Charge-conserving models for superconducting quantum devices

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The Richardson model, originally introduced in nuclear physics as a simplified model for nucleon pairing, also provides an appropriate description for small superconducting islands with fixed charge. It includes an all-to-all pairing interaction and is exactly solvable. Electric circuits comprising superconducting islands and quantum dots can be modeled using Hamiltonians that combine instances of the Richardson model and the Anderson impurity model, coupled via electron tunneling terms. We have demonstrated that such models can be transformed into matrix-product-operator form using small matrices, enabling solutions through the density matrix renormalization group [1,2]. This method allows for an unbiased study of superconducting quantum devices, capturing key phenomena such as exchange interactions (e.g., Kondo screening, Yu-Shiba-Rusinov subgap states), charge repulsion (e.g., Coulomb blockade, capacitive coupling) [3], and spin-orbit coupling [4]. Our theoretical results agree well with experimental data from hybrid semiconductor-superconductor devices [3,4,5].

References

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Figures

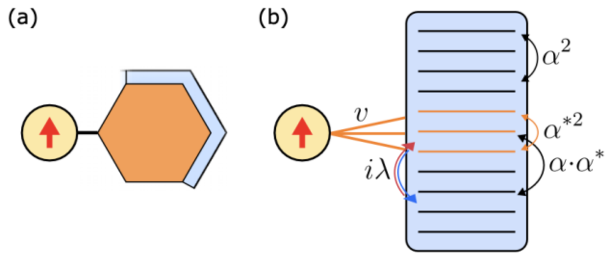

Figure 1: Generalized impurity model with an interacting superconducting bath (Richardson model), with two types of bath levels (superconductor, proximitized semiconductor) and spin-orbit coupling.