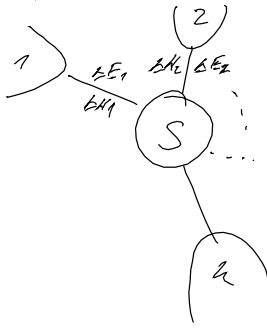


Wahl. Symmetrien in der AGF \Leftrightarrow Fluktuationstheorem: stochastische Formulierung des 2. HS



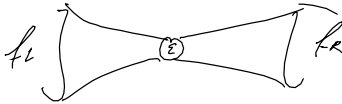
$$\lim_{t \rightarrow \infty} \frac{P_{\pm \Delta E, +\Delta E(t)}}{P_{\pm \Delta E, -\Delta E(t)}} = e^{-\sum_{\nu \neq 1} \beta_{\nu} (\Delta E_{\nu} - \mu_{\nu} \Delta E_{\nu})} = e^{\Delta S}$$

Trajektorien mit $\Delta S > 0$ sind viel wahrscheinlicher als $\Delta S < 0$

$$\text{vorher: } \dot{S}_i = \frac{d}{dt} S[\rho_S] - \sum_{\nu} \beta_{\nu} [\dot{I}_{E}^{(\nu)} - \mu_{\nu} \dot{I}_{A}^{(\nu)}] \xrightarrow{t \rightarrow \infty} - \sum_{\nu} \beta_{\nu} [\dot{I}_{E}^{(\nu)} - \mu_{\nu} \dot{I}_{A}^{(\nu)}]$$

- starke Kopplung \rightarrow nicht so gilt mehr
- + nichtwechselwirkende Hadelle sind für Elektronen nicht mehr

Transmission $0 \leq T(\omega) \leq 1$



$$\begin{aligned} \text{Strom } I_A &= \frac{1}{2\pi} \int T(\omega) [f_L(\omega) - f_R(\omega)] d\omega \\ I_E &= \frac{1}{2\pi} \int T(\omega) \omega [f_L(\omega) - f_R(\omega)] d\omega \end{aligned}$$

$$\dot{S}_i \rightarrow (\beta_R - \beta_L) \cdot I_E + (\beta_L \mu_L - \beta_R \mu_R) I_A \geq 0 \quad (\text{schwache Kopplung})$$

$$\rightarrow \frac{1}{2\pi} \int T(\omega) \underbrace{[(\beta_R - \beta_L) \omega + (\beta_L \mu_L - \beta_R \mu_R)]}_{\geq 0} [f_L(\omega) - f_R(\omega)] d\omega \geq 0$$

↑
starke Kopplung

→

4.2. Polaron Mastergleichungen

4.2.1. Ein bosonisches Reservoir

Spin-Operator

$$\begin{aligned} H &= H_S + \sum_k \omega_k \left[b_k^\dagger + \frac{\omega_k}{\omega_c} S \right] \left[b_k + \frac{\omega_k}{\omega_c} S \right] \\ &= H_S + \sum_k \omega_k b_k^\dagger b_k + S \sum_k (\omega_k b_k + \omega_k^* b_k^\dagger) \end{aligned}$$

$B^\dagger B$ ist immer positiv

$$\langle \psi | B^\dagger B | \psi \rangle = \sum_k \langle \psi | B^\dagger \omega_k \omega_k^\dagger B | \psi \rangle = \sum_k |\langle \psi | B | \psi \rangle|^2 \geq 0$$

$$\begin{aligned} H_0 &= H_S + \sum_k \frac{\omega_k^2}{\omega_c} S^2 \\ &= H_S + \frac{1}{2\pi} \int \frac{\gamma(\omega)}{\omega} d\omega \cdot S^2 \end{aligned}$$

$$\mathcal{U}_P = \exp \left[S \sum_k \left(\frac{\omega_k^*}{\omega_c} b_k^\dagger - \frac{\omega_k}{\omega_c} b_k \right) \right]$$

Polaron-Transform (Lang-Firsov-Transform) anfert

$$S = S^\dagger$$

$$\bullet \mathcal{U}_P S \mathcal{U}_P^\dagger = S$$

$$\bullet \mathcal{U}_P b_k \mathcal{U}_P^\dagger = b_k - \frac{\omega_k^*}{\omega_c} S \quad \bullet \mathcal{U}_P b_k^\dagger \mathcal{U}_P^\dagger = b_k^\dagger - \frac{\omega_k}{\omega_c} S$$

$$e^{+A} B e^{-A} = \sum_{n=0}^{\infty} \frac{1}{n!} [A, B]_n \quad [A, B]_0 = B \quad [A, B]_n = [A, [A, B]_{n-1}]$$

$$= B + [A, B] + \dots$$

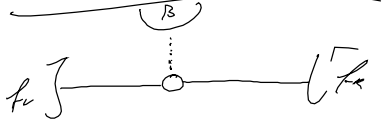
$$H' = t_{lp} H t_p^\dagger = t_{lp} t_{ls} t_p^\dagger + \sum_k u_k b_k^\dagger b_k$$

↑
Kopplung steht bei dir

$$= \underbrace{\text{Tr}_B \left\{ t_{lp} t_{ls} t_p^\dagger \frac{e^{-\beta \sum_k u_k d_k^\dagger b_k}}{Z} \right\}}_{H_S'} + \underbrace{\left[t_{lp} t_{ls} t_p^\dagger - \text{Tr}_B \left\{ t_{lp} t_{ls} t_p^\dagger \frac{e^{-\beta \sum_k u_k d_k^\dagger b_k}}{Z} \right\} \right]}_{H_I'} + \underbrace{\sum_k u_k b_k^\dagger b_k}_{H_B'}$$

→ Ableitung Standard Mastergleichung im Polaronbild
 + Polaron-Trafo nutzt nicht alle Terme der Störungsreihe aus, aber beinhaltet alle Ordnungsn
 + technisch schwierig

4.2.2. Phänomen-geladener SET



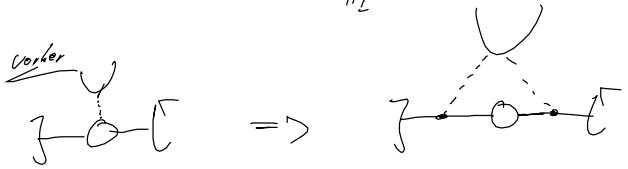
$$H = \underbrace{\varepsilon d^\dagger d + \sum_{k, \nu} \sum_{\nu'} \varepsilon_{\nu \nu'} C_{\nu \nu'}^\dagger C_{\nu \nu'}}_{\text{SET}} + \underbrace{\sum_k \sum_{\nu} (t_{k\nu} C_{\nu} d^\dagger + h.c.)}_{H_{\text{SET/EL}}} + \underbrace{d^\dagger d \sum_{q=1}^Q (u_q a_q + u_q^* a_q^\dagger)}_{H_{\text{SET/PL}}} + \underbrace{\sum_q u_q a_q^\dagger a_q}_{H_B}$$

$$U_p = \exp \left\{ d^\dagger d \sum_q \left(\frac{u_q^*}{u_q} a_q^\dagger - \frac{u_q}{u_q^*} a_q \right) \right\} = e^{d^\dagger d \hat{A}} = \mathbb{1} + d^\dagger d (e^{\hat{A}} - \mathbb{1}) \rightarrow t_{lp} d t_p^\dagger = d \cdot e^{-\hat{A}}$$

$$t_{lp} d^\dagger t_p^\dagger = d^\dagger \cdot e^{\hat{A}}$$

$$t_{lp} H t_p^\dagger = H' = \left(\varepsilon - \sum_q \frac{(u_q)^2}{u_q} \right) d^\dagger d + \sum_{\nu \nu'} \varepsilon_{\nu \nu'} C_{\nu \nu'}^\dagger C_{\nu \nu'} + \sum_q u_q a_q^\dagger a_q$$

$$+ \underbrace{\sum_{\nu \nu'} (t_{\nu \nu'} d C_{\nu \nu'}^\dagger e^{-\hat{A}} + t_{\nu \nu'}^* C_{\nu \nu'} d^\dagger e^{\hat{A}})}_{H_I'}$$



jeder elektronische Sprung kann Phononen erzeugen oder vernichten

• $t_{\nu \nu'}$ perturbativ u_q nicht perturbativ

$$\rho_B' = \bar{\rho}_B^L \bar{\rho}_B^R \bar{\rho}_B^{\text{ph}}$$

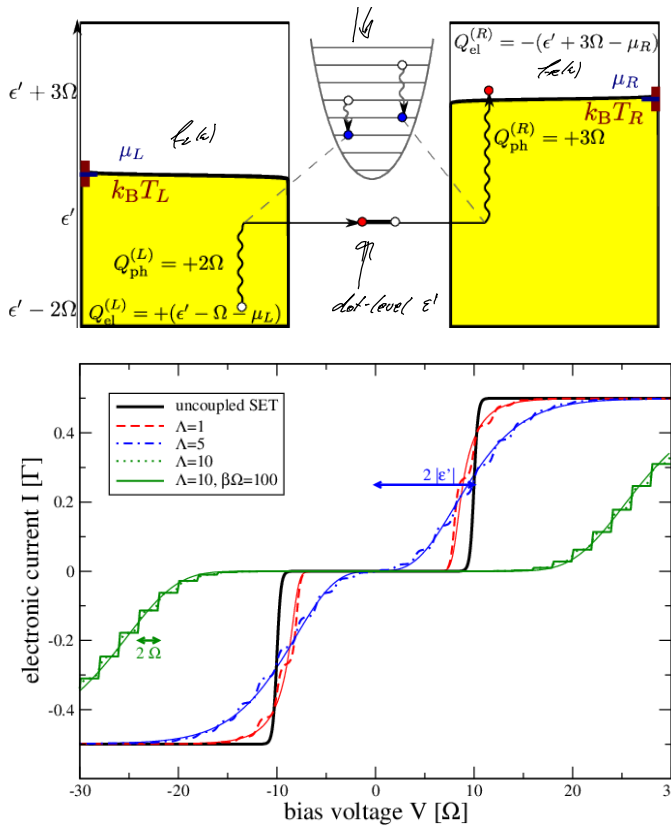
$$B_{\nu \nu'} = \sum_k t_{k\nu} C_{k\nu}^\dagger e^{-A} \quad B_{2\nu} = \sum_k t_{k\nu}^* C_{k\nu} e^{+A} \quad \frac{1}{2\pi} \int \Gamma_\nu(k) f_\nu(-\omega) \cdot e^{-i\omega \bar{t}} d\omega$$

$$C_{12}^\nu(\bar{t}) = \langle B_{1\nu}(\bar{t}) B_{2\nu} \rangle_{\rho_B'} = C_{12, \text{el}}^\nu(\bar{t}) C_{21, \text{ph}}(\bar{t})$$

$$C_{21}^\nu(\bar{t}) = \dots = C_{21, \text{el}}^\nu(\bar{t}) C_{21, \text{ph}}(\bar{t})$$

$$\frac{1}{2\pi} \int \Gamma_\nu(k) [1 - f_\nu(\omega)] e^{-i\omega \bar{t}} d\omega$$

$$C_{12, \text{ph}}(\bar{t}) = \exp \left\{ \sum_q \frac{(u_q)^2}{u_q^2} \left[e^{-i u_q \bar{t}} \int \Gamma_\nu(k) f_\nu(\omega) + e^{+i u_q \bar{t}} \int \Gamma_\nu(k) [1 - f_\nu(\omega)] \right] \right\} = C_{21, \text{ph}}(\bar{t})$$



4.3. Bosonische Reaktionskoordinaten - Abbildungen

4.3.1. Bosonische Bogz-Trafo

Lineare Trafo, welche die Kommutator-Relationen respektiert

$$a_{\kappa} = \sum_q \Lambda_{\kappa q} b_q + \mathcal{O}_{\kappa q} b_q^{\dagger}$$

\uparrow Bosonen
 \uparrow Bosonen
 $\in \mathbb{C}$

$$[a_{\kappa}, a_{\kappa}^{\dagger}] = \delta_{\kappa\kappa'} \iff [b_{q_1}, b_{q_1}^{\dagger}] = \delta_{q_1 q_1'}$$

$$[a_{\kappa_1}, a_{\kappa_2}] = 0 \iff [b_{q_1}, b_{q_2}] = 0$$

$$\Lambda_{\kappa q} = (U)_{\kappa q} \quad \mathcal{O}_{\kappa q} = (V)_{\kappa q}$$

$$(\text{symplektische Trafo:}) \quad U U^{\dagger} - V V^{\dagger} = \mathbb{1} \quad U V^{\dagger} - V U^{\dagger} = 0$$

Speziellfall: $\mathcal{O}_{\kappa q} = 0 \implies U U^{\dagger} = \mathbb{1} \implies$ Unitar

$$\Lambda_{\kappa q} = \frac{1}{2} \left(\frac{\alpha_{\kappa}}{\beta_{q_2}} + \frac{\beta_{q_1}}{\alpha_{\kappa}} \right) \Lambda_{\kappa q} \quad \mathcal{O}_{\kappa q} = \frac{1}{2} \left(\frac{\alpha_{\kappa}}{\beta_{q_2}} - \frac{\beta_{q_1}}{\alpha_{\kappa}} \right) \Lambda_{\kappa q}$$

$$\sum_q \Lambda_{\kappa q} \Lambda_{\kappa' q} = \delta_{\kappa\kappa'}$$