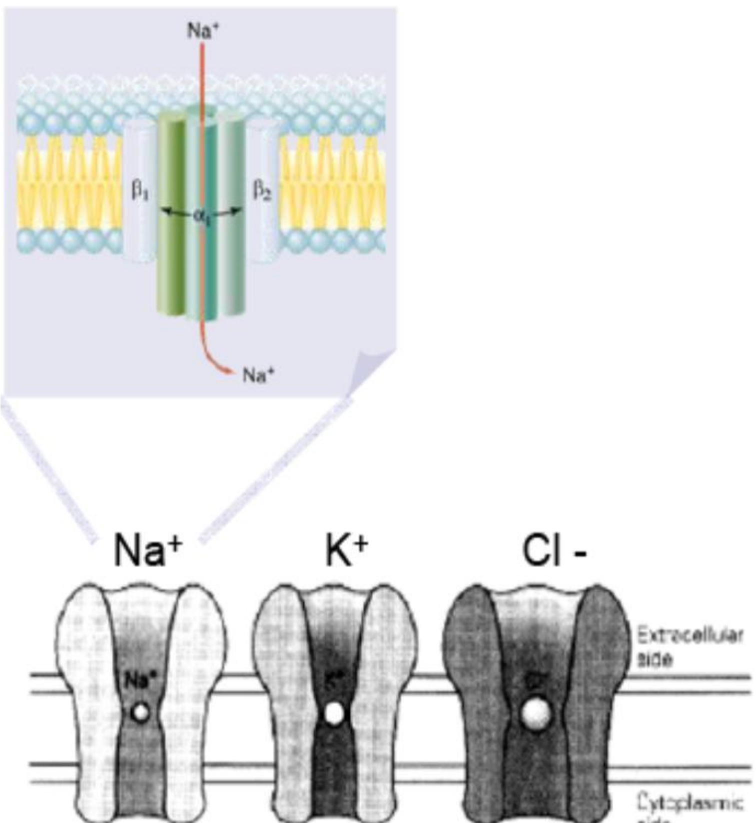
Neuroprothetik

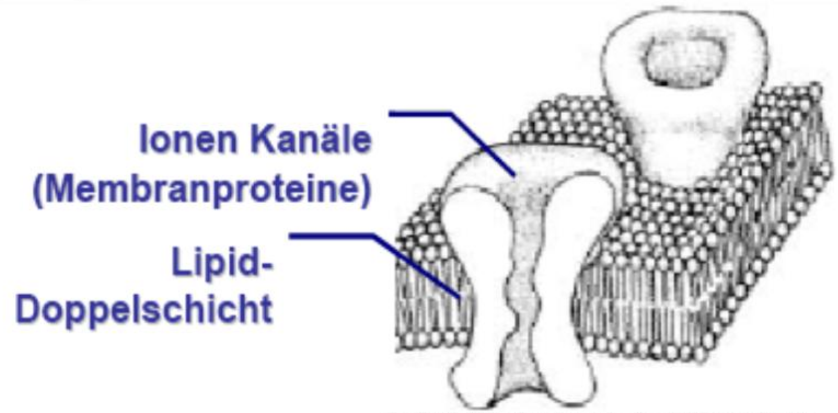
1) Vorstellung Neuroprothesen
2) Einführung in die Biologie
3) Das Membranpotential
4) Spannungsgesteuerte Ionenkanäle
5) **Die Hodgkin-Huxley-Gleichungen**
6) **Elektrische Stimulation von Neuronen**

Lernziele:

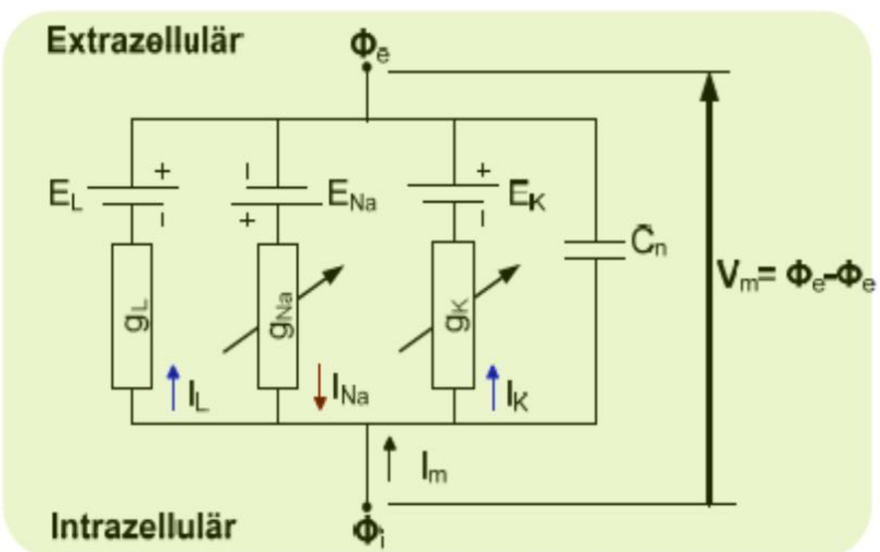
- **Hodgkin-Huxley-Gleichungen**
- **Stimulation im externen elektrischen Feld?**

Ionenkanäle: Spannungsgesteuerter Natriumkanal

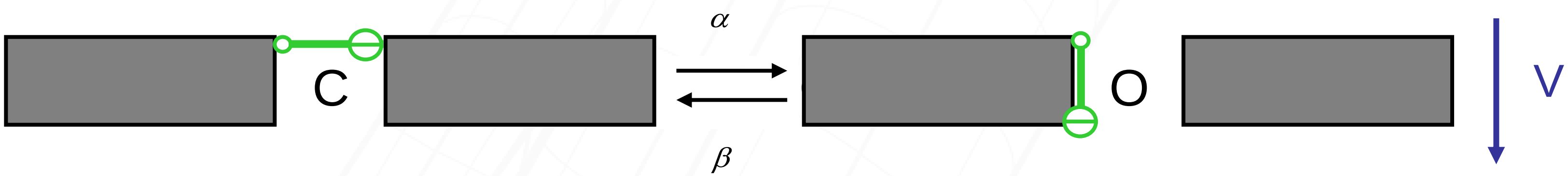




Quelle: B. Hille, Ion channels of excitable membranes, -3rd ed., Sinauer, Sunderland, 2001



Voltage Activated Ion Channels: fitting α and β



$$\alpha = A_\alpha \exp\left(-qB_\alpha / kT\right) = A_\alpha \exp\left(-B_\alpha V / V_T\right)$$

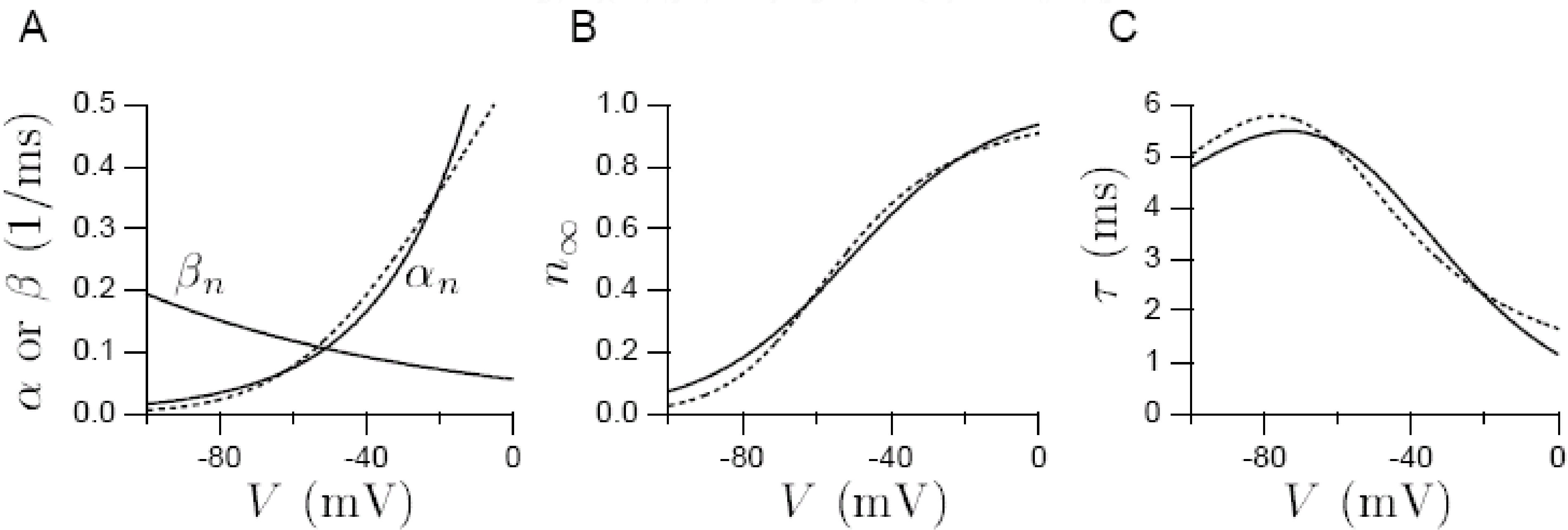
$$\beta = A_\beta \exp\left(-qB_\beta / kT\right) = A_\beta \exp\left(-B_\beta V / V_T\right)$$

$$\alpha = \frac{V + 55\ \mathrm{mV}}{\left(1 - \mathrm{e}^{-(V + 55\ \mathrm{mV})/10\ \mathrm{mV}}\right) 100\ \mathrm{s}}$$

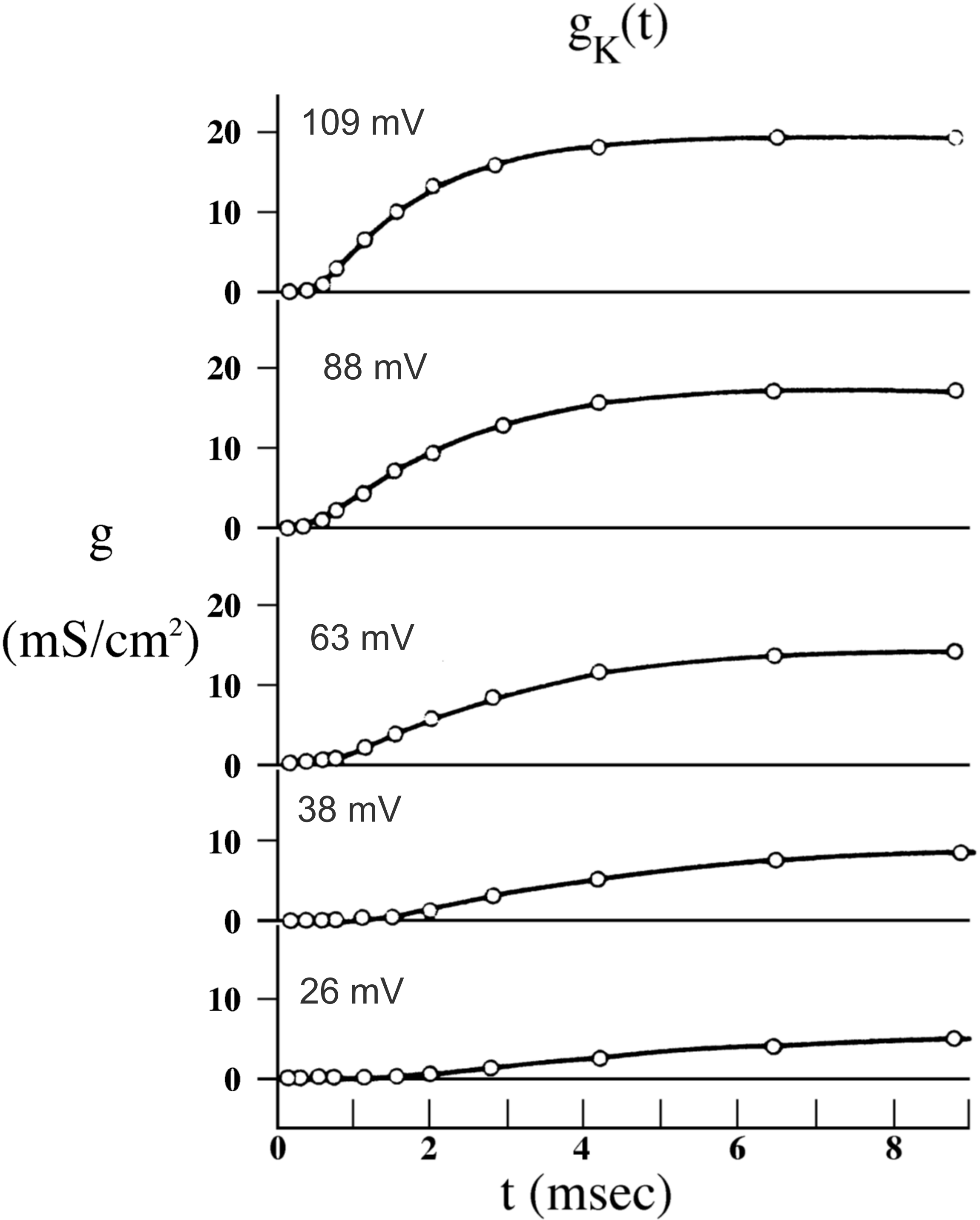
$$\beta = \frac{\mathrm{e}^{-(V + 65\ \mathrm{mV})/80\ \mathrm{mV}}}{8\ \mathrm{s}}$$

Hodgkin and Huxley (1952)
for delayed rectifier K^+ conductance

Voltage Activated Ion Channels



Generic voltage-dependent gating functions compared with Hodgkin-Huxley results for the delayed-rectifier K^+ conductance. A) The exponential α_n and β_n functions expected from thermodynamic arguments are indicated by the solid curves. Parameter values used were A_α=1.22ms−1, A_β=0.056 ms−1, B_α/VT = −0.04/mV, and B_β/VT = 0.0125/mV. The fit of Hodgkin and Huxley for β_n is identical to the solid curve shown. The Hodgkin-Huxley fit for α_n is the dashed curve. B) The corresponding function $n_\infty(V)$ of equation 5.21 (solid curve). The dashed curve is obtained using the α_n and β_n functions of the Hodgkin-Huxley fit (equation 5.22). C) The corresponding function $\tau_n(V)$ obtained from equation 5.18 (solid curve). Again the dashed curve is the result of using the Hodgkin-Huxley rate functions.

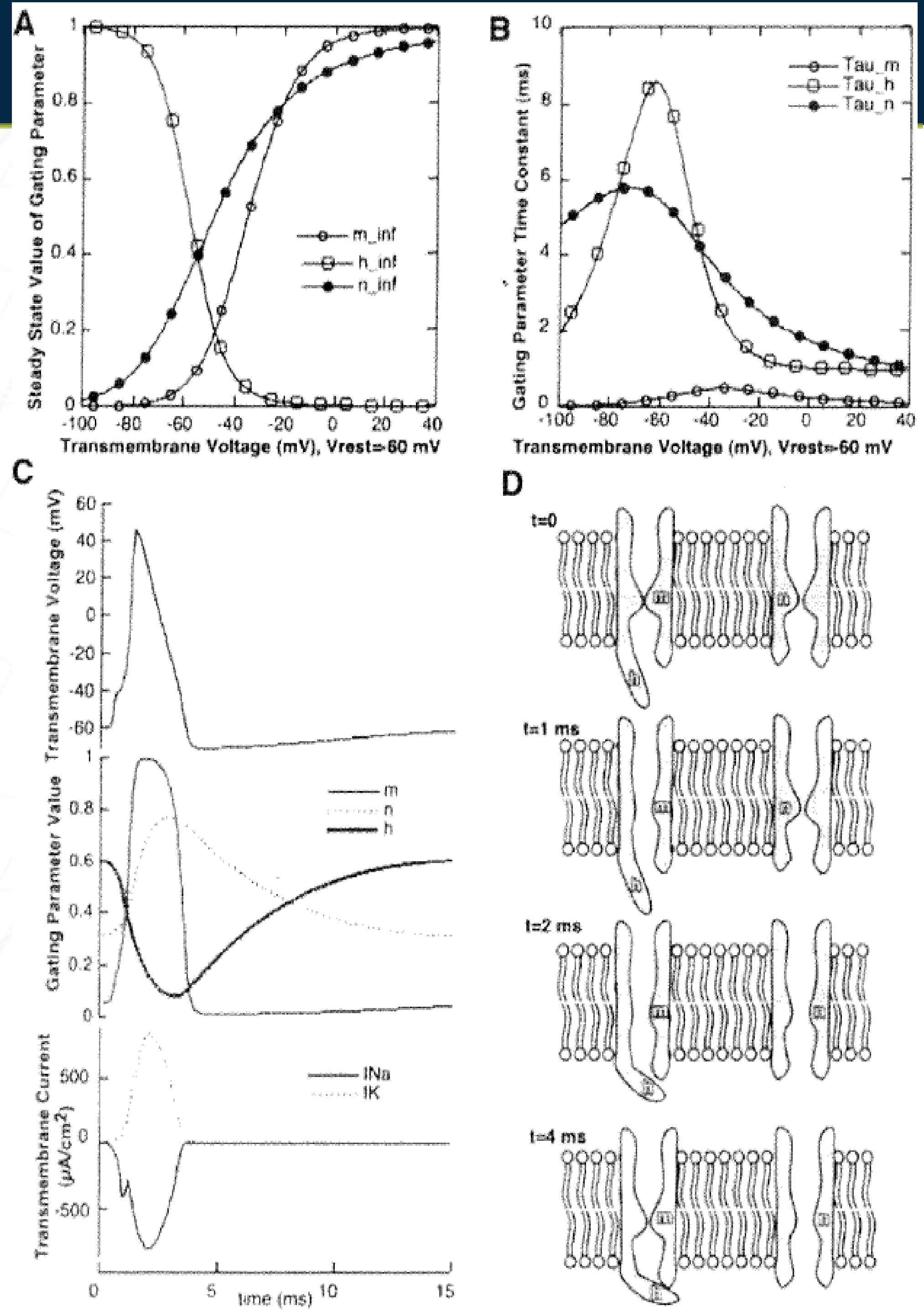


K conductance during a voltage step

The experimentally recorded circles and the theoretically calculated smooth curves changes in G_K in the squid giant axon at 6.3ºC during depolarizing voltage steps away the resting potential which is here set to zero.

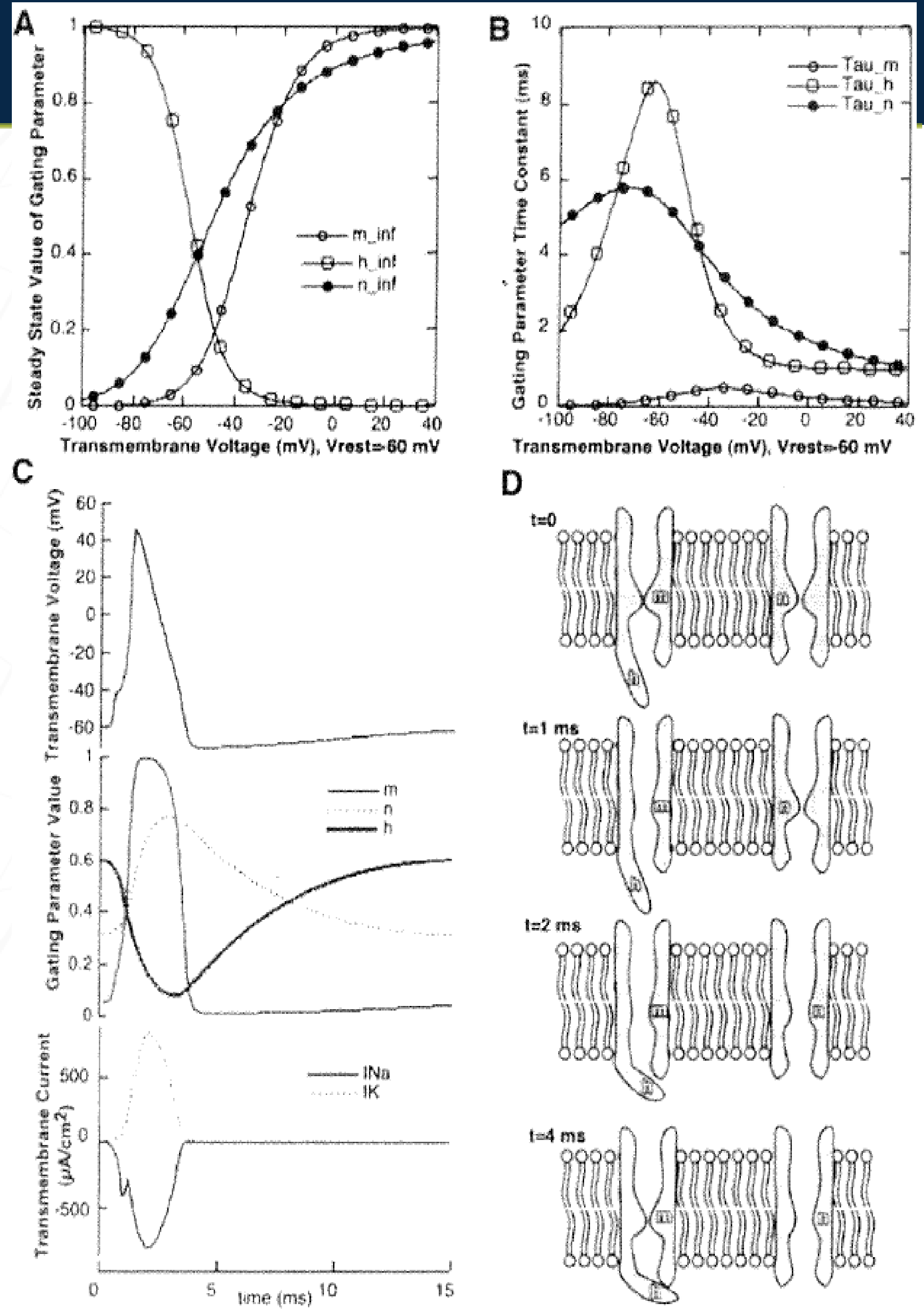
From Hodgkin (1958)

Hodgkin-Huxley model of a nerve membrane patch.



Bio-Inspired Information Processing

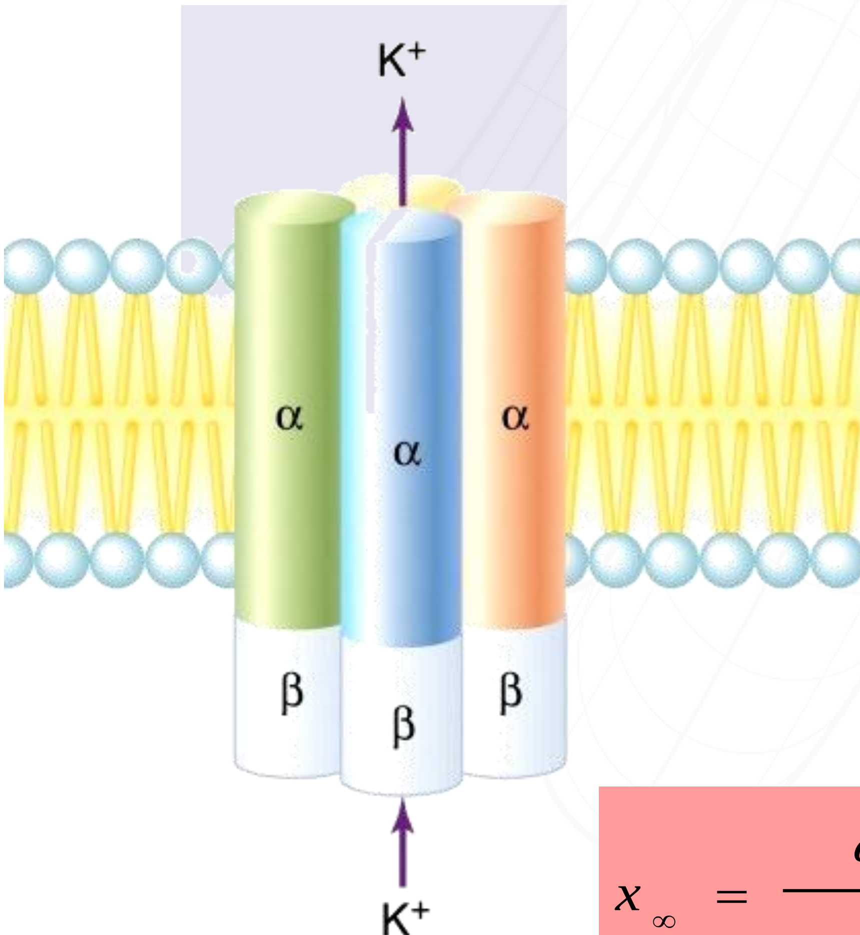
Hodgkin-Huxley model of a nerve membrane patch.



http://www.youtube.com/watch?feature=player_detailpage&v=Iiiz5CpFCQo

http://www.youtube.com/watch?v=iDgKqJbdiDk http://www.youtube.com/watch?v=Iiiz5CpFCQo

Ionenkanäle: Der spannungsgesteuerte Kaliumkanal

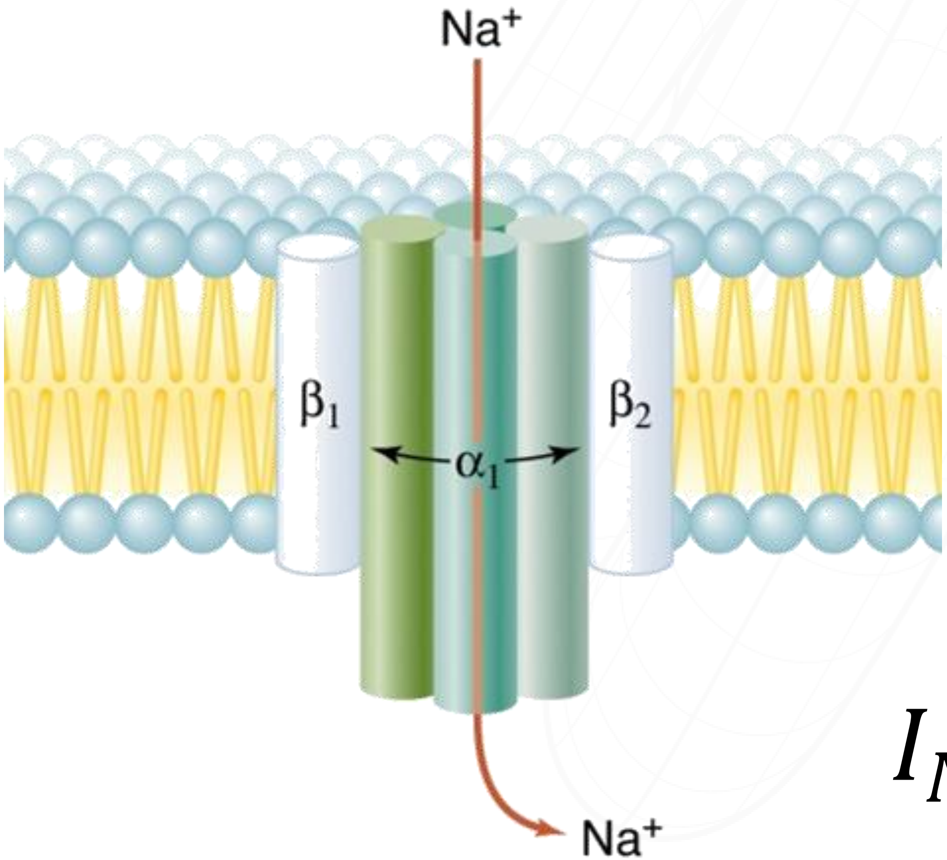


$$g_K = \hat{g}_K\, n^4$$

$$I_K = g_K (V_m - E_K)$$

$$x_\infty = \frac{\alpha}{\alpha + \beta} \Leftrightarrow x_\infty = \frac{1}{1 + {}^{B}\!/\!{}_{A}\, e^{(E_O - E_C)/kT}}$$

Ionenkanäle: Spannungsgesteuerter Natriumkanal



$$g_{Na} = \hat{g}_{Na}\, m^3 h$$

$$I_{Na} = g_{Na}(V_m - E_{Na})$$

Neuroprothetik

Wiederholung: Numerische Verfahren

1) Stabilität numerischer Verfahren (A-Stabilität)

$$\frac{dy(t)}{dt} = \lambda y(t)$$

2) Genauigkeit der Lösung

3) Plausibilität der Lösung

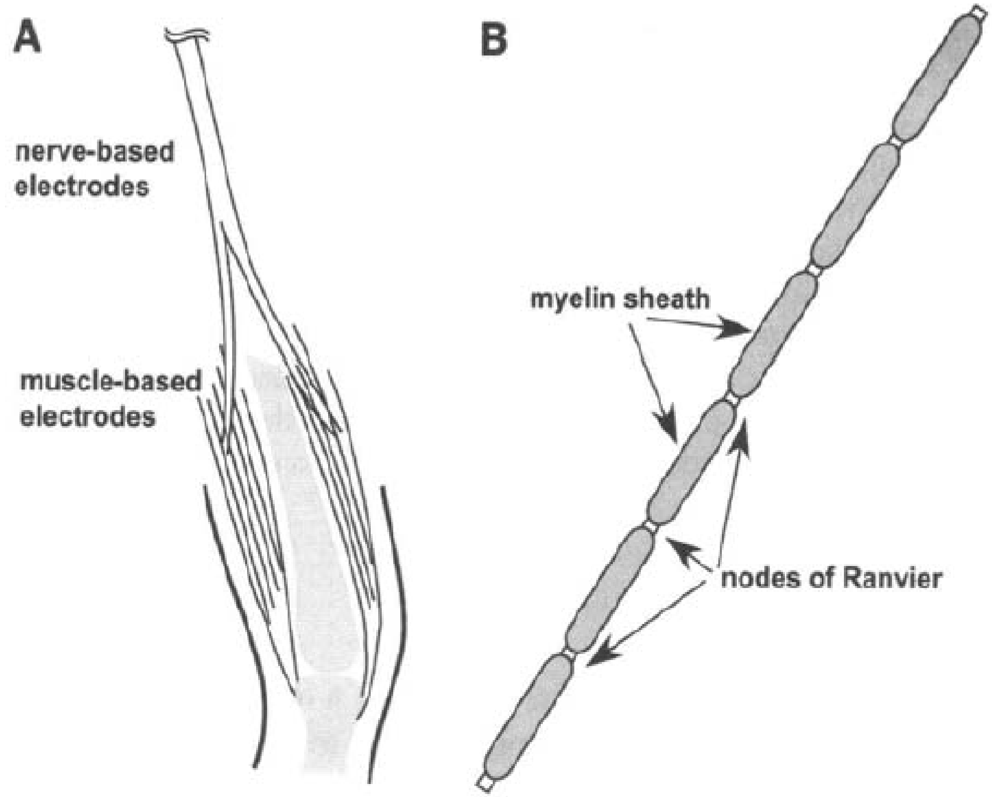
$$\frac{dm}{dt} = \frac{1}{\tau}(m_\infty - m)$$

4) Numerische Realisation
(fixed-point Arithmetik, Zahlenüberlauf, Rundung)

Agenda

1. Einführung Neuroprothetik
2. Biophysikalische und physiologische Grundlagen
3. Das Membranpotential
4. Ionenkanäle
5. Das Aktionspotential
6. Extrazelluläre elektrische Stimulation eines Neurons
7. Kabelgleichung und Aktivierungsfunktion
8. Das Hörorgan
9. Neuronale Verarbeitung entlang der Hörbahn
10. Aufbau eines Cochleaimplantats
11. Elektrochemie und Biokompatibilität
12. Prüfungsvorbereitung

Electrical stimulation of peripheral nerve fibers

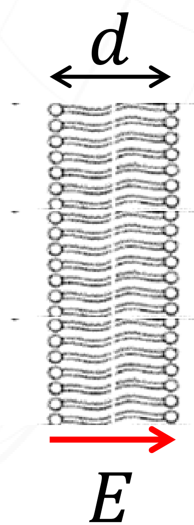


(A) Electrodes for stimulation of peripheral nerve fibers may be placed in or on the skeletal muscle (muscle-based electrodes) or in, on, or around the peripheral nerve trunk (nerve-based electrodes). Note that muscle-based electrodes do not activate the muscle directly, but stimulate the terminal nerve fibers that, in tum, activate the muscle. (B) The basic structure of a myelinated nerve fiber consists of a tube of membrane, surrounded over most of its area by the myelin sheath. The myelin sheath is interrupted at regular intervals by exposed sections of membrane called nodes of Ranvier.

Membrane in electric field

Consider a cell membrane high resistivity with a membrane potential V_m. The membrane potential is proportional to E across the membrane and the thickness d of the membrane.

$$V_m = -Ed$$



$d \approx 7.5 \ldots 10$ nm

Hine, Robert. "Membrane." The Facts on File Dictionary of Biology. 3rd ed. New York: Checkmark, 1999: 198.

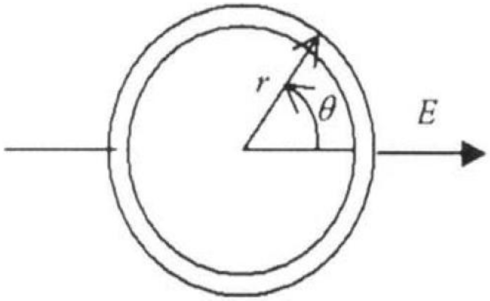
Fig. 5: Electric field E across cell membrane with thickness d.

Cylindrical axon in electric field

Consider a simplified axon with a membrane having a very high resistivity and a plasma with high conductivity in a highly conductive extracellular medium. If the axon is running perpendicular to a homogeneous external electric field, *E*, one side of the membrane will become depolarized and the other hyperpolarized with membrane potential:

$$V_m = -Er\cos\theta$$

where *r* is the axon's radius and θ is the angle with the field axis as shown in Fig. 6 below.



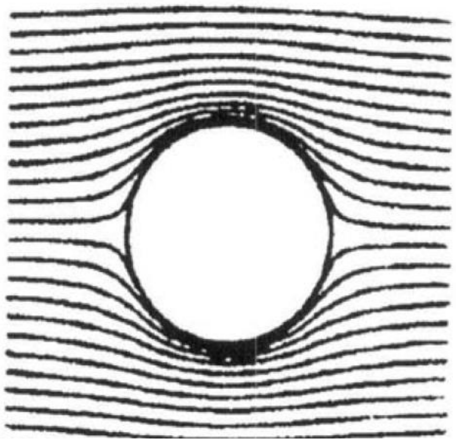
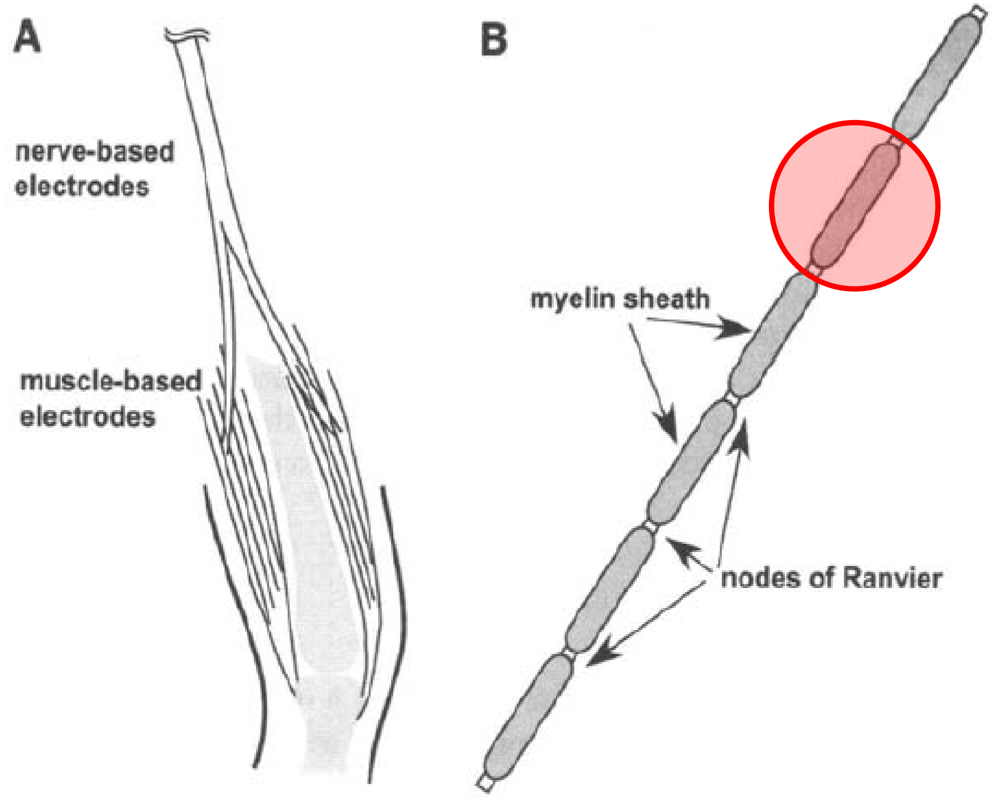


Fig. 6: left: cylindrical axon lying perpendicular to an electric field *E* and definition of angle θ. Right: current flow around axon with very high membrane resistivity.

Electrical stimulation of peripheral nerve fibers



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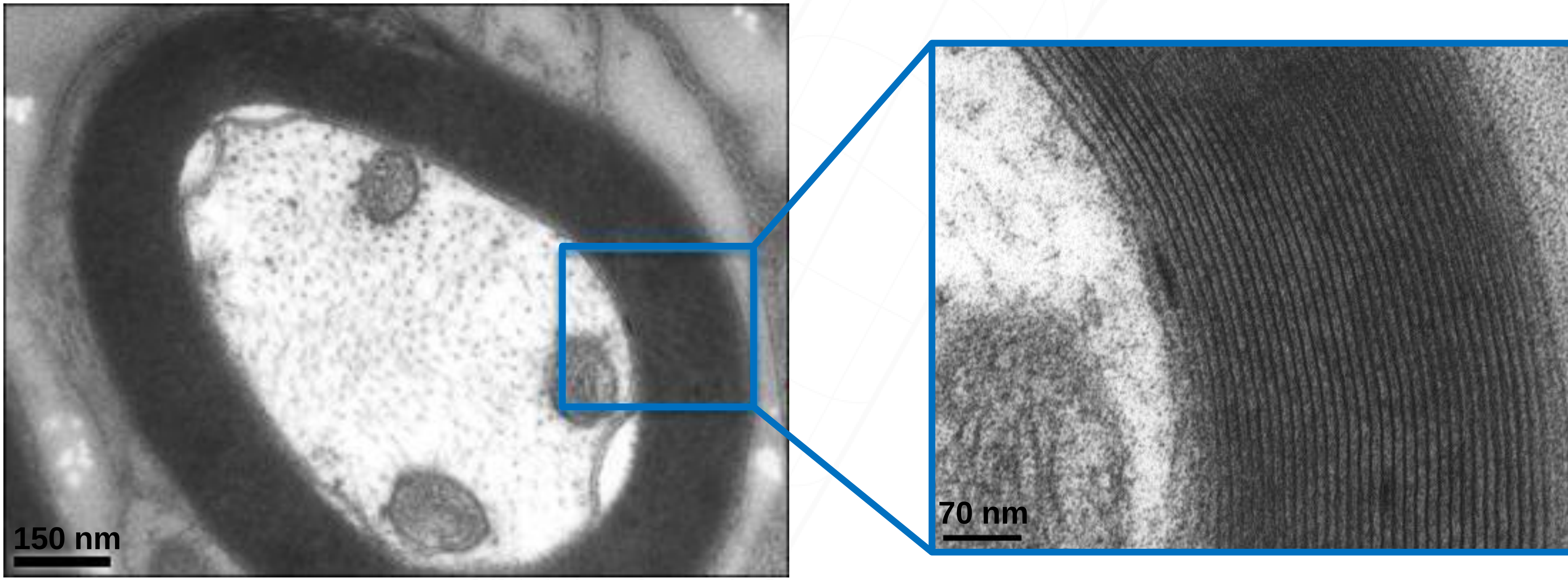
Electrical stimulation of peripheral nerve fibers



Left: Cross-section of a myelinated osseous spiral lamina fibre (peripheral axon from a type I neuron). Within the axon, 3 mitochondria and numerous microtubules are seen (scale bar: 150 nm).

Right: The myelin sheath is formed of 35 layers (scale bar: 70 nm)

Rémy Pujol, http://www.cochlea.eu/en/cochlea