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Andreev non-Hermitian Hamiltonian for open Josephson junctions from Green's functions

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Abstract: We investigate the transport properties of open Josephson junctions through a minimal effective non-Hermitian approach derived from the barrier equilibrium Green's function, proposing to build a non-Hermitian Hamiltonian for the junction Andreev sub-gap levels.

We investigate the transport properties of open Josephson junctions (JJs) through a minimal effective non-Hermitian (NH) approach derived from the equilibrium Green's function (GF) formalism. Specifically, we consider a JJ with a quantum dot barrier coupled to a normal metal reservoir, Fig. 1 (a). The coupling introduces an imaginary self-energy term ($\Sigma_N(\omega = 0) = i\Gamma_N$) in the JJ Hamiltonian which can be naturally accounted for in the NH formalism [1-3]. While most approaches to similar problems work with the full junction Hamiltonian [1-2] we propose a scheme for deriving an effective NH Hamiltonian for the Andreev levels only, that we compute from the singular part of the barrier GF. To establish the range of applicability of this NH model we benchmark our results for both the dot density of states and the supercurrent against exact GF predictions in different transport regimes. We focus on the so called weak- and strong-coupling limits where the hybridization of the dot with the leads Γ is respectively smaller and larger than the superconducting gap Δ. We find that, as a rule of thumb, the Andreev NH description is accurate when the spectral overlap between the Andreev bound states (ABS) and the near-gap continuum states is negligible, i.e. when the ABS energies lie sufficiently far from the superconducting gap relative to their line-width, see Fig. 1 (b). This method not only highlights the effective physics of the JJ but also offers a scalable framework for studying large-size devices.

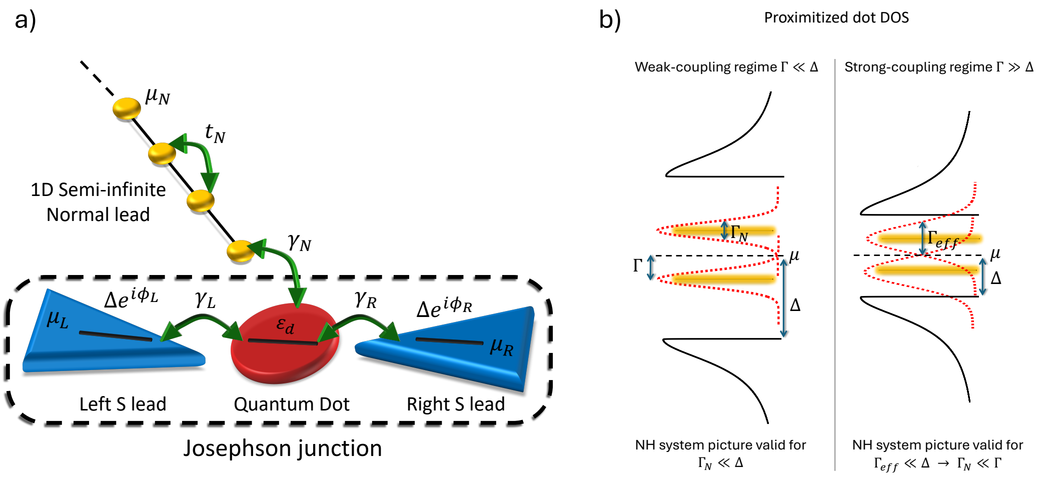

Fig. 1 In the left panel (a), we show a scheme of the SQDNS JJ consisting of two bulk s-wave superconducting leads (S), a single-level quantum dot (QD) and a 1D semi-infinite normal lead (N). ε_d is the energy of the quantum dot level. t_N is the hopping amplitude along the 1D normal chain. The leads have equal chemical potential $\mu_L = \mu_R = \mu_N = \mu$. γ_L, γ_R and γ_N are the hopping amplitudes between the S and N leads and the dot. Δ is the superconducting gap in the S leads and their phases are ϕ_L / ϕ_R. In the right panel (b), we show the dot DOS for the junction in the weak- and strong-coupling limits. In the first case, the ABS (in yellow) occur at energy scales of $\Gamma \ll \Delta$ while their broadening is given by the normal lead - dot hybridization Γ_N (red dashed line). In the second situation, the ABS energy is at energy scales of $\Delta \ll \Gamma$ and their imaginary part, i.e. the effective broadening, Γ_{eff} (red dashed line) induces an overlap between the sub-gap and the supra-gap states.

References

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