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Quantum simulation of chaotic behaviour of the discrete Gross-Pitaevskii equation with ultracold atoms in optical lattices

Classical computing has been successfully applied as a method to solve many a problem in physics since its creation, but it could not be effectively used to model many-body quantum systems due to their exponential complexity in computation time and memory. Quantum computing was proposed to solve this difficulty, but rapid decoherence intrinsic to large systems of quantum qubits is limiting its performance at the moment. Quantum simulation is a compromise between universal quantum and classical computing. On the one hand, quantum simulators do provide quantum computing with exponential gain in memory and performance in comparison to classical computers, but on the other hand they lack universality, since they are specific to a particular problem and for each quantum calculation one has to design a new quantum simulator. The idea behind quantum simulation is to create a controllable quantum system effectively modelling the Hamiltonian of a quantum system under investigation, for some reason unachievable or uncontrollable experimentally. One of the most common and well-studied physical systems currently used for quantum simulation is ultracold atoms in optical lattices, due to its high controllability and a broad range of experimental detection possibilities. A set of 10 Bose-Einstein condensates of ultracold atoms in a ring-shape optical lattice with periodic boundary conditions is considered as a quantum simulator of the discrete Gross-Pitaevskii equation dynamics. Chaotic behaviour of such a system and its largest Lyapunov exponent as a measure of chaos are studied numerically and a method to provide a time-reversal experiment similar to the Loschmidt echo technique in nuclear magnetic resonance is discussed as a promising experimental approach to measure chaotic properties in such a quantum simulator.