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Quantum Information Scrambling and Quantum Chaos in Silicon-Based Fermi-Hubbard Quantum Dot Arrays

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Abstract : We investigate entanglement and quantum information scrambling (QIS) by the example of a many-body Extended and spinless effective Fermi-Hubbard Model (EFHM and e-FHM, respectively) that describes a special type of quantum dot array provided by Equal1 labs silicon-based quantum computer. The concept of QIS is used in the framework of quantum information processing by quantum circuits and quantum channels. In general, QIS is manifest as the de-localization of quantum information over the entire quantum system; more compactly, information about the input cannot be obtained by local measurements of the output of the quantum system. In our work, we will first make an introduction to the concept of quantum information scrambling and its connection with the 4-point out-of-time-order (OTO) correlators. In order to have a quantitative measure of QIS we use the tripartite mutual information, in similar lines to previous works, that measures the mutual information between 4 different spacetime partitions of the system and study the Transverse Field Ising (TFI) model; this is used to quantify the dynamical spreading of quantum entanglement and information in the system. Then, we investigate scrambling in the quantum many-body Extended Hubbard Model with external magnetic field Bz and spin-spin coupling J for both uniform and thermal quantum channel inputs and show that it scrambles for specific external tuning parameters (e.g., tunneling amplitudes, on-site potentials, magnetic field). In addition, we compare different Hilbert space sizes (different number of qubits) and show the qualitative and quantitative differences in quantum scrambling as we increase the number of quantum degrees of freedom in the system. Moreover, we find a "scrambling phase transition" for a threshold temperature in the thermal case, that is, the temperature of the model that the channel starts to scramble quantum information. Finally, we make comparisons to the TFI model and highlight the key physical differences between the two systems and mention some future directions of research.

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