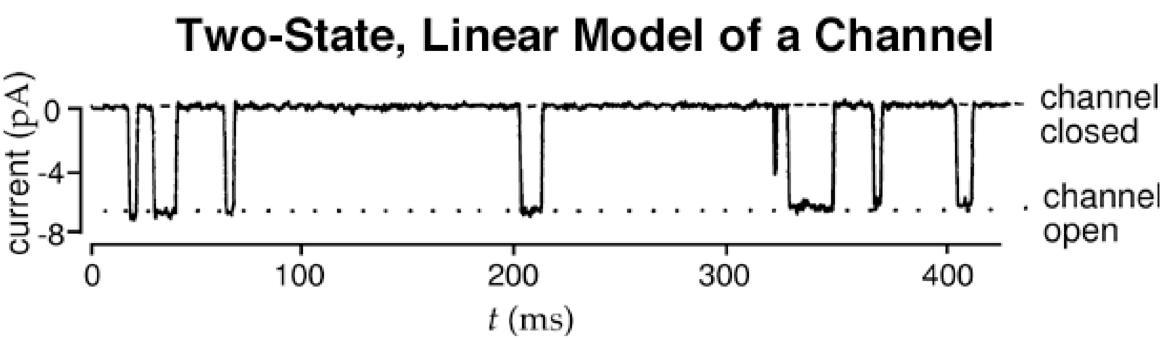
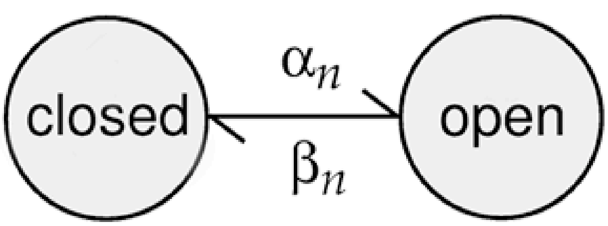
10_channelStates.psd



11_ch5fig8.png

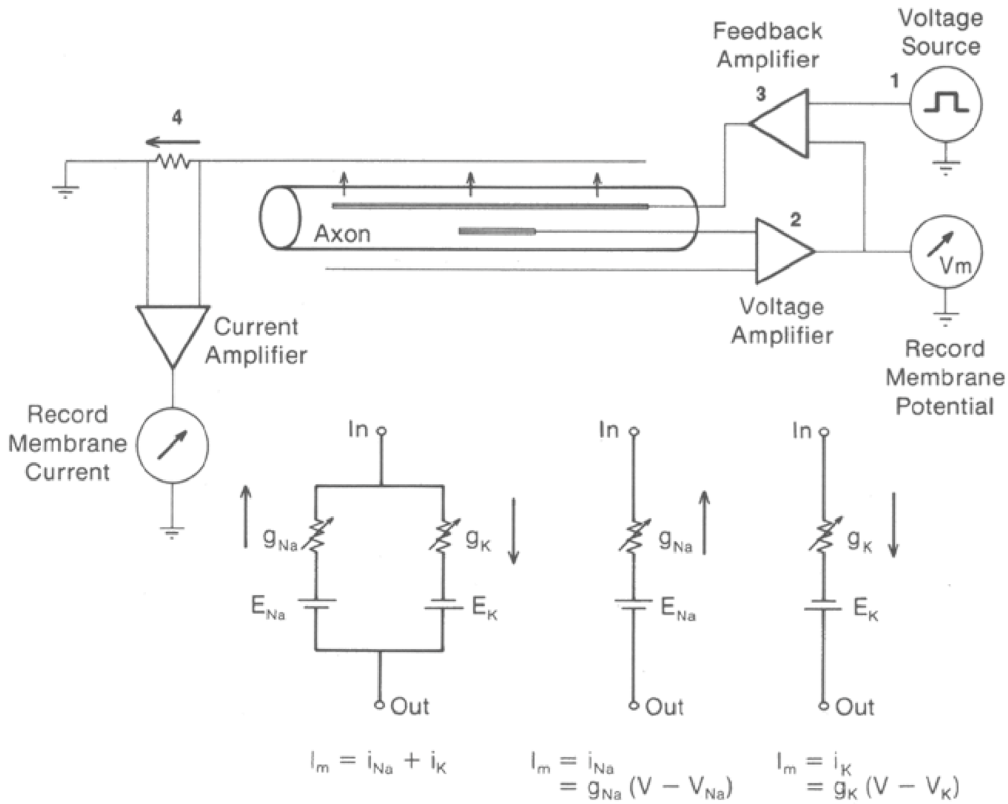




$$\frac{dn}{dt} = \alpha_n(V)(1-n) - \beta_n(V)n$$

12_channelModel.psd

Hodgkin-Huxley Experiment (1952)



Neurobiology (1988) Gordon M. Shepard

14_Shepard88ed2Fig6_5.psd

Hodgkin-Huxley Circuit

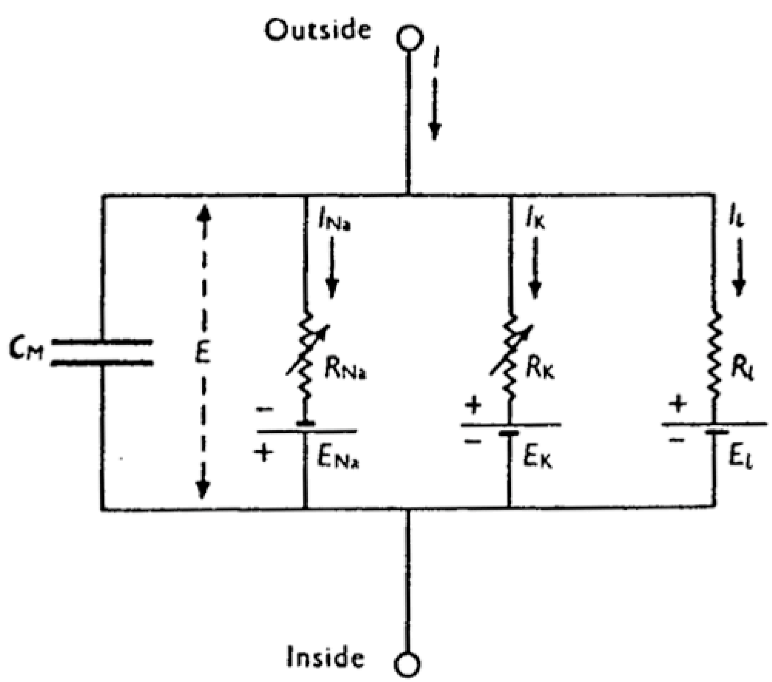
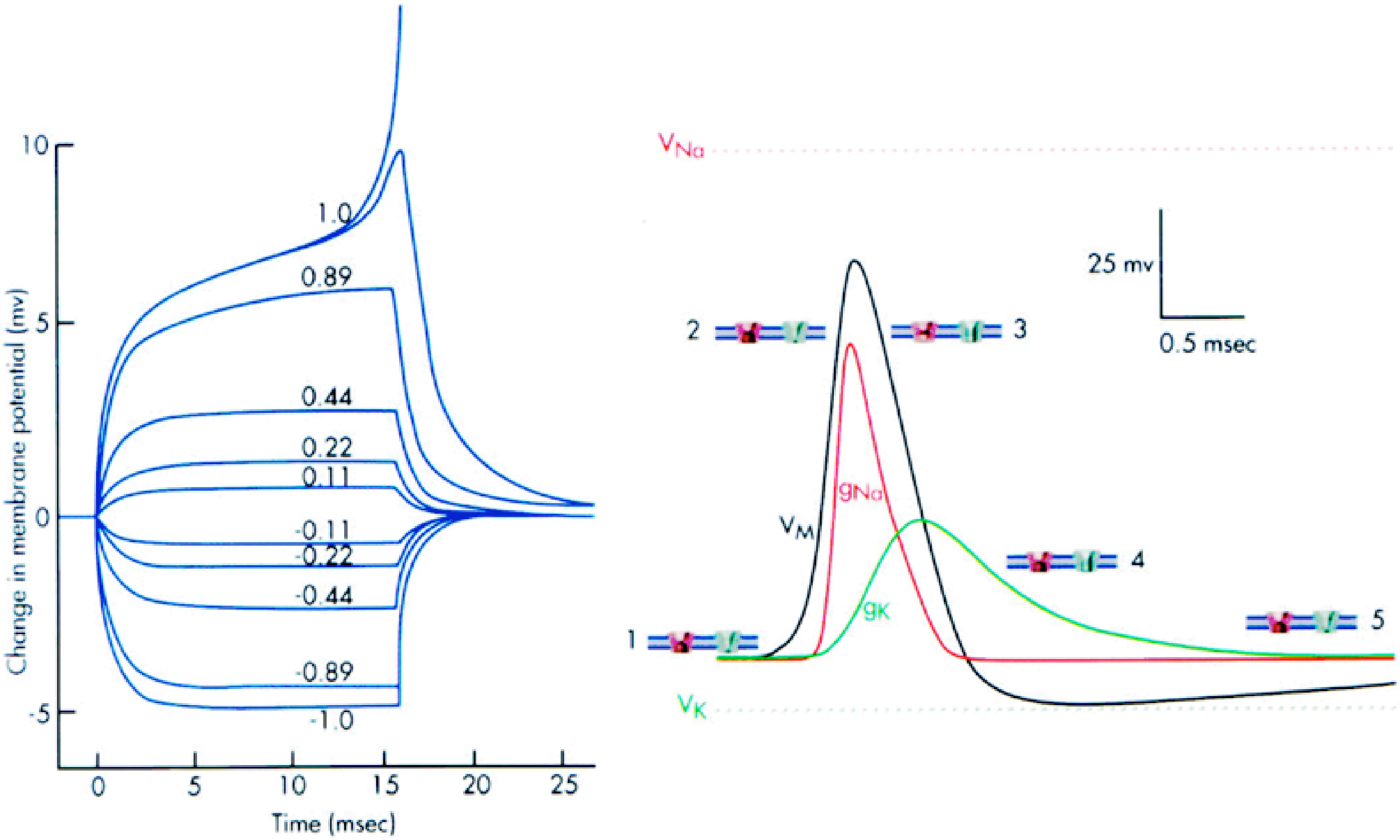


Fig. 1. Electrical circuit representing membrane. $R_{Na} = 1/g_{Na}$; $R_K = 1/g_K$; $R_l = 1/\bar{g}_l$. R_{Na} and R_K vary with time and membrane potential; the other components are constant.

Hodgkin, A. L. and Huxley, A. F. (1952) "A Quantitative Description of Membrane Current and its Application to Conduction and Excitation in Nerve" J. Physiology 117: 500-544

14b_Hodgkin52Fig1.psd



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15_HodgkinHuxley.psd

Hodgkin-Huxley Equation

$$C\,\frac{dV}{dt} \;=\; \overbrace{I}^{\text{injected current}} - \overbrace{\bar{g}_{Na} m^3 h (V - V_{Na})}^{\text{sodium current}} - \overbrace{\bar{g}_K n^4 (V - V_K)}^{\text{potassium current}} - \overbrace{g_L (V - V_L)}^{\text{leak current}}$$

$$\frac{dm}{dt} \;=\; \alpha_m(V)(1-m) - \beta_m(V)m \qquad\qquad \frac{dh}{dt} \;=\; \alpha_h(V)(1-h) - \beta_h(V)h$$

$$\frac{dn}{dt} \;=\; \alpha_n(V)(1-n) - \beta_n(V)n$$

16_hhEq.psd

Hodgkin-Huxley Equation II

membrane currents

injected current

$$C\frac{dV}{dt} = \sum_a g_a(V - E_a) + I_{ex}$$

$$g_a = \overline{g}_a x_a^{n_a} y_a, \text{ and } \quad \frac{dx_a}{dt} = \frac{1}{\tau_{x_a}}(x_a^{\infty} - x_a)$$

$$x_a^{\infty} = \alpha_{x_a}/(\alpha_{x_a} + \beta_{x_a}) \text{ and } \tau_{x_a} = 1/(\alpha_{x_a} + \beta_{x_a})$$

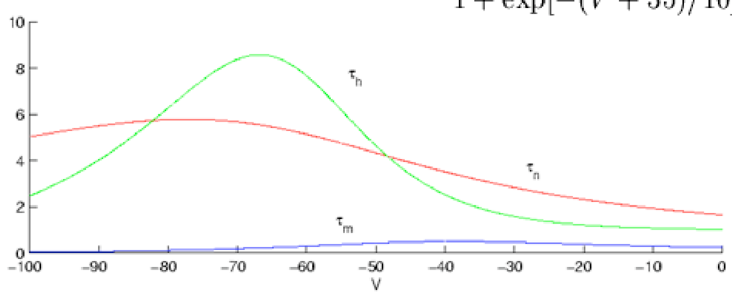
17_hhEq2.psd

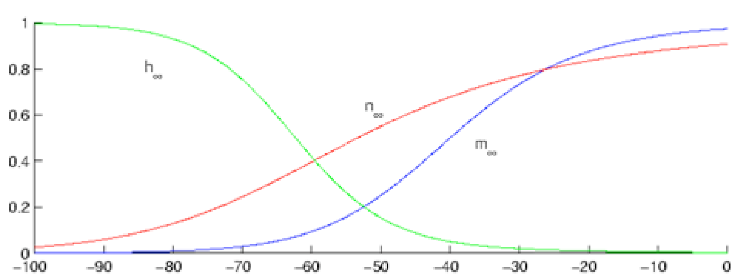
Hodgkin-Huxley Rate “Constants”

$$\alpha_n(V) = \frac{0.01(V+55)}{1-\exp[-(V+55)/10]}, \qquad \beta_n(V) = 0.125\exp[-(V+65)/80],$$

$$\alpha_m(V) = \frac{0.1(V+40)}{1-\exp[-(V+40)/10]}, \qquad \beta_m(V) = 4\exp[-(V+65)/18],$$

$$\alpha_h(V) = 0.07\exp[-(V+65)/20], \qquad \beta_h(V) = \frac{1}{1+\exp[-(V+35)/10]}.$$

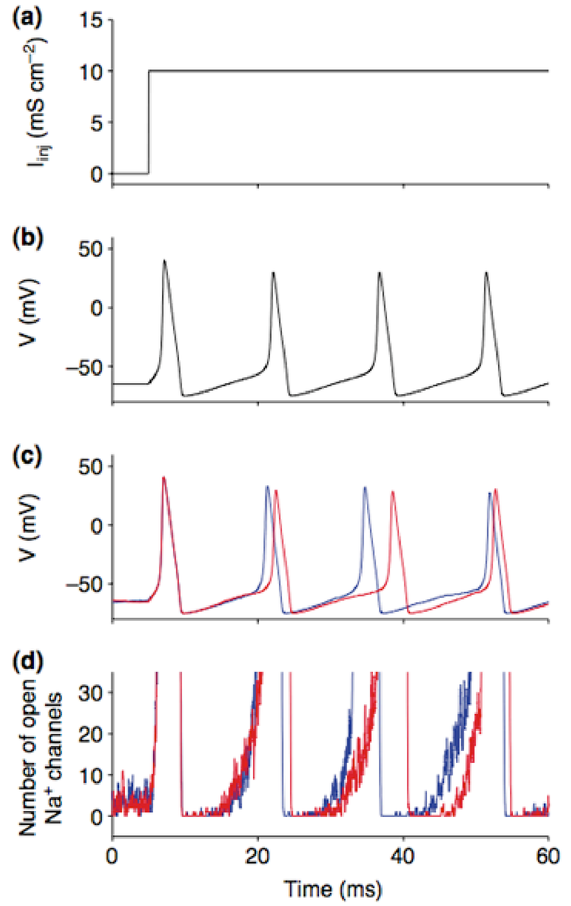




18_rateConsts.psd

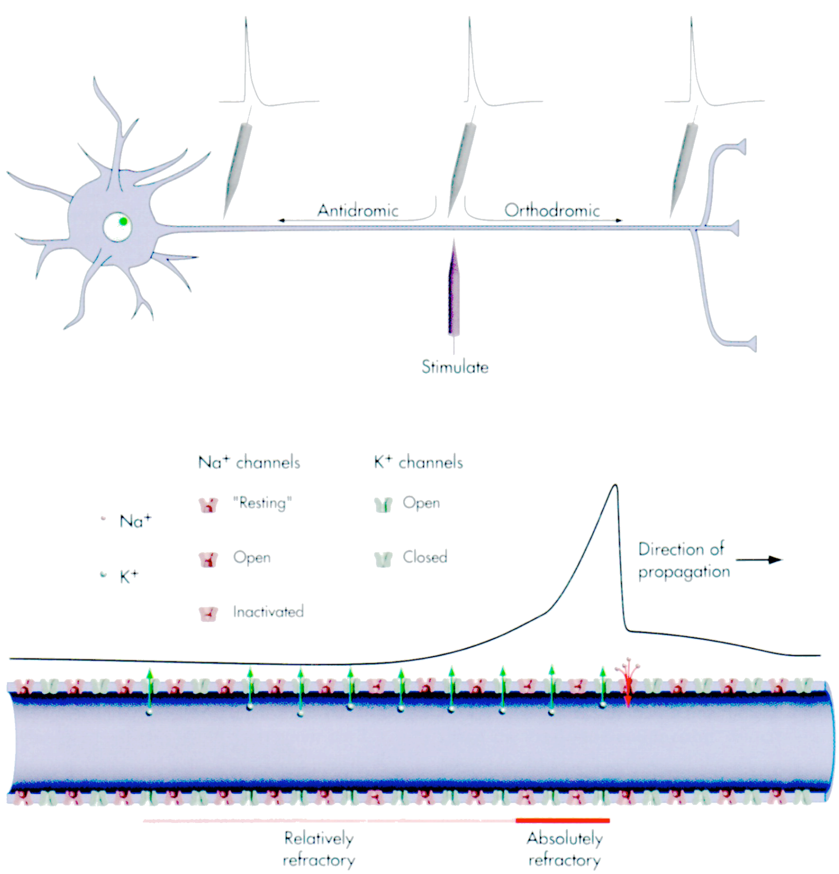
Channel Noise Introduces Jitter into the Spike Response

Deterministic versus stochastic models. The behavior of a Hodgkin–Huxley model of an excitable membrane patch of 600 µm2with 10800 K-channels and 36000 Na-channels is compared to the behavior of a corresponding microscopic model.



Meunier and Segev (2002) "Playing the devil's advocate: is the Hodgkin-Huxley model useful?" Trends Neurosci 25:558-563

19_channelNoise.psd



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20_axonProp.psd

Hodgkin-Huxley Equation

$$\frac{1}{r_a}\frac{\partial^2 V}{\partial x^2} + C\,\frac{dV}{dt} \quad = \quad \overset{\text{injected current}}{I} - \overset{\text{sodium current}}{\bar{g}_{Na} m^3 h (V - V_{Na})} - \overset{\text{potassium current}}{\bar{g}_K n^4 (V - V_K)} - \overset{\text{leak current}}{g_L (V - V_L)}$$

$$\frac{dm}{dt} \quad = \quad \alpha_m(V)(1-m) - \beta_m(V)m \qquad\qquad \frac{dh}{dt} \quad = \quad \alpha_h(V)(1-h) - \beta_h(V)h$$

$$\frac{dn}{dt} \quad = \quad \alpha_n(V)(1-n) - \beta_n(V)n$$

21_hh_eq_space.psd