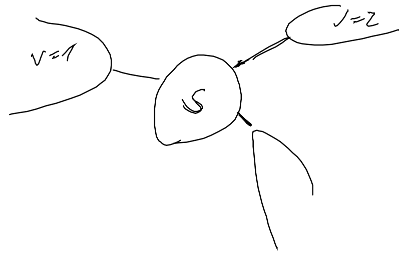
Wdh

Zustände: Energie E_i & T? N_i

$$\dot P_i = \sum_j \sum_\nu W_{ij}^{(\nu)} P_j \quad \rightsquigarrow \langle E\rangle = \sum_i E_i P_i$$



$$I_E^{(\nu)} = \sum_{ij} (E_i - E_j) W_{ij}^{(\nu)} P_j$$

Ströme

$$I_M^{(\nu)} = \sum_{ij} (N_i - N_j) W_{ij}^{(\nu)} P_j$$

1. HS: $\frac{d}{dt}\langle E\rangle = \dot W_{mech} + \dot W_{chem} + \sum_\nu \dot Q^{(\nu)}$

$$\dot Q^{(\nu)} = I_E^{(\nu)} - \mu_\nu \cdot I_M^{(\nu)}$$

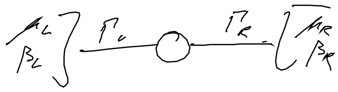
$$\dot W_{chem} = \sum_\nu \mu_\nu \cdot I_M^{(\nu)}$$

$$\dot W_{mech} = \sum_i \dot E_i \cdot P_i$$

2. HS lok. det. GG: $\frac{W_{ji}^{(\nu)}}{W_{ij}^{(\nu)}} = e^{-\beta_\nu [E_j - E_i - \mu_\nu (N_j - N_i)]}$

$$\dot S_i = \underbrace{\frac{d}{dt}\left[-k_B \sum_i P_i \ln P_i\right]}_{\text{Änd. der Syst.-Entropie}} - \underbrace{k_B \sum_\nu \beta^{(\nu)} \dot Q^{(\nu)}}_{\text{Änderung d. Res.-Entropie}} \geq 0$$

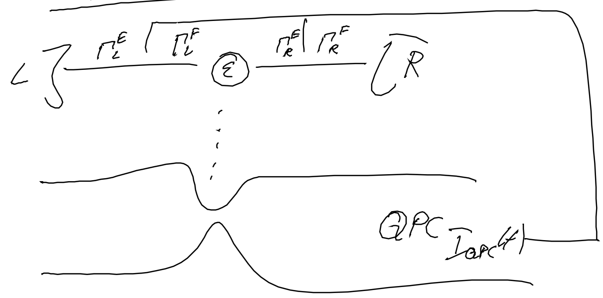
◦ 2 Terminal



1. HS: $I_E^{(L)} = -I_E^{(R)}$ (in SS)

2. HS steady state $\quad I_E^{L\to R}(\beta_R - \beta_L) + I_M^{L\to R}(\beta_L \mu_L - \beta_R \mu_R) \geq 0$

4.7.5 Elektr. Maxwell-Dämon



a) QP sei leer zur Zeit t

$$\mathcal{L}_E = \sum_{\alpha \in L,R} \Gamma_\alpha^E \begin{pmatrix} -f_\alpha & 1-f_\alpha \\ f_\alpha & -(1-f_\alpha) \end{pmatrix}$$

$$\begin{pmatrix} P_E^{(E)}(t+\Delta t) \\ P_F^{(E)}(t+\Delta t) \end{pmatrix} = e^{\mathcal{L}_E \cdot \Delta t} \frac{1}{P_E(t)} \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} P_E(t) \\ P_F(t) \end{pmatrix}$$

b) $\Gamma_\alpha \to \Gamma_\alpha^F$

$$\begin{pmatrix} P_E(t+\Delta t) \\ P_F(t+\Delta t) \end{pmatrix} = \left[e^{\mathcal{L}_E \cdot \Delta t} \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} + e^{\mathcal{L}_F \cdot \Delta t} \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \right] \begin{pmatrix} P_E(t) \\ P_F(t) \end{pmatrix}$$

$$\approx \left\{ \mathbb{1} + \left[\mathcal{L}_E \cdot \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} + \mathcal{L}_F \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \right] \Delta t \right\} \begin{pmatrix} P_E(t) \\ P_F(t) \end{pmatrix} + \mathcal{O}(\Delta t^2)$$

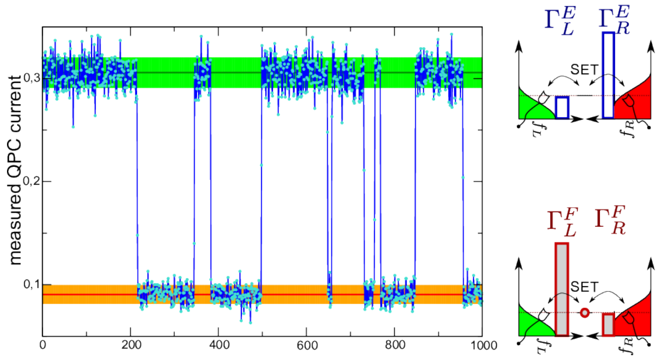
$$\frac{d}{dt} \begin{pmatrix} P_E \\ P_F \end{pmatrix} = \mathcal{L}_{fb} \begin{pmatrix} P_E \\ P_F \end{pmatrix}$$

$$\boxed{\mathcal{L}_{fb} = \mathcal{L}_E \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} + \mathcal{L}_F \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \quad \text{feedback - Ratengleichung}}$$

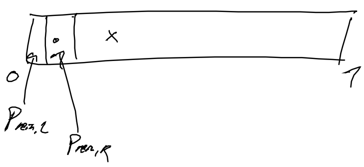
$$\lim_{\Delta t \to 0} \frac{P_E(t+\Delta t) - P_E(t)}{\Delta t} = \frac{d}{dt} P_E(t)$$

$$\mathcal{L}_{eff} = \begin{pmatrix} -\Gamma_L^E f_L - \Gamma_R^E f_R & +\Gamma_L^F(1-f_L) + \Gamma_R^F(1-f_R) \\ +\Gamma_L^E f_L + \Gamma_R^E \cdot f_R & -\Gamma_L^F(1-f_L) - \Gamma_R^F(1-f_R) \end{pmatrix}$$

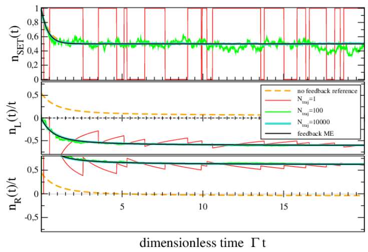
$$\frac{Z_{\rm eff}^{0,\nu}}{Z_{\rm eff}^{1,\nu}} = \frac{\Gamma_\nu^F}{\Gamma_\nu^E}\, e^{+\beta_\nu(\varepsilon-\mu_\nu)}$$ Verletzung dkl. GG.

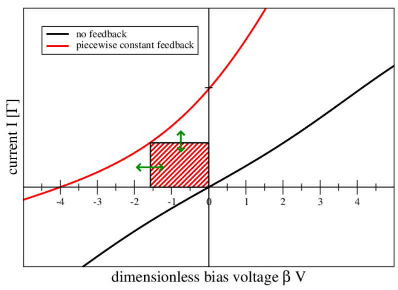


$$P^{(E)}_{\rm rein,L} = \Gamma_L^E \cdot f_L \cdot \Delta t \ll 1$$
$$P^{(E)}_{\rm rein,R} = \Gamma_R^E f_R \cdot \Delta t \ll 1$$
$$P_{\rm nichts} = 1 - P^{(E)}_{\rm rein,L} - P^{(E)}_{\rm rein,R}$$

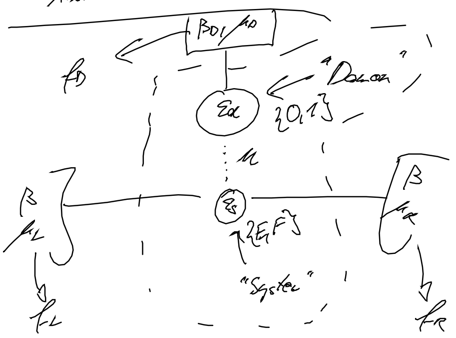


$\beta_L = \beta_R = \beta$
$V = \mu_L - \mu_R$

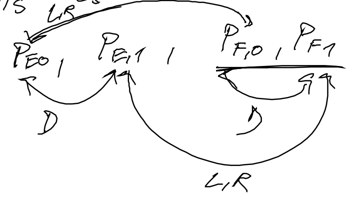




Autonomer Dämon



$$H_S = \varepsilon_s d_s^\dagger d_s + \varepsilon_d d_d^\dagger d_d + U d_s^\dagger d_s d_d^\dagger d_d$$



$$\mathcal{L} = \mathcal{L}_D + \mathcal{L}_L + \mathcal{L}_R$$

$$\mathcal{L}_D = \begin{pmatrix} -\Gamma_D f_D & \Gamma_D(1-f_D) & 0 & 0 \\ \Gamma_D f_D & -\Gamma_D(1-f_D) & 0 & 0 \\ 0 & 0 & -\Gamma_D^U f_D^U & \Gamma_D^U(1-f_D^U) \\ 0 & 0 & \Gamma_D^U f_D^U & -\Gamma_D^U(1-f_D^U) \end{pmatrix}$$

$$\Gamma_\alpha(\varepsilon) = \Gamma_\alpha$$
$$\Gamma_\alpha(\varepsilon+U) = \Gamma_\alpha^U$$
$$f_\alpha = \frac{1}{e^{\beta(\varepsilon-\mu_\alpha)}+1}$$
$$f_\alpha^U = \frac{1}{e^{\beta(\varepsilon+U-\mu_\alpha)}+1}$$

$$\mathcal{L}_{\alpha\in\{L,R\}} = \begin{pmatrix} -\Gamma_\alpha f_\alpha & 0 & +\Gamma_\alpha(1-f_\alpha) & 0 \\ 0 & -\Gamma_\alpha^U f_\alpha^U & 0 & +\Gamma_\alpha^U(1-f_\alpha^U) \\ +\Gamma_\alpha f_\alpha & 0 & -\Gamma_\alpha(1-f_\alpha) & 0 \\ 0 & +\Gamma_\alpha^U f_\alpha^U & 0 & -\Gamma_\alpha^U(1-f_\alpha^U) \end{pmatrix}$$

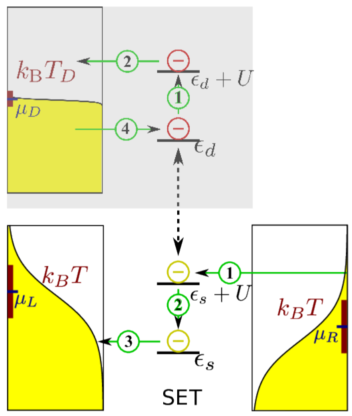
im SS: $\dot{S}_i \longrightarrow -\beta_D \cdot \dot{Q}^{(D)} - \beta \dot{Q}^{(L)} - \beta \dot{Q}^{(R)} \geq 0$

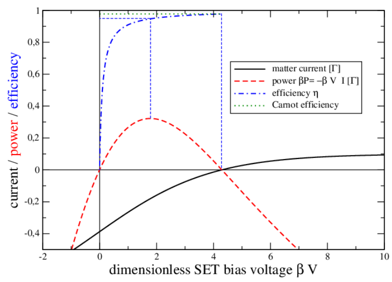
$$\Rightarrow (\beta-\beta_D)\cdot I_E^{D} + \beta\underbrace{(\mu_L-\mu_R)\cdot I_M^{(L)}}_{-P_{el}} \geq 0$$

$$\dot{Q}^{(D)} = I_E^{(D)}$$
$$\dot{Q}^{(L)} = I_E^{(L)} - \mu_L I_M^{(L)}$$
$$\dot{Q}^{(R)} = I_E^{(R)} - \mu_R I_M^{(R)}$$

$$I_M^{(R)} = -I_M^{(L)}$$
$$I_E^{(L)} + I_E^{(R)} + I_E^{(D)} = 0$$

$$\beta_D \gg \beta, \quad I_E^{D} < 0$$





Startpunkt: (E,1)

1. $\Gamma_R^U \gg \Gamma_L^U$ — e^- springt rein von rechts
2. $\Gamma_D^{(U)} \gg \Gamma_{R/L}^{(U)}$ — e^- springt raus ins Dämon-Res.

Asymmetrie

3. $\Gamma_L \gg \Gamma_R$ — e^- springt raus nach Links
4. e^- springt rein aus Dämon-Res

e^- wird gegen den bias transportiert

$$\eta = \frac{P}{\dot{Q}_{diss} + P} \leq 1 - \frac{T_D}{T} = \eta_{Ca}$$

<u>bisher</u> $\dot{P}_\alpha = \sum_{\alpha'} \underset{\substack{\uparrow \\ \text{4x4 Ratenmatrix}}}{Z_{\alpha\alpha'}} P_{\alpha'}$ $\qquad \alpha \in \{E0, E1, F0, F1\}$

$$\dot{P}_{iq} = \sum_{i' \in \{E,F\}} \sum_{q' \in \{0,1\}} Z_{iq,i'q'} P_{i'q'} \qquad P_i = \sum_q P_{iq}$$

$$\dot{P}_i = \sum_{i'} \sum_{qq'} Z_{iq,i'q'} P_{i'q'} = \sum_{i'} \left[\sum_{qq'} Z_{iq,i'q'} \underbrace{\frac{P_{q'|i'}}{P_{i'}}}_{\to \text{ const für Zeitskalenseparation}} \right] P_{i'} = \sum_{i'} W_{ii'} P_{i'}$$

$$P_{0|E} \to 1 - f_D \qquad P_{1|E} = f_D$$

$$P_{0|F} \to 1 - f_D^u \qquad P_{1|F} = f_D^u$$

$$\rightsquigarrow Z = \begin{pmatrix} -Z_{FE} & Z_{EF} \\ Z_{FE} & -Z_{EF} \end{pmatrix}$$