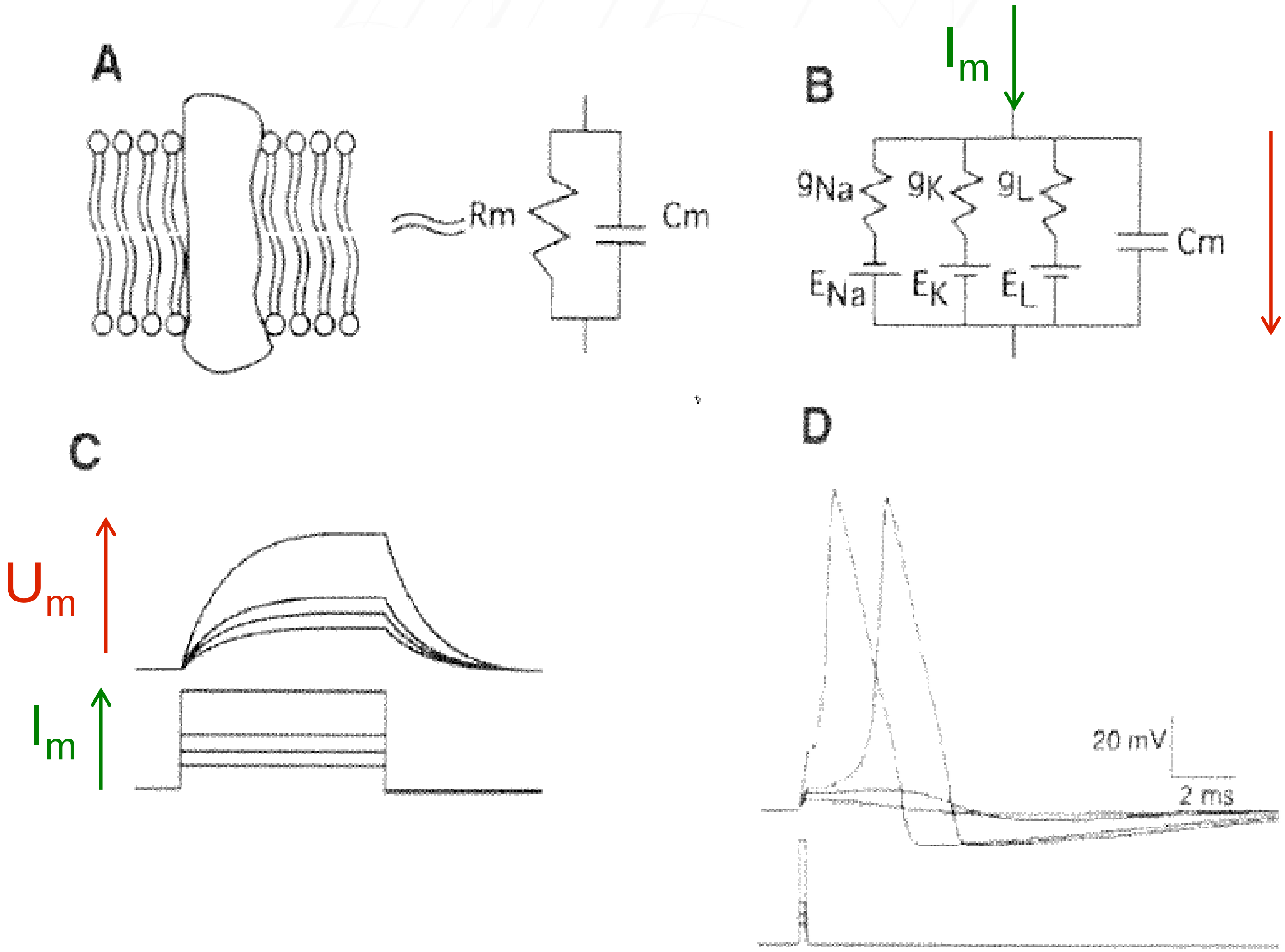
Neuroprothetik

1) Vorstellung Neuroprothesen
2) Einführung in die Biologie
3) Das Membranpotential
4) **Spannungsgesteuerte Ionenkanäle**

Lernziele:

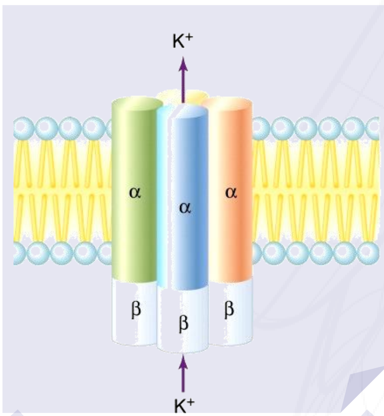
- Dynamik spannungsgesteuerter Ionenkanäle
  - Boltzmann-Verteilung
  - Ratengleichungen
  - Öffnungswahrscheinlichkeit
  - Zeitkonstanten
- Hodgkin-Huxley-Gleichungen

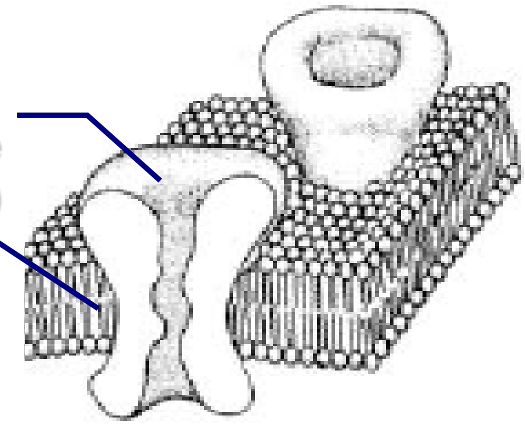
Response and models of a nerve fiber membrane



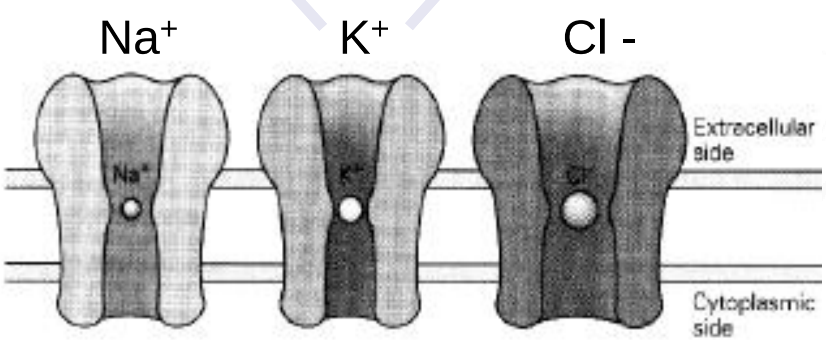
04_1_TransmembraneVoltage.mp4
http://www.youtube.com/watch?v=Xiza8nLww-I

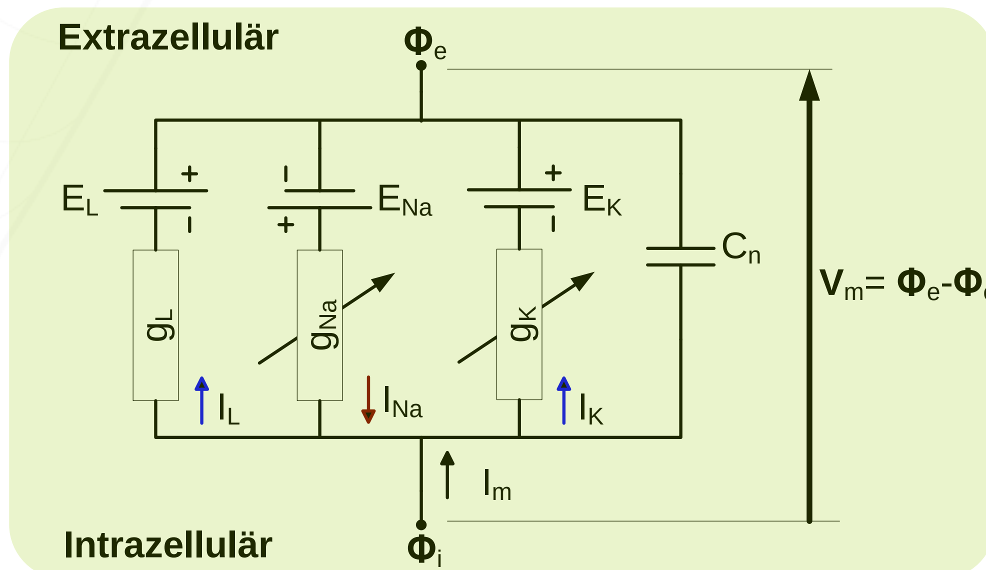
Ionenkanäle: Der spannungsgesteuerte Kaliumkanal





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

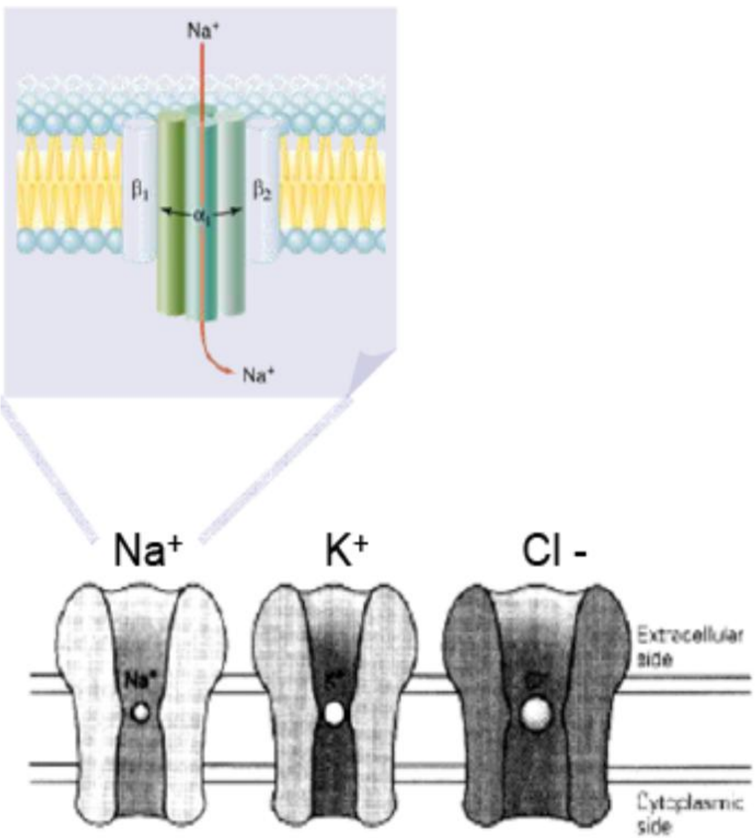


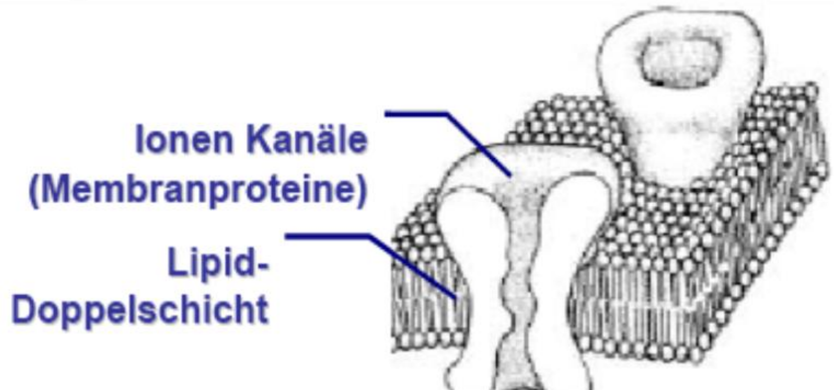


04_2_PotassiumChannel.mp4

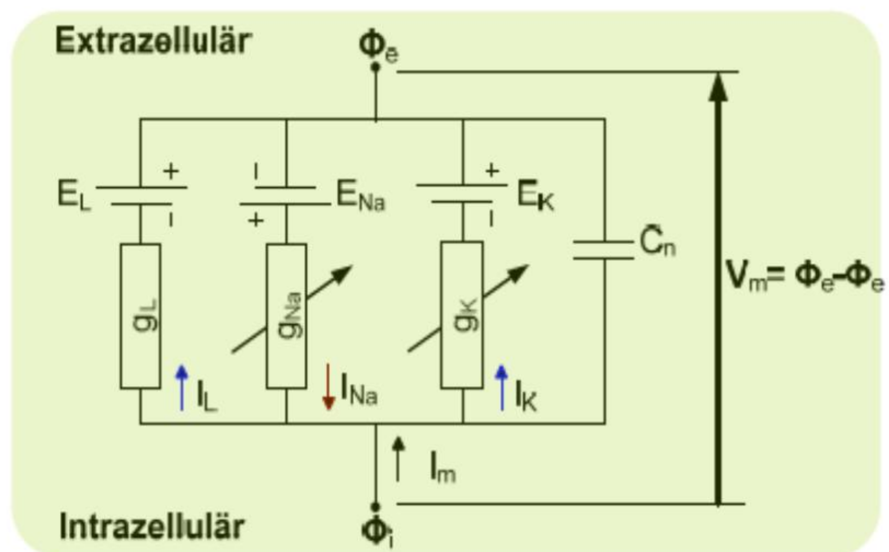
04_3_Passive transport 1a Potassium channel.mp4

Ionenkanäle: Spannungsgesteuerter Natriumkanal



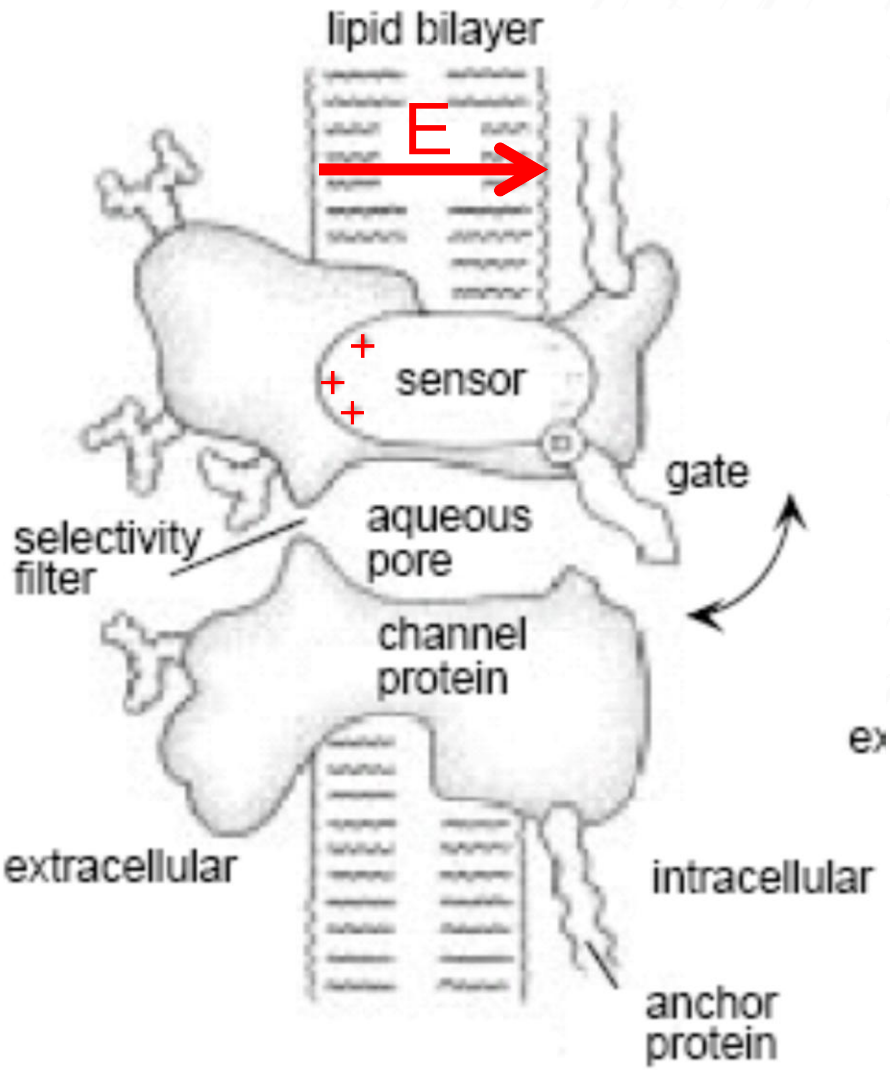


Quelle: B. Hille, Ion channels of excitable membranes, -3rd ed., Sinauer, Sunderland, 2001



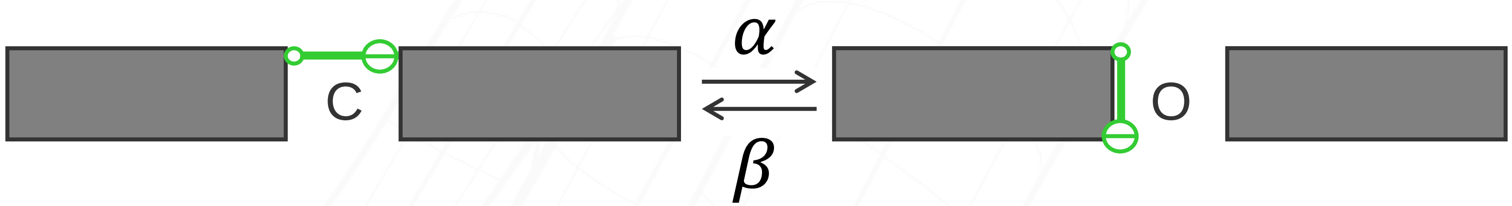
04_4_SodiumChannel-VoltageGate.mp4

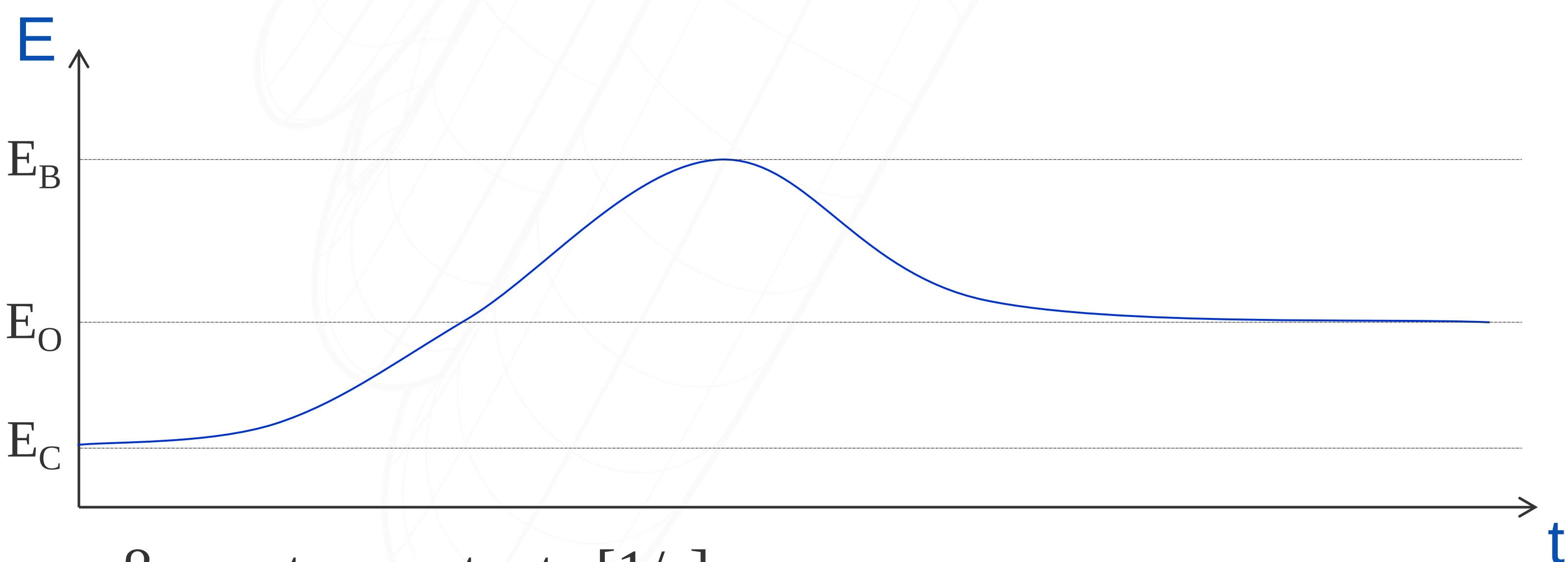
Cartoon of gating



A gate is opened and closed by a sensor that responds to the membrane potential. The channel also has a region that selectively allows ions of a particular type to pass through the channel, for example, K^+ ions for a potassium channel.

States of ion channels and energy levels





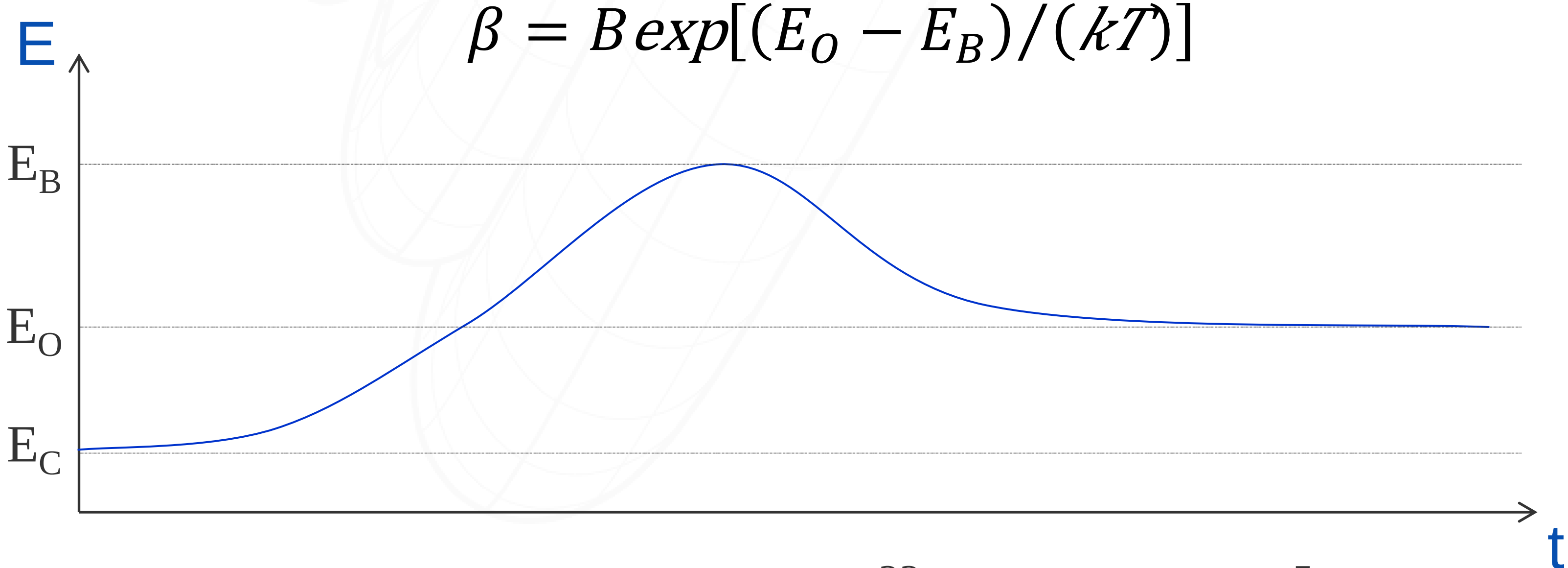
α, β	rate constants [1/s]
E_C	energy level of closed state
E_O	energy level of open state
E_B	energy barrier

Transition between states

$$\text{closed} \underset{\beta}{\overset{\alpha}{\Leftrightarrow}} open$$

$$\alpha = A\,exp[(E_C - E_B)/(kT)]$$

$$\beta = B\,exp[(E_O - E_B)/(kT)]$$



k Boltzmann constant ($1.38 \cdot 10^{-23}$ J/K or $8.6 \cdot 10^{-5}$ eV/K)

α, β rate constants [1/s]

Dynamics of state transition

1-x(t) $\quad \text{closed} \underset{\beta}{\overset{\alpha}{\rightleftarrows}} \textit{open} \quad$ x(t)

$$\alpha = A\exp\left[\left(E_C - E_B\right)/\left(kT\right)\right]$$

$$\beta = B\exp\left[\left(E_O - E_B\right)/\left(kT\right)\right]$$

$$\boxed{\frac{dx(t)}{dt} = \alpha\left(1 - x(t)\right) - \beta x(t)}$$

x(t) open probability of channel

Steady-state

1-x(t) $\quad \text{closed} \underset{\beta}{\overset{\alpha}{\rightleftarrows}} \textit{open} \quad$ x(t)

$$\alpha = A \exp\left[\left(E_C - E_B\right)/\left(kT\right)\right]$$

$$\beta = B \exp\left[\left(E_O - E_B\right)/\left(kT\right)\right]$$

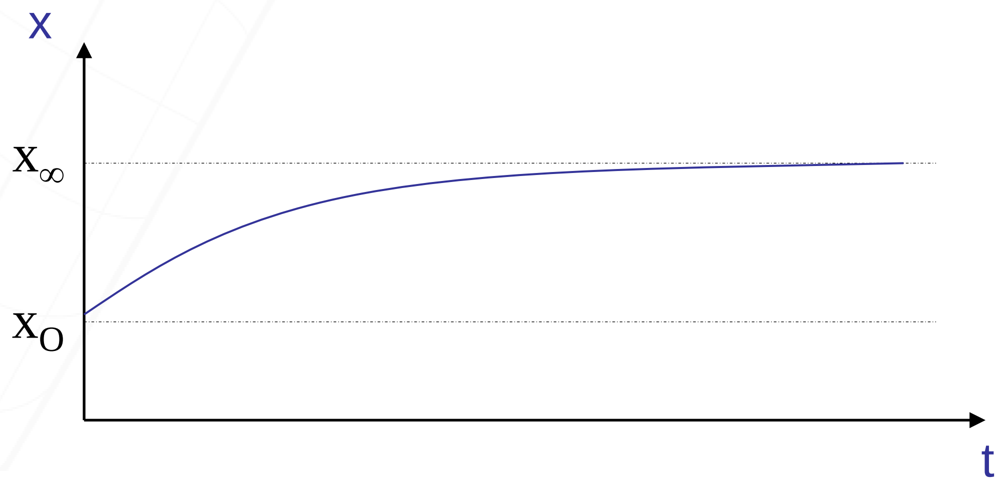
$$\frac{dx(t)}{dt} = \alpha\left(1 - x(t)\right) - \beta x(t) \equiv 0$$

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

Time constant of state transition

$$\frac{dx(t)}{dt} = \alpha\left(1 - x(t)\right) - \beta x(t)$$

$$\boxed{\frac{dx(t)}{dt} = \alpha - (\alpha + \beta)x(t)}$$

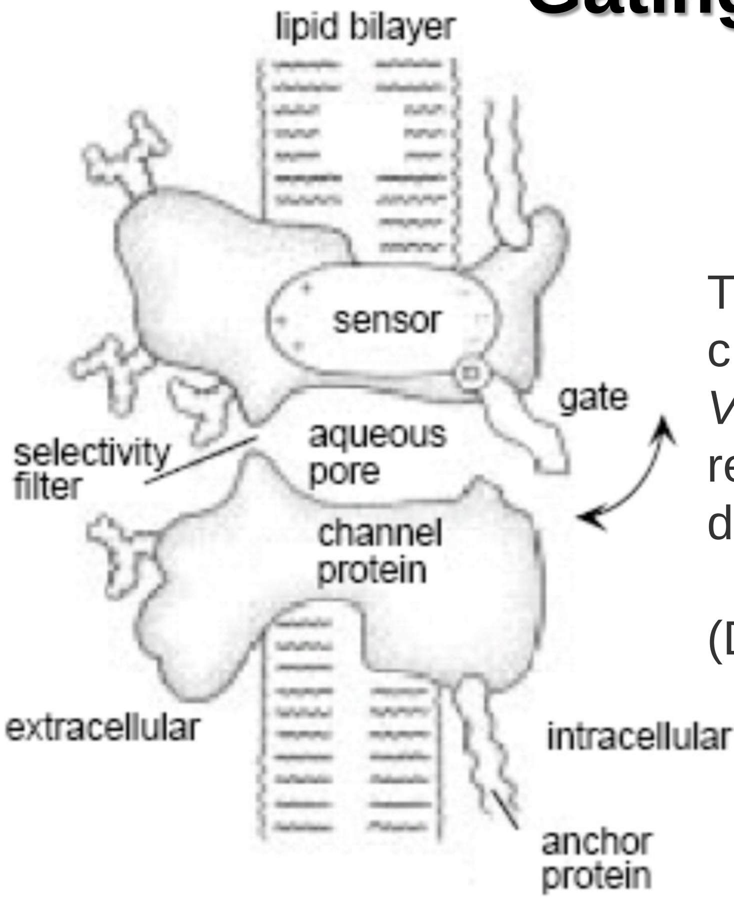


$$x(t) = x_\infty - (x_0 - x_\infty)\exp(-t/\tau_x)$$

$$x_\infty = \frac{\alpha}{\alpha + \beta}$$

$$\boxed{\tau_x = \frac{1}{\alpha + \beta}}$$

Gating of a conductance



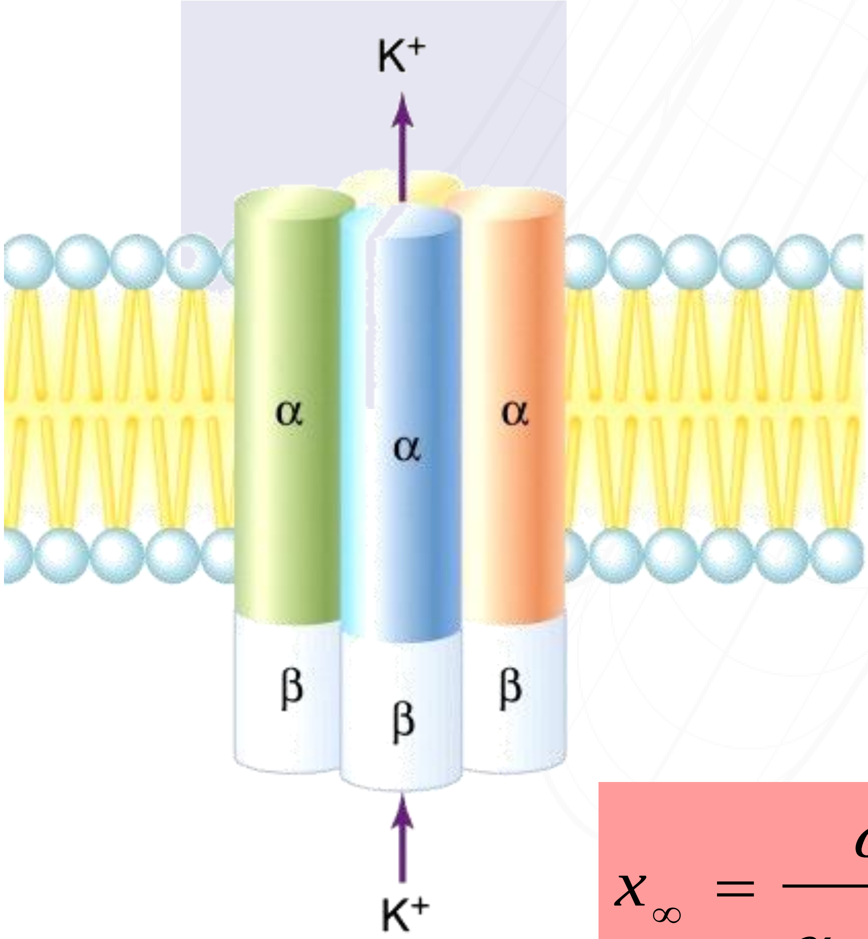
The transition requires the movement of an effective charge, which we denote by qB_α, through the potential V. This requires an energy $qB_\alpha V$. The constant B_α reflects both the amount of charge being moved and the distance over which it travels.

(Dayan & Abbott 2000 Chapter 5, p19)

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

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

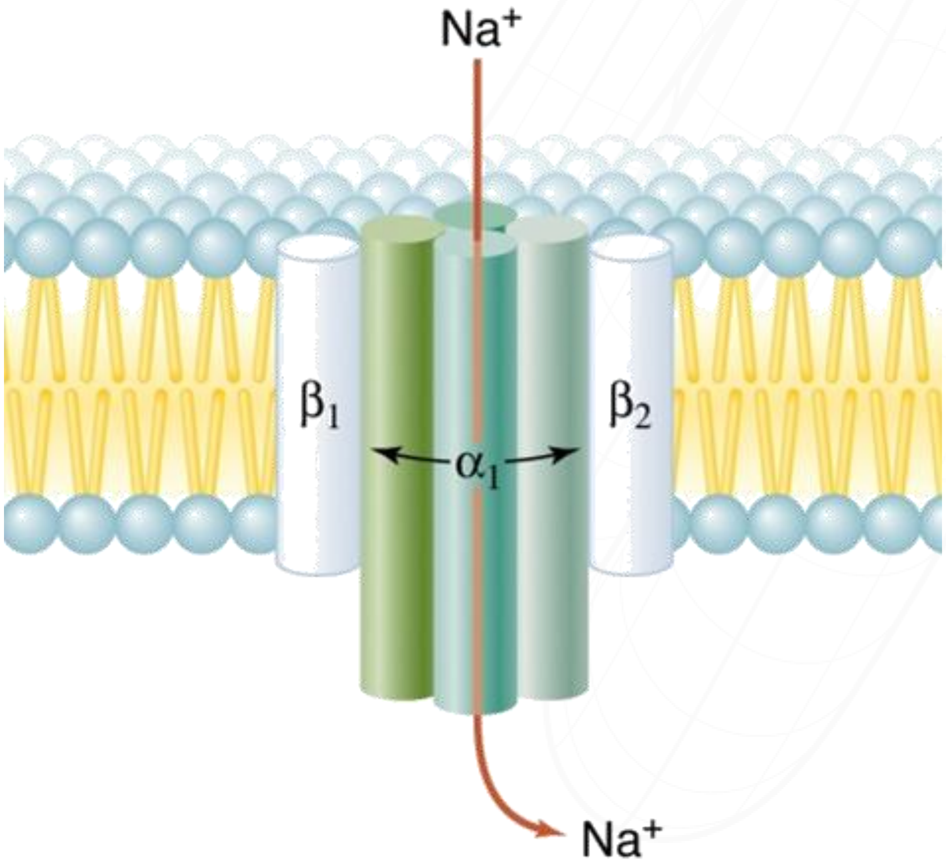
Ionenkanäle: Der spannungsgesteuerte Kaliumkanal



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

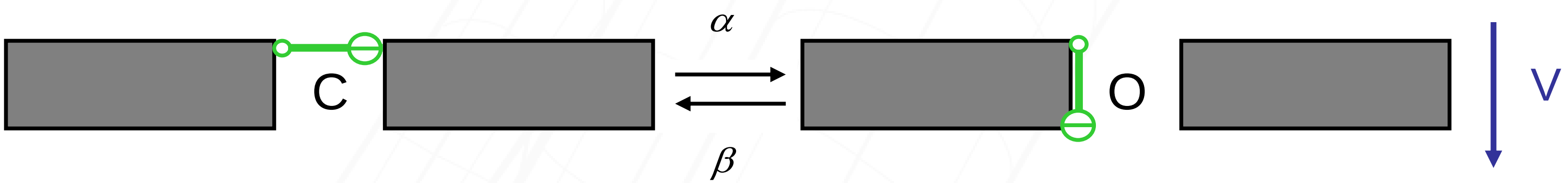
$$x_\infty = \frac{\alpha}{\alpha + \beta} \Leftrightarrow x_\infty = \frac{1}{1 + {}^{B}\!/_{A}\, e^{(E_O - E_C)/kT}}$$

Ionenkanäle: Spannungsgesteuerter Natriumkanal



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

Voltage Activated Ion Channels: fitting α and β



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

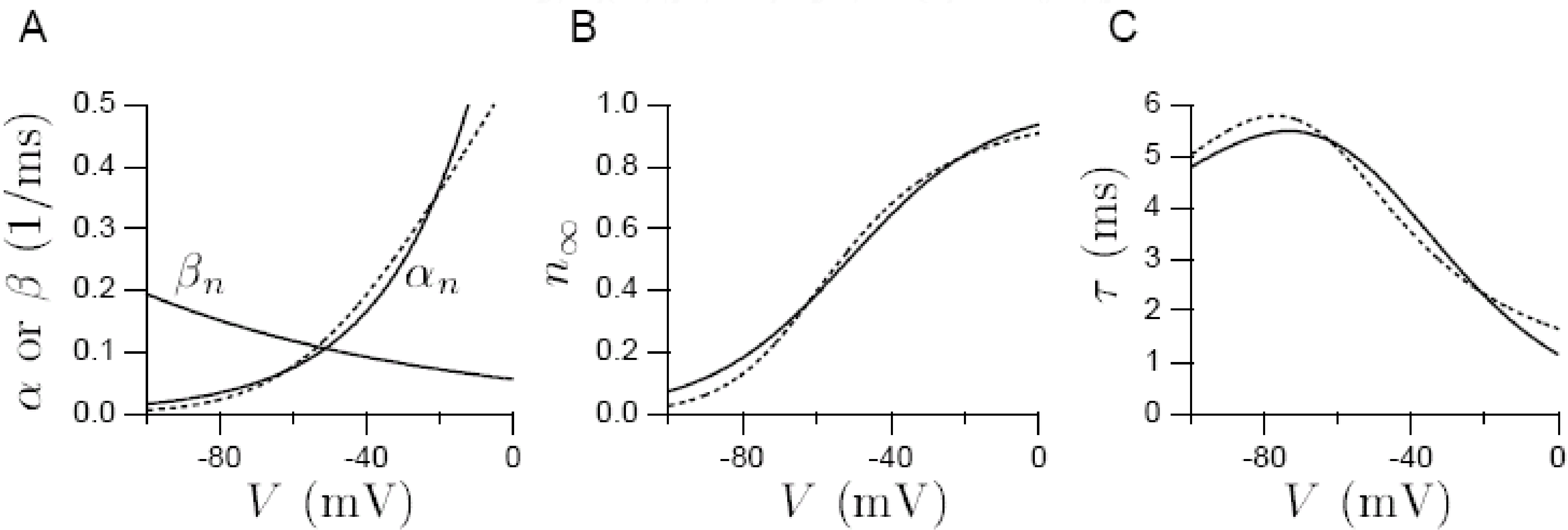
$$\beta = A_\beta \exp\left(-qB_\beta / kT\right) = A_\beta \exp\left(-B_\beta V / V_T\right)$$

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

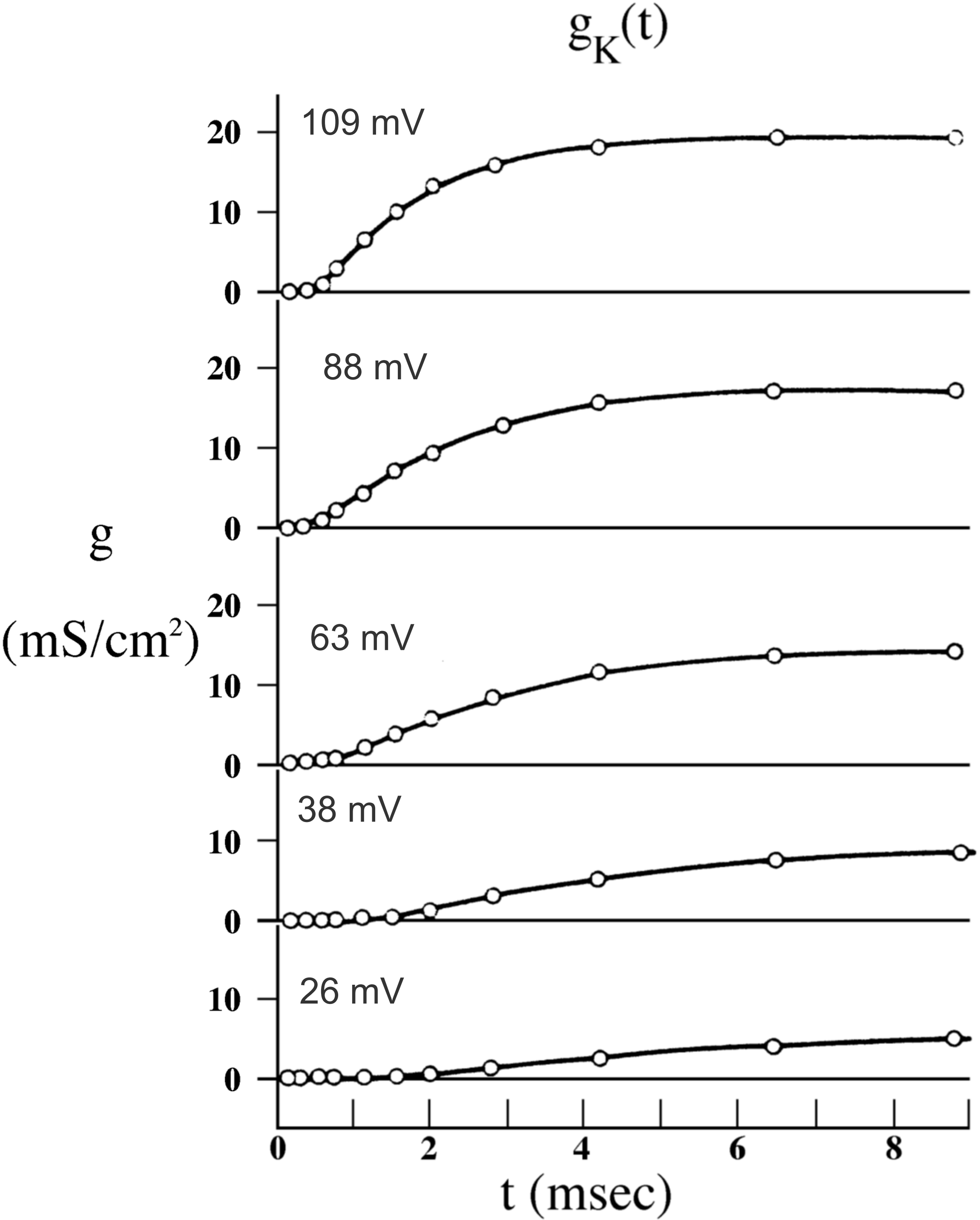
$$\beta = \frac{\mathrm{e}^{-(V + 65\,\mathrm{mV})/80\,\mathrm{mV}}}{8\,\mathrm{s}}$$

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

Voltage Activated Ion Channels



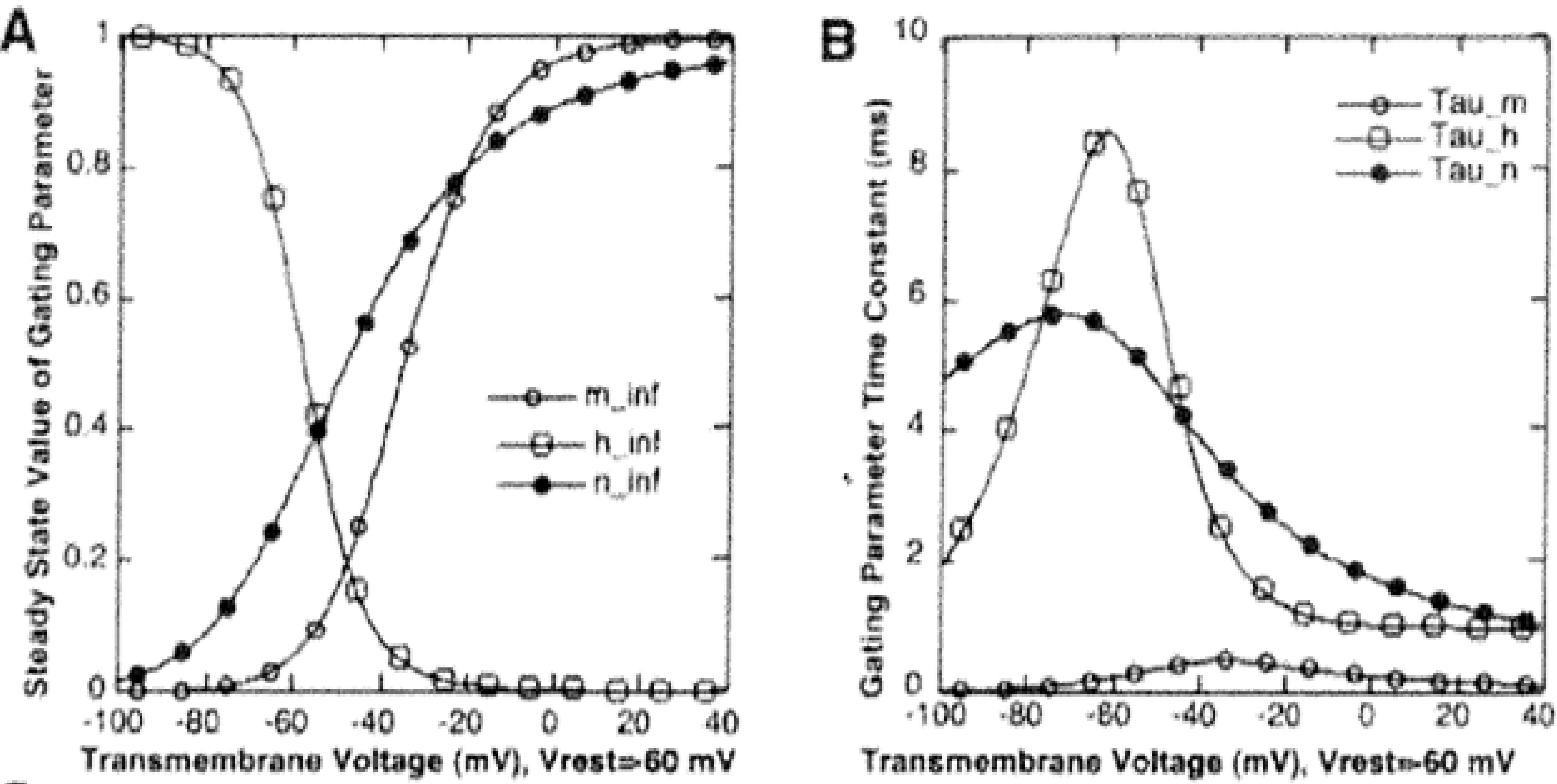
Generic voltage-dependent gating functions compared with Hodgkin-Huxley results for the delayed-rectifier K^+ conductance. A) The exponential α_n and β_n functions expected from thermodynamic arguments are indicated by the solid curves. Parameter values used were A_α=1.22ms−1, A_β=0.056 ms−1, $B_\alpha/VT = -0.04$/mV, and $B_\beta/VT = 0.0125$/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)


A
Steady State Value of Gating Parameter
m_inf
h_inf
n_inf
Transmembrane Voltage (mV), Vrest=-60 mV
B
Gating Parameter Time Constant (ms)
Tau_m
Tau_h
Tau_n
Transmembrane Voltage (mV), Vrest=-60 mV