# Researchers realize two coherently convertible qubit types using a single ion species

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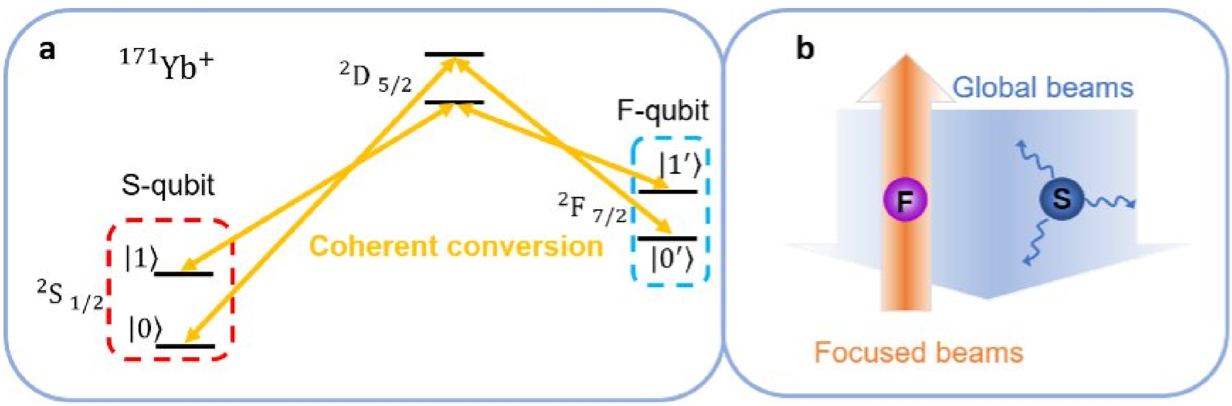


Coherently convertible dual-type qubits implemented by Yb-171 ions. a, One qubit type is encoded in the S_(1/2) hyperfine levels which are insensitive to magnetic field noise, and the other type in the F_(7/2) hyperfine levels. For coherent conversion between the S-qubit and the F-qubit, we transfer the two basis states |0⟩↔|0^'⟩ and |1⟩↔|1^'⟩ simultaneously using narrowband laser beams through the intermediate D_(5/2) levels. b, After preparing an F-qubit using focused laser beams, the crosstalk error due to operations on another S-qubit is suppressed, including state preparation, detection, gates and sympathetic cooling. Credit: Yang et al.

Trapped ion computers are quantum computers in which the qubits (quantum units of information) are ions trapped by electric fields and manipulated with lasers. To avoid crosstalk between nearby qubits, physicists and engineers design these computers using two different types of qubits.

The use of two different types of qubits ultimately enables quantum error connection and the creation of quantum networks, which facilitate the transmission of information in quantum computers. Of the two types of qubits used, one stores and processes quantum information and the other performs auxiliary operations, such as the collection of error syndrome measurements or the execution of sympathetic cooling and photonic entangling.

So far, most engineers developing trapped ion computers employed two different species of ions as these two different qubit types. Researchers at Tsinghua University's Center for Quantum Information, however, have recently showed that two different qubit types could be created using the same species of ion. Their findings, published in *Nature Physics*, could open interesting avenues for the creation of trapped ion quantum devices.

"In ion trap quantum computing, auxiliary operations scatter photons that can destroy the quantum information stored in other qubits, which is known as the crosstalk error," Luming Duan, one of the researchers who carried out the study, told Phys.org. "Previously, researchers had to use two ion species to encode the two types of qubits, which have different transition frequencies, to suppress the crosstalk error. However, controlling multiple ion species is increasingly difficult as the system scales up, and it is also impossible to coherently convert between two species of ions."

To overcome the limitations of previous trapped ion quantum computing approaches, Duan and his colleagues encoded the two different types of qubits in different ground-state manifolds of the same ion species, which had no crosstalk between them. The use of these qubits based on the same ion species could greatly simplify the fabrication of trapped ion devices, while also allowing greater control over its qubits.

"We realized the two types of qubits using two pairs of long-lived energy levels (hyperfine S levels and hyperfine F levels) of the Yb-171 ion that are insensitive to the magnetic field in the environment)," Duan said. "We coherently convert between these two types using narrow-band laser beams through a pair of intermediate levels (hyperfine D levels. The two basis states of the qubit are converted simultaneously using the same laser to suppress the decoherence due to the phase noise of the laser."

Duan and his colleagues evaluated their newly proposed approach to trapped ion quantum computing in an initial proof-of-principle demonstration. This demonstration yielded remarkable results, with their two types of qubits performing important operations while retaining crosstalk with adjacent qubits below 0.06%.

"We demonstrate fast and high-fidelity coherent conversion between the two qubit types, and we demonstrate the required operations on one qubit type, including state preparation, detection, single-qubit gates and sympathetic laser cooling, with a crosstalk error on the other qubit type significantly below the threshold of fault-tolerant quantum computing," Duan said.

The recent study by this team of researchers introduces a new basic toolkit for effectively implementing the dual-type qubit scheme in trapped ion quantum computers using the same ion species. In the future, this toolkit could enable the implementation of large-scale ion trap quantum computers and quantum networks.

"We now plan to improve the conversion fidelity between the two qubit types, and then apply the dual-type qubit scheme to the multi-ion quantum computing setup with in-computation measurements and cooling," Duan added. "We also plan to apply the dual-type qubit scheme in ion-photon quantum network to suppress the crosstalk error."

**More information:** H.-X. Yang et al, Realizing coherently convertible dual-type qubits with the same ion species, *Nature Physics* (2022). DOI: 10.1038/s41567-022-01661-5