Quantum Information Science with Trapped Ca+ Ions

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Trapped strings of cold ions provide an ideal system for quantum information processing. The quantum information can be stored in individual ions and these qubits can be individually prepared; the corresponding quantum states can be manipulated and measured with nearly 100% detection efficiency. With a small ion-trap quantum computer based on up to eight trapped Ca+ ions as qubits we have generated genuine quantum states in a preprogrammed way. In particular, we have generated GHZ and W states in a fast and scalable way and we have demonstrated a Toffoli gate operation with trapped ions which was analyzed via state and process tomography. Entanglement swapping was demonstrated on demand and high fidelity CNOT-gate operations were investigated towards fault-tolerant quantum computing. Using logical qubits encoded in decoherence-free subspaces, a universal set of gate operations was implemented and analyzed. With two ions as qubits and using logical operations an experimental state-independent test of quantum contextuality was performed. Employing the quantum information tools with trapped ions allowed for the simulation of the Dirac equation and a quantum random walk.

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