Quantum Simulations of Lattice Gauge Theories using Ultracold Atoms in Optical Lattices

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Can high energy physics can be simulated by low-energy, nonrelativistic, many-body systems, such as ultracold atoms? Such ultracold atomic systems lack the type of symmetries and dynamical properties of high energy physics models: in particular, they manifest neither local gauge invariance nor Lorentz invariance, which are crucial properties of the quantum field theories which are the building blocks of the standard model of elementary particles. However, it turns out, surprisingly, that there are ways to configure atomic system to manifest both local gauge invariance and Lorentz invariance. In particular, local gauge invariance can arise either as an effective, low energy, symmetry, or as an "exact" symmetry, following from the conservation laws in atomic interactions. Hence, one could hope that such quantum simulators may lead to new type of (table-top) experiments, that shall be used to study various QCD phenomena, as the con?nement of dynamical quarks, phase transitions, and other effects, which are inaccessible using the currently known computational methods. In this report, we review the Hamiltonian formulation of lattice gauge theories, and then describe our recent progress in constructing quantum simulation of Abelian and non-Abelian lattice gauge theories in 1 + 1 and 2 + 1 dimensions using ultracold atoms in optical lattices.

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