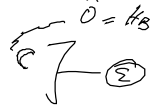
__Wdh__

· SRL

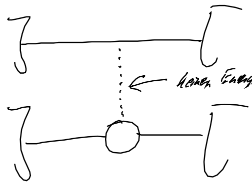


$\hat{O} = H_B = \sum_k \varepsilon_k c_k^\dagger c_k$

$\rightsquigarrow \mathcal{Z}(\xi) = \Gamma \begin{pmatrix} -f & +(1-f)e^{+i\xi\cdot\varepsilon} \\ f e^{-i\xi\cdot\varepsilon} & -(1-f) \end{pmatrix}$

$\rightsquigarrow$ Methode ist konsistent

∘ SET



QPC

SET

keinen Energie-Austausch

4-Terminal System

$$A = \underbrace{\mathbb{1} - \alpha d^\dagger d}_{\text{Unterdrückungsfaktor}} \rightsquigarrow \mathcal{Z}_{QPC}(\xi) = \begin{pmatrix} 1 & 0 \\ 0 & |1-\alpha|^2 \end{pmatrix} [\gamma^{\xi}(0) - \gamma^{0}(0)]$$

ZF

Energie-Übertrag

$$\gamma^{\xi}(0) = \frac{e^{-i\xi}}{2\pi} \int T(\omega,\omega)\,[1-f_L(\omega)]\cdot f_R(\omega)\,d\omega + \frac{e^{+i\xi}}{2\pi} \int T(\omega,\omega)\cdot f_L(\omega)\,[1-f_R(\omega)]\,d\omega$$

beob. $\alpha = 0$

$$C(\xi,t) = \ln \mathrm{Tr}\{ e^{\mathcal{Z}_{QPC}(\xi)\cdot t} \rho_0 \} = \underbrace{[\gamma^{\xi}(0) - \gamma^{0}(0)]}_{C_I(\xi)}\cdot t$$

$$I = (-i\partial_\xi)\, C_I(\xi)\big|_{\xi=0} = \frac{1}{2\pi}\int T(\omega,\omega)\{ f_L(\omega)[1-\cancel{f_R(\omega)}] - [1-\cancel{f_L(\omega)}]\cdot f_R(\omega)\}\,d\omega$$

$$= \frac{1}{2\pi}\int T(\omega,\omega)\,[f_L(\omega) - f_R(\omega)]\,d\omega$$ "Landauer Formel"

Transmission (hier nur perturbativ in t_{kq})

allg $\mathcal{Z}_{tot}(\xi) = \sum_{\alpha\in\{L,R\}} \Gamma_\alpha \begin{pmatrix} -f_\alpha & +(1-f_\alpha) \\ +f_\alpha & -(1-f_\alpha) \end{pmatrix} + \mathcal{Z}_{QPC}(\xi)$

Interpretation als Ladungsdetektor

3.4.3. Pure-Dephasing

Welche Energie wird in das Bad abgestrahlt

$\hat{O} = H_B$

$$H = \underbrace{\Omega\sigma^z}_{H_S} + \underbrace{\sigma^z}_{A} \otimes \underbrace{\sum_k (h_k b_k + h_k^* b_k^\dagger)}_{B} + \underbrace{\sum_k \omega_k b_k^\dagger b_k}_{H_B}$$

ex. Lsg: · Populationen konstant
· Kohärenzen zerfallen

(CG liefert die ex. Lösung für $\tau = t$

$\rho(t) = e^{\mathcal{Z}_t \cdot t} \rho_0 = \rho_{ex}(t)$)

a.) Mastergl. mit ZF

$$C^{\chi}(t) = \mathrm{Tr}\{ e^{-iH_B\cdot\chi} \left(\sum_k h_k b_k e^{-i\omega_k\cdot t} + h_k^* b_k^\dagger e^{+i\omega_k\cdot t}\right) e^{+iH_B\chi} \left(\sum_q h_q b_q + h_q^* b_q^\dagger\right) \bar{\varrho}_B \}$$

$$= \sum_k |h_k|^2 \left[e^{+i\omega_k\cdot\chi} e^{-i\omega_k\cdot t} (1+n_B(\omega_k)) + e^{-i\omega_k\cdot\chi} e^{+i\omega_k\cdot t} n_B(\omega_k) \right]$$

$$= \frac{1}{2\pi}\int_0^\infty \Gamma(\omega) \left[e^{+i\omega\chi - i\omega t} [1+n_B(\omega)] + e^{-i\omega\chi + i\omega t} \underset{\omega\to-\omega}{n_B(\omega)} \right] d\omega$$

$$= \frac{1}{2\pi}\int_{-\infty}^\infty \Gamma(\omega) [1+n_B(\omega)] \Theta(\omega) e^{+i\omega\chi} e^{-i\omega t} d\omega$$

$$+ \frac{1}{2\pi}\int_{-\infty}^\infty \Gamma(-\omega)\cdot n_B(-\omega)\, \Theta(-\omega)\, e^{+i\omega\chi} e^{-i\omega t} d\omega$$

$$\leadsto \gamma^{\chi}(\omega) = \Gamma(\omega)[1+n_B(\omega)]\cdot\Theta(\omega) e^{+i\omega\chi} + \Gamma(-\omega) n_B(-\omega)\Theta(-\omega) e^{+i\omega\chi}$$

$\rightarrow$ z. CG-Mastergl. $\qquad e^{+iH_S t}\sigma^z e^{-iH_S t} = \sigma^z$

$$\dot{\tilde{\varrho}}_S = \underset{\text{CG-Zeitskala}}{\frac{1}{2\pi\tau}} \int_0^\tau dt_1 \int_0^\tau dt_2 \int d\omega \Big\{ \Theta(\omega)\Gamma(\omega)[1+n_B(\omega)] e^{-i\omega(t_1-t_2)} \left[e^{+i\omega\chi} \sigma^z \tilde{\varrho} \sigma^z - \tilde{\varrho}_S \right]$$
$$\Theta(-\omega)\Gamma(-\omega) n_B(-\omega) e^{-i\omega(t_1-t_2)} \left[e^{+i\omega\chi} \sigma^z \tilde{\varrho}_S \sigma^z - \tilde{\varrho}_S \right]$$

$$\dot{\tilde{\varrho}}_S = [\gamma_-(\chi,\tau)\sigma^z\tilde{\varrho}_S\sigma^z - \gamma_-(0,\tau)\tilde{\varrho}_S] + [\gamma_+(\chi,\tau)\sigma^z\tilde{\varrho}_S\sigma^z - \gamma_+(0,\tau)\tilde{\varrho}_S]$$

$$\dot{\varrho}_{00} = \underline{[\gamma_-(\chi,\tau) - \gamma_-(0,\tau) + \gamma_+(\chi,\tau) - \gamma_+(0,\tau)]}\, \varrho_{00}$$

$$\dot{\varrho}_{11} = [\quad - \text{''} - \quad]\, \varrho_{11} \qquad \dot{\varrho}_{01} = [\ldots]\,\varrho_{01}$$

$$C(\chi,t) = \ln \mathrm{Tr}\{ e^{Z(\chi)\cdot t} \varrho_0 \}$$

$$= \ln (1,1,0,0) \left(e^{Z(\chi)\cdot t} \right) \begin{pmatrix} \varrho_{00}^0 \\ \varrho_{11}^0 \\ \varrho_{01}^0 \\ \varrho_{10}^0 \end{pmatrix}$$

$$= \ln e^{[\ldots]\cdot t} \underbrace{(1,1)\begin{pmatrix}1&0\\0&1\end{pmatrix}\begin{pmatrix}\varrho_{00}^0\\ \varrho_{11}^0\end{pmatrix}}_{1} = \underline{[\ldots]\cdot t}$$

$$\Delta E(t) = -i\partial_\chi C(\chi,t)\big|_{\chi=0} = \int d\omega\, \Theta(\omega)\cdot\omega\,\Gamma(\omega)[1+n_B(\omega)] \cdot \frac{\tau\cdot t}{2\pi}\cdot \mathrm{sinc}^2\left[\frac{\omega\tau}{2}\right] d\omega$$
$$+ \int d\omega\, \Theta(-\omega)\cdot\omega\,\Gamma(-\omega) n_B(-\omega) \frac{\tau\cdot t}{2\pi} \mathrm{sinc}^2\left[\frac{\omega\tau}{2}\right] d\omega$$

$$\Delta E(\tau) \overset{\tau=t}{=} \boxed{\frac{2}{\pi}\int_0^\infty \frac{\Gamma(\omega)}{\omega} \sin^2\left(\frac{\omega\cdot\tau}{2}\right) d\omega = \Delta E(\tau)}$$

b) exakte Lösung

Heisenberg-Bild

$$\rho(t) = \rho_S^0 \otimes \bar\rho_B$$

$$\tilde\sigma^z = e^{+iH_{tot}\cdot t}\, \sigma^z\, e^{-iH_{tot}\cdot t}$$

$$\frac{d}{dt}\tilde\sigma^z = i\, e^{+iH_{tot}\cdot t}\left[H_{tot}, \sigma^z\right] e^{-iH_{tot}\cdot t} = 0 \quad \rightsquigarrow \quad \tilde\sigma^z = \sigma^z$$

$$\left.\begin{array}{l} \frac{d}{dt}\tilde b_k = -i\omega_k \tilde b_k - i h_k^* \sigma^z \\ \frac{d}{dt}\tilde b_k^\dagger = +i\omega_k \tilde b_k^\dagger + i h_k \sigma^z \end{array}\right\} \begin{array}{l} \tilde b_k(t) = b_k \cdot e^{-i\omega_k t} + \frac{h_k^*}{\omega_k}\sigma^z\left(e^{-i\omega_k t} - 1\right) \\ \text{analog } \tilde b_k^\dagger \end{array}$$

$$\langle E\rangle_t = \sum_k \omega_k \,\mathrm{Tr}\left\{\left[b_k^\dagger e^{+i\omega_k t} + \frac{h_k}{\omega_k}\sigma^z\left(e^{+i\omega_k t}-1\right)\right]\left[b_k e^{-i\omega_k t} + \frac{h_k^*}{\omega_k}\sigma^z\left(e^{-i\omega_k t}-1\right)\right]\rho_S^0\otimes\bar\rho_B\right\}$$

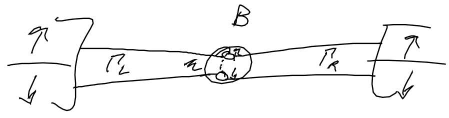
$$= \underbrace{\sum_k \omega_k \,\mathrm{Tr}_B\left\{b_k^\dagger b_k\, \bar\rho_B\right\}}_{\langle E\rangle_0} + \underbrace{\sum_k \frac{|h_k|^2}{\omega_k}\left(2 - 2\cos(\omega_k\cdot t)\right)}_{\langle \Delta E\rangle_t}$$

$$\langle \Delta E\rangle_t = \frac{2}{\pi}\int_0^\infty \frac{\Gamma(\omega)}{\omega}\sin^2\left(\frac{\omega\cdot t}{2}\right) d\omega$$

konsistent für $t = \tilde\tau$ Energie kommt aus der Kopplung

3.4.4 Beispiel Spin-Ströme

lokales Magnetfeld



$$H_S = (\varepsilon + b)\, d_\uparrow^\dagger d_\uparrow + (\varepsilon - b)\, d_\downarrow^\dagger d_\downarrow + U d_\uparrow^\dagger d_\uparrow d_\downarrow^\dagger d_\downarrow$$

Onsite-Energie Zeeman-Splitting Coulomb-WW

$$H_I = \sum_k \sum_{\nu\in\{L,R\}} \sum_{\sigma\in\{\uparrow,\downarrow\}} \left[t_{k\nu}\, d_\sigma^\dagger c_{k\nu\sigma} + h.c.\right]$$

$$H_B = \sum_k \sum_\nu \sum_\sigma \varepsilon_{k\nu}\, c_{k\nu\sigma}^\dagger c_{k\nu\sigma}$$

$$\hat O = S_R = \sum_k \left(c_{kR\uparrow}^\dagger c_{kR\uparrow} - c_{kR\downarrow}^\dagger c_{kR\downarrow}\right)$$

$$e^{+i\alpha c^\dagger c}\, c\, e^{-i\alpha c^\dagger c} = c\, e^{-i\alpha}$$

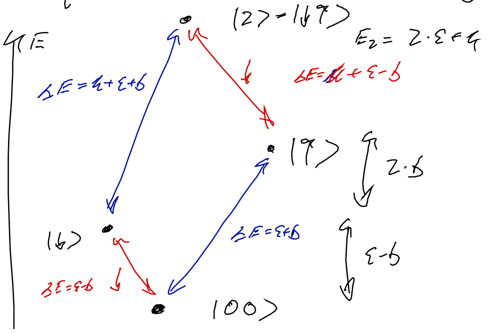
$$\bullet\; e^{-iS\chi} e^{+iH_B t} c_{R\uparrow} e^{-iH_B t} e^{+iS\chi} = c_{R\uparrow} \cdot e^{-i\varepsilon_{R\uparrow} t} e^{+i\chi}$$

$$[\quad] c_{R\downarrow} [\quad] = c_{R\downarrow} e^{-i\varepsilon_{R\downarrow} t} e^{-i\chi}$$

$$[\quad] c_{L\uparrow} [\quad] = c_{L\uparrow} \cdot e^{-i\varepsilon_{L\uparrow} t}$$

$$[\quad] c_{L\downarrow} [\quad] = c_{L\downarrow} e^{-i\varepsilon_{L\downarrow} t}$$

Erzeuger analog

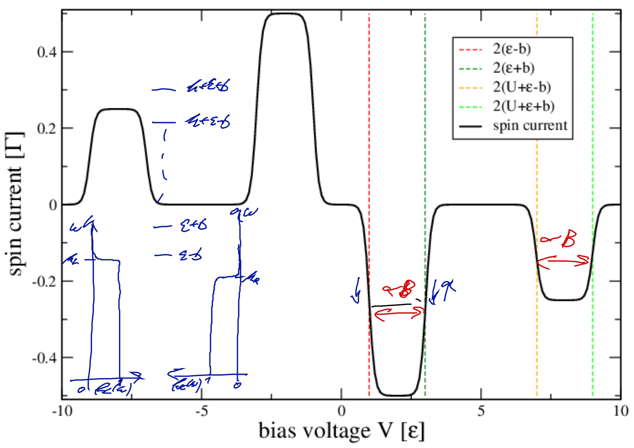


$\mathcal{L}(\chi)$

$\mathcal{L}(0)\bar{\rho} = 0 \rightsquigarrow \bar{\rho}$

$\underline{I} = -i\,\mathrm{Tr}\{\mathcal{L}'(0)\,\bar{\rho}\}$

z.B. $I\left(\mu_L = +\frac{V}{2}, \mu_R = -\frac{V}{2}\right)$



Spinventil