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New quantum gate operating on three qubits realized

The research group of Rainer Blatt of the Institute for Experimental Physics of the University of Innsbruck and the Institute for Quantum Optics and Quantum Information (IQOQI) has realized another crucial basic element for producing a quantum computer: a gate consisting of three qubits (quantum bits) or a Toffoli-gate. The researchers have published their findings in the journal Physical Review Letters.

Using the laws of quantum mechanics, quantum computers can process data faster and more efficiently than conventional computers. In addition, they can execute the most difficult algorithms in only a few steps. The basic elements of quantum computers are gates (mathematical operations) operating on one or more quantum bits (qubits). Basic experiments in quantum physics can already be carried out by using one-qubit operations and a two-qubit operation, which was clearly shown by the research group of Rainer Blatt in the last few years. For example, in 2005, they were able to teleport the quantum state of an atom onto another atom in a completely controlled way. Last year the researchers were first in carrying out a deterministic transfer of entanglement (entanglement swapping).

Gates operating on three qubits

While, in principle every algorithm can be realized by one or two qubit gates, when dealing with more complex operations in practical applications, these gates reach their limits. Thus, researchers worldwide are in search of gates operating on three qubits. The experimental physicists in Innsbruck have succeeded in realizing a quantum Toffoli gate operating on three trapped calcium ions each representing a qubit. The target qubit of the Toffoli gate will only be switched when both control qubits acquire value "1" – in all other cases the target qubit does not change.

Essential step towards a quantum computer

This new gate does not only increase the number of quantum gates available in the lab but also increases their efficiency. "In order to realize a Toffoli-gate conventionally, we would have to link six

controlled switch operations", explains Thomas Monz, a Tyrolean junior physicist. "In comparison, our Toffoli-gate promises a three times faster switch operation and, in addition, it shows a lower error ratio." The new gate can be applied to procedures for quantum error correction or quantum mechanical prime factorization. Thus, it is an essential basic element for the development of a quantum computer.

Illustrations can be found at http://www.iqoqi.at/media/download

Realization of the quantum Toffoli gate with trapped ions. T. Monz, K. Kim, W. Hänsel, M. Riebe, A. S. Villar, P. Schindler, M. Chwalla, M. Hennrich, and R. Blatt. Physical Review Letters 2009
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