Experimental proposal to probe the extended Pauli principle

Nika Akopian [a]

Lucas Fabian Hackl [b, †]
Dayang Li [a,†]
Matthias Christandl [c]

[a] *Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark*
[b] *School of Mathematics and Statistics & School of Physics, The University of Melbourne, Melbourne, Australia*
[c] *QMATH, Department of Mathematical Sciences, University of Copenhagen, Copenhagen, Denmark*
[†] *Equal contribution*

dayli@fotonik.dtu.dk

Fundamental principles in Physics — such as the well-known Pauli exclusion principle — lie at the core of the entire discipline with far-reaching implications: from the electron shell structure of atoms to the stability of matter itself, including neutron stars. The extended Pauli principle is not an exception — it too provides a fundamental constraint on the natural occupation numbers of any pure fermionic state. It is, for instance, an important benchmark for the simulation of fermionic quantum matter.
So far, however, it has never been accessed experimentally. Here, we propose an experiment [1] in a multi-quantum-dot system capable of producing the highly entangled fermionic states necessary to reach the regime, where the inequalities of the extended Pauli principle become relevant. Our proposal combines recent theoretical results revealing an onion-like structure of barriers limiting the allowed entanglement and experimental advances that enable us to transcend these barriers by carefully controlling the quantum states. The multi-quantum-dot system and coherent fermionic operations in our proposal are recently developed by us in [2]. We simulate our state preparation procedures in realistic structures, including all main decoherence sources, and find fidelities above 0.97. All highly entangled states comply with the extended Pauli constraints well within error margins.
The extended Pauli constraints are present in every fermionic system. Our proposal therefore opens up a standardized pathway for experimental exploration of the extended Pauli principle.

References

[1] L. Hackl, D. Li, N. Akopian, and M. Christandl, Experimental proposal to probe the extended pauli principle (2021),arXiv:2107.05961 [quant-ph].
[2] D. Li and N. Akopian, Location qubits in a multi-quantum-dot system (2021), arXiv:2107.05960 [quant-ph].

Figures

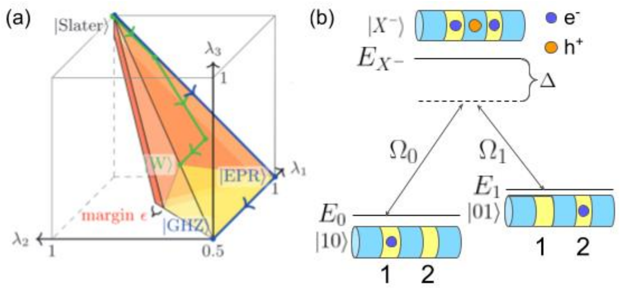

Fig. 1: (a) The all-optical manipulation scheme of our multi-quantum-dot system. A section of a semiconductor nanowire (GaAs or InP) in the Wurtzite (WZ, blue) phase with a pair of crystal-phase quantum dots in the zincblende phase (ZB, yellow). There is a localized spin-orbital for electrons (dark blue dots) on each quantum dot that share a common excited state with a hole (orange dot) in the WZ region. Two laser pulses Ω_0 and Ω_1 of different wavelengths drive the left and right optical transitions respectively, both far detuned from the common excited state by Δ. By exploiting the dynamics of such a system, we coherently manipulate the fermionic states. (b) Our simulation results show that the representative highly entangled fermionic states (EPR, GHZ & W state) can be prepared with high fidelity. Both merit functions $F_1=\lambda_1+\lambda_2-\lambda_3$ and $F_2=\lambda_1+\lambda_2+\lambda_4$ satisfy the extended Pauli constraints $F_1\leq 1+\varepsilon$ and $F_2\leq 2+\varepsilon$ for all three states, taking into account the error margins due to the slightly impure nature of the prepared states.