Quantum advantage in the charging of batteries by repeated interactions

Raffaele Salvia[3], Martí Perarnau-Llobet[2], Géraldine Haack[2], Nicolas Brunner[2], and
Stefan Nimmrichter[1]

[1] *University of Siegen, Physics Department, Walter-Flex-Str. 3, 57072 Siegen, Germany*
[2] *Département de Physique Appliquée, Université de Genève, 1211 Genève, Switzerland*
[3] *Scuola Normale Superiore and University of Pisa, 56127 Pisa, Italy*

We study self-contained collisional models for the charging of a quantum battery by a stream of identical nonequilibrium qubit units, comparing the charging power for coherent and incoherent protocols on an initially empty battery. The battery can be an oscillator, a large spin, or any other linear energy ladder with a ground state, while the qubits are assumed to be resonant with the ladder, which obviates the need for additional work input as they exchange excitations with the battery.

When the qubits are prepared in a population-inverted, incoherent mixture of energy eigenstates, the energy and ergotropy gain in the battery can be described by a generalized classical random walk process with level-dependent rates. We provide an upper bound on the charging power for any incoherent protocol, including adaptive charging strategies. We show that this bound can be broken by non-adaptive protocols with qubits that contain quantum coherence, thus demonstrating a quantum speedup at the level of a single battery. In homogeneous ladder models with level-independent transition rates, the speedup can be attributed to quantum walk-like interference effects. In oscillator and spin batteries, the greatest speedup is reached in the limit when the charging process approximates a coherent Rabi drive.

We show that such a quantum protocol can significantly outperform the most general adaptive classical schemes, leading to 90% and 38% higher charging power for the cavity and large spin batteries respectively. Concerning possible experimental realizations, we characterise the robustness of the quantum advantage to imperfections (noise and decoherence) and consider implementations with state-of-the-art micromasers and hybrid superconducting devices.

[1] Seah et al, Phys. Rev. Lett. 127, 100601 (2021)
[2] Salvia et al, arXiv:2205.00026 (2022)