Search for Majorana Bound States in Short Chains of Proxmitised Quantum Dots

Bogdan R. Bułka[1] and Karol I. Wysokiński[2]

[1] *Institute of Molecular Physics, PAS, 60-179 Poznań, Poland*

[2] *Institute of Physics, M. Curie-Skłodowska University, 20-031 Lublin, Poland*

Majorana bound states (MBSs), with their nonlocal and non-Abelian properties, are promising for quantum computing, motivating the search for suitable host platforms. Early proposals using proximitised semiconducting nanowires with strong spin–orbit coupling in magnetic fields proved highly sensitive to disorder, often producing spurious zero modes. More recent proposals [1] instead focus on a small number of well-controlled quantum dots, reducing disorder effects.

In this work, we propose a different hybrid platform composed of a chain of N quantum dots (NQD), each proximitised by a common s-wave superconductor as well as a semiconductor with strong spin–orbit coupling – a *sandwich structure*: superconductor–NQD–semiconductor. Crossed Andreev reflections (CAR), accompanied by spin-flip hopping (SFH), are crucial for the formation of MBSs in this spinful chain [2]. Like in the previous paper [3], we show that CAR and SFH processes are dual within the Bogoliubov–de Gennes formalism. Our effective model consists of two equivalent sublattice chains with staggered hopping and pairing terms.

Our study focuses on nontrivial topological features in short chains composed of a small number of quantum dots (N=3,4,5 or 6). In particular, we analyze the role of chiral symmetry in protecting topological states. We demonstrate that onsite energy detuning provides a controllable mechanism to break the duality and can serve as a quantitative tool to assess the robustness of MBSs. As shown earlier for a 2QD system [3], MBSs appear at the chain ends for a well-defined set of parameters α_0, known as *sweet spots*. However, as the number of dots N increases, the MBSs become more robust. Deviations from the sweet spot $(\alpha - \alpha_0)$ shift the energies from the canonical zero value according to $(\alpha - \alpha_0)^{(N-1)}$, indicating less stringent fine-tuning requirements.

We also investigate charge transport as an experimental probe for local/nonlocal transport properties and examine the efficiency of decoherence processes. For this purpose, two normal electrodes are attached to the outermost quantum dots. We derive exact analytical expressions for the transmission coefficients of our 3-terminal system, describing particle transfer between the normal electrodes and the superconductor. In the sweet spot limit, the transmission coefficients exhibit perfect long-range CAR across the entire chain, accompanied by electron entanglement. Our research clarifies the interaction-driven formation of MBSs, while neglecting superconducting phase fluctuations expected to destroy these states in longer chains.

References:

[1] T. Dvir et al., Nature 614, 445 (2023); A. Borodin et al., Nat. Nanotechnol. 20, 726 (2025).
[2] M. Luethi, et al., Phys. Rev. B 110, 245412 (2024).
[3] B.R. Bułka, T. Domański, K. I. Wysokiński, arXiv:2510.17379