Hodgkin-Huxley model of action potential generation

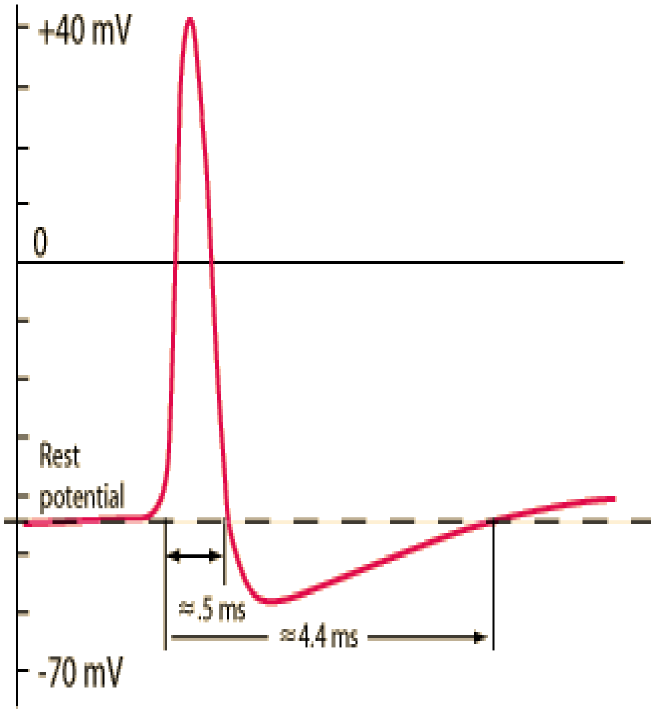
Lecture 5.

http://www.swarthmore.edu/NatSci/echeeve1/Ref/HH/index.htm

Historical background I.

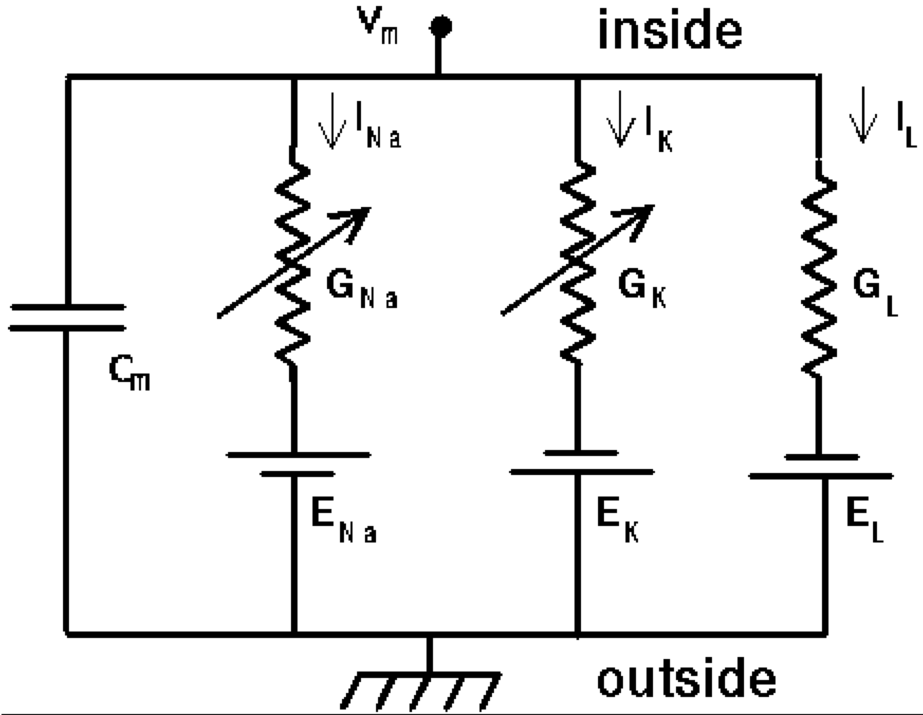
- 1902: J. Bernstein proposes a theory of how neurons communicate based on changes in potassium ions. Membrane permeability is thought to change during activity.
- 1930: Cole and Curtis show that during excitation the membrane resistance and membrane capacity decreases suggesting an overall change in membrane potential (but not membrane structure). First to observe membrane potential.

Historical background II



- Hodgkin and Huxley (and Katz) begin their work in 1939 on squid axons: overshoot at the peak is likely due to sodium ions
- 1949: reduction of external Na+ concentration reduces overshoot
- 1952: series of 5 papers that explore action potential generation (final paper: mathematical model)
- 1963:Nobel prize in physiology

Cells as circuits



When the membrane is depolarized, sodium conductance increases rapidly while potassium conductance also increases, although slower and in a more sustained fashion

Conductances

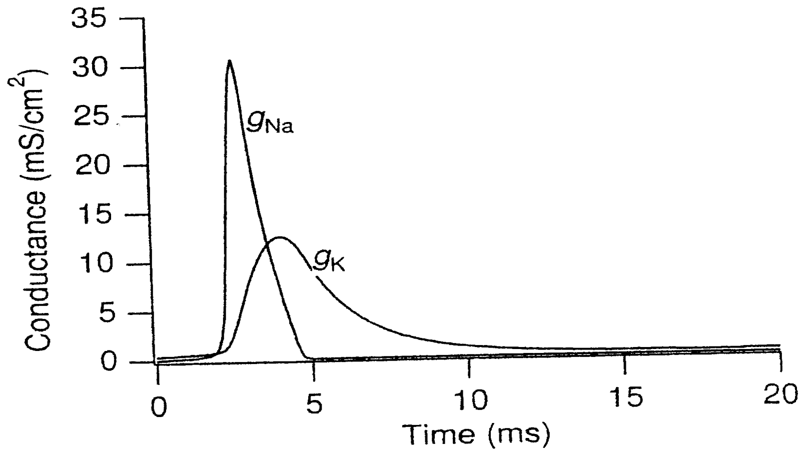


Figure 4.9 Conductances g_{Na} and g_K during an action potential.

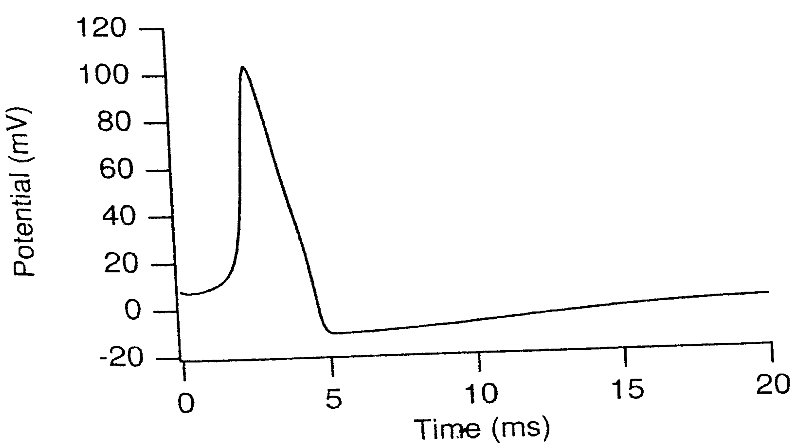
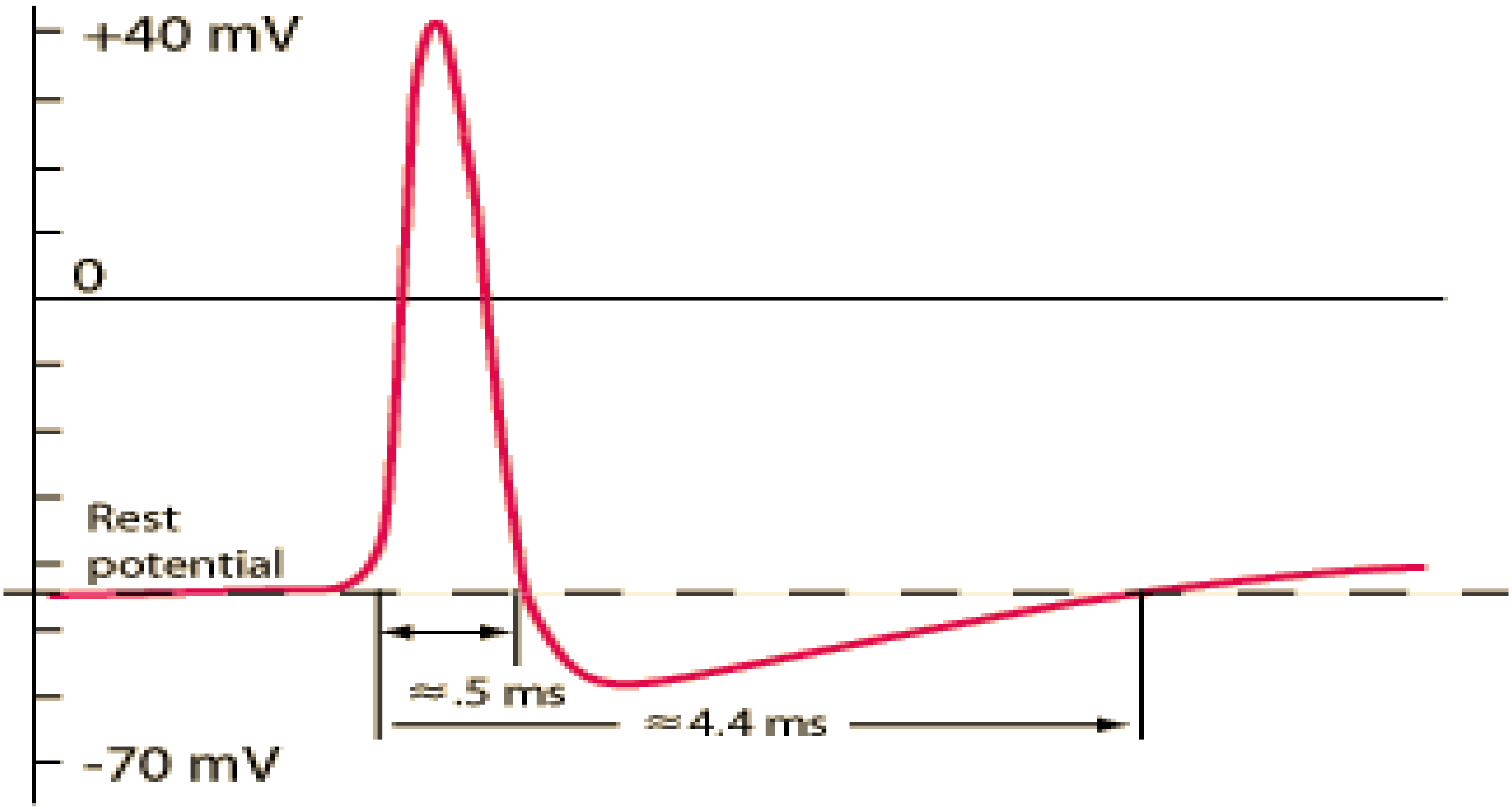


Figure 4.7 Action potential of the Hodgkin–Huxley equations.

Action potential generation (in words)



Action potential generation (in equations)

$$\frac{dv}{dt}=\frac{-1}{C}\left[g_{Na}m^{3}(v)h(v)(v-v_{Na})+g_{K}n^{4}(v)(v-v_{K})+g_{L}(v-v_{L})\right]$$

$$\frac{dn}{dt}=\frac{0.01(10-v)}{e^{(10-v)/10}-1}(1-n)-0.125e^{-v/80}n$$

$$\frac{dh}{dt}=0.07e^{-v/20}(1-h)-\frac{1}{e^{(30-v)/10}+1}h$$

$$\frac{dm}{dt}=\frac{0.1(25-v)}{e^{(25-v)/10}-1}(1-m)-4e^{-v/18}m$$

Gating variables in the HH model

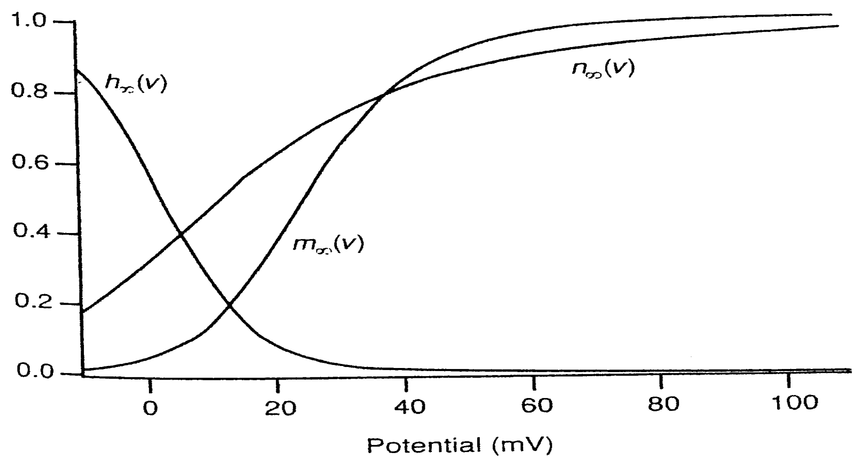


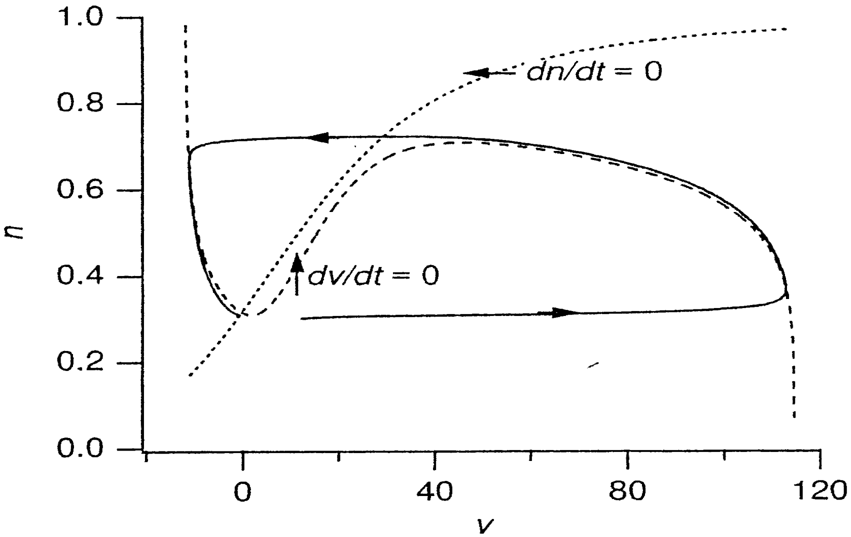
Figure 4.5 Steady-state functions m_∞ $n_\infty(v)$ and $h_\infty(v)$.

A reduction of the model

$$\frac{dv}{dt} = \frac{-1}{C} g_K n^4 (v - v_K) - g_{Na} m_{inf}^3(v)(0.8 - n)(v - v_{Na}) - g_L (v - v_L)$$

$$\frac{dn}{dt} = \frac{0.01(10 - v)}{e^{(10-v)/10} - 1}(1 - n) - 0.125\, e^{-v/80} n$$

Phase-plane diagram of (reduced) Hodgkin-Huxley model



Using pplane to look at simplification of HH model