Bioelectricity/ biopotentials II

- Malmivuo, Plonsey (MP)
  - Ch 2: Nerve and muscle cells
  - Ch 3: Subthreshold membrane phenomena
  - Ch 4: Active behavior of the membrane (4.1-4.4)
  - Ch 5: Synapse (5.1-5.3)

The action potential

- The resting state of the cell can be altered by chemical, electrical or mechanical stimulation.
- The stimulation causes a rapid increase in $\text{Na}^+$ conductance and a delayed increase in the $\text{K}^+$ conductance.
- The membrane potential increases from its resting value of about $-90 \text{ mV}$ towards the Nernst potential for $\text{Na}^+$ ($+60 \text{ mV}$). When the $\text{K}^+$ conductance increases the potential decreases towards the resting potential.
The Hodgkin-Huxley cell membrane model

- General cable equation for cell membrane
- Voltage clamping experiments
- Kinetics of ion conductances
The cable equation:

\[
\frac{1}{r_i + r_e} \frac{\partial^2 V}{\partial x^2} = I_m = c_m \frac{\partial V}{\partial t} + I_{ion}
\]

\(I_{ion}\) can be obtained from a HH model of the cell membrane.
• If the conductances are constant, the cable equation is linear.
• In general, the conductances are a function of $V$ and time.

$$
\frac{1}{r_i + r_e} \frac{\partial^2 V}{\partial x^2} = c_m \frac{\partial V}{\partial t} + g_K (V, t)(V - E_K) + g_{Na}(V, t)(V - E_{Na}) + g_L (V - E_L)
$$

• Ionic current composition?

Squid giant axon potential when diluting Na+ with isotonic dextrose.
A. 33% sea water (curve 2)
B. 50% sea water (curve 2)
**Fig. 4.4.** Realistic voltage clamp measurement circuit. Current is applied through electrodes (a) and (e), while the transmembrane voltage, $V_m$, is measured with electrodes (b) and (c). The current source is controlled to maintain the membrane voltage at some preselected value $V_c$. 
Kinetics of Na$^+$ and K$^+$ conductances

Model for Na/ K conductance

- $g_{Na} = m^3 h G_{Na}$
- $G_{Na}$ = maximal conductance
- $m$ = probability for open Na-activation gate
- $h$ = probability for open Na-inactivation gate
- $g_{K} = n^4 G_{K}$
- $n$ = probability for opening a K-gate
HH model of voltage clamped axon

- General cable eq:

\[
\frac{1}{r_i + r_e} \frac{\partial^2 V}{\partial x^2} = c_m \frac{\partial V}{\partial t} + I_{ion}
\]

\[
\frac{\partial V}{\partial x} = 0, \text{ gives } 0 = c_m \frac{\partial V}{\partial t} + I_K + I_{Na} + I_L
\]

- Differential equation for m:

\[
0 = c_m \frac{dV}{dt} + G_K n^4 (V_m - E_K) + G_{Na} m^3 h (V_m - E_{Na}) + G_L (V_m - V_L)
\]

\[
\frac{dm}{dt} = \alpha_m (1 - m) - \beta_m m,
\]

\[
\alpha_m = 0.1(V + 25) / (e^{0.1V+2.5} - 1),
\]

\[
\beta_m = 4e^{V/18}
\]

- Full set of equations are given in the guidelines for the simulations
A constant current of 50 uA/cm$^2$

Subthreshold stimulus
Stimulus just above threshold

Stronger stimulus
Comparison