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Towards analog quantum simulations of lattice gauge theories with trapped ions

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Gauge field theories play a central role in nuclear physics and are at the heart of the Standard Model. Despite significant progress in applying classical computational techniques to perform Euclidean simulation of gauge theories, it has remained a challenging task to compute the real-time dynamics of these theories, which describe processes such as the evolution of matter after heavy ion collisions. An exciting possibility that has been explored in recent years is the use of highly-controlled quantum systems to simulate, in an analog fashion, properties of a target system whose dynamics are difficult to compute. Engineered atom-laser interactions in a linear crystal of trapped ions offer a wide range of possibilities for quantum simulations of complex physical systems. Here, we present practical proposals for analog simulation of lattice gauge theories whose dynamics can be mapped into spin-spin interactions in any dimension. In addition, the evolution of the Schwinger model (1+1 QED) is simulated using the effective Hamiltonian describing the interactions of the ions and phonons in a Paul trap. Future possibilities to extend such a mapping to a larger class of gauge field theories include devising higher-order spin interactions and taking advantage of phononic excitations.

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