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***Atomic quantum simulations  
of Abelian and non-Abelian Gauge Theories***

Gauge theories, which realize symmetries locally in space and time, play an important role in many areas of physics. In elementary particle physics, an Abelian  $U(1)$  gauge symmetry governs the electromagnetic interaction between electrons mediated by photons, while a non-Abelian  $SU(3)$  gauge symmetry controls the strong interaction between quarks mediated by gluons. In condensed matter physics, gauge symmetries arise, for example, in the description of spin liquids, and in quantum information theory Kitaev's toric code is an Abelian  $Z(2)$  gauge theory. The solution of gauge theories is often very complicated, in particular, in the presence of strong interactions, as between quarks and gluons in a dense neutron star or between electrons in a spin liquid. Numerical simulations of such systems on classical computers suffer from very severe sign problems. Quantum simulators are accurately controllable quantum systems that can mimic other quantum systems. They do not suffer from sign problems, because their hardware is intrinsically quantum mechanical. Recently, using ultracold atoms in optical lattices, quantum simulators have been designed for Abelian and non-Abelian gauge theories. Their experimental realization is a challenge for the foreseeable future, which holds the promise to access physical phenomena, as, for example, the evolution of strongly coupled quantum systems in real time, whose understanding has remained beyond reach of the traditional tools of theoretical physics.