Russian physicists discover a new approach for building quantum computers

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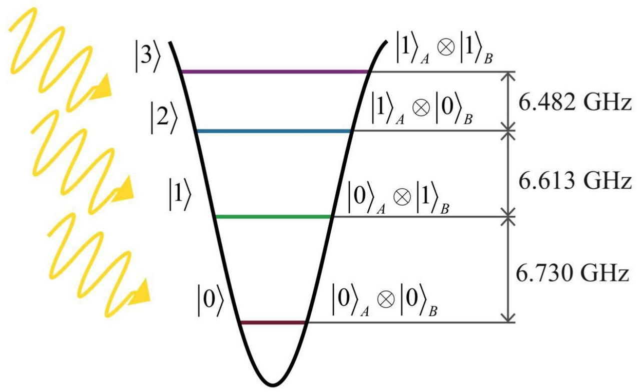

A multi-level quantum system - ququart. Image courtesy of the authors of study. Credit: Moscow Institute of Physics and Technology

Physicists from MIPT and the Russian Quantum Center have developed an easier method to create a universal quantum computer using multilevel quantum systems (qudits), each one of which is able to work with multiple "conventional" quantum elements – qubits.

Professor Vladimir Man'ko, Aleksey Fedorov and Evgeny Kiktenko have published the results of their studies of multilevel quantum systems in a series of papers in *Physical Review A*, *Physics Letters A*, and also *Quantum Measurements and Quantum Metrology*.

"In our studies, we demonstrated that correlations similar to those used for quantum information technologies in composite quantum systems also occur in non-composite systems – systems which we suppose may be easier to work with in certain cases. In our latest paper we proposed a method of using entanglement between internal degrees of freedom of a single eight-level system to implement the protocol of quantum teleportation, which was previously implemented experimentally for a system of three two-level systems," says Vladimir Man'ko.

Quantum computers, which promise to bring about a revolution in computer technology, could be built from elementary processing elements called quantum bits – qubits. While elements of classical computers (bits) can only be in two states (logic zero and logic one), qubits are based on quantum objects that can be in a coherent superposition of two states, which means that they can encode the intermediate states between logic zero and one. When a qubit is measured, the outcome is either a zero or a one with a certain probability (determined by the laws of quantum mechanics).

In a quantum computer, the initial condition of a particular problem is written in the initial state of the qubit system, then the qubits enter into a special interaction (determined by the specific problem). Finally, the user reads the answer to the problem by measuring the final states of the quantum bits.

Quantum computers will be able to solve certain problems that are currently far beyond the reach of even the most powerful classical supercomputers. In cryptography, for example, the time required for a conventional computer to break the RSA algorithm, which is based on the prime factorization of large numbers, would be comparable to the age of the universe. A quantum computer, on the other hand, could solve the problem in a matter of minutes.

However, there is a significant obstacle standing in the way of a quantum revolution – the instability of quantum states. Quantum objects that are used to create qubits – ions, electrons, Josephson junctions etc. can only maintain a certain quantum state for a very short time. However, calculations not only require that qubits maintain their state, but also that they interact with one another. Physicists all over the world are trying to extend the lifespan of qubits. Superconducting qubits used to "survive" only for a few nanoseconds, but now they can be kept for milliseconds before decoherence – which is closer to the time required for calculations.

In a system with dozens or hundreds of qubits, however, the problem is fundamentally more complex.

Man'ko, Fedorov, and Kiktenko began to look at the problem from the other way around – rather than try to maintain the stability of a large qubit system, they tried to increase the dimensions of the systems required for calculations. They are investigating the possibility of using qudits rather than qubits for calculations. Qudits are quantum objects in which the number of possible states (levels) is greater than two (their number is denoted by the letter D). There are qutrits, which have three states; ququarts, which have four states, etc. Algorithms are now actively being studied in which the use of qudits could prove to be more beneficial than using qubits.

"A qudit with four or five levels is able to function as a system of two "ordinary" qubits, and eight levels is enough to imitate a three-qubit system. At first, we saw this as a mathematical equivalence allowing us to obtain new entropic correlations. For example, we obtained the value of mutual information (the measure of correlation) between virtual qubits isolated in a state space of a single four-level system," says Fedorov.

He and his colleagues demonstrated that on one qudit with five levels, created using an artificial atom, it is possible to perform full quantum computations—in particular, the realization of the Deutsch algorithm. This algorithm is designed to test the values of a large number of binary variables.

It can be called the *fake coin algorithm*: imagine that you have a number of coins, some of which are fake – they have the same image on the obverse and reverse sides. To find these coins using the "classical method", you have to look at both sides. With the Deutsch algorithm, you "merge" the obverse and reverse sides of the coin and you can then see a fake coin by only looking at one side.

The idea of using multilevel systems to emulate multi-qubit processors was proposed earlier in the work of Russian physicists from the Kazan Physical-Technical Institute. To run a two-qubit Deutsch algorithm, for example, they proposed using a nuclear spin of 3/2 with four different states. In recent years, however, experimental progress in creating qudits in superconducting circuits has shown that they have a number of advantages.

However, superconducting circuits require five levels: the last level performs an ancillary role to allow for a complete set of all possible quantum operations.

"We are making significant progress, because in certain physical implementations, it is easier to control multilevel qudits than a system of the corresponding number of qubits, and this means that we are one step closer to creating a full-fledged quantum computer. Multilevel elements offer advantages in other quantum technologies too, such as quantum cryptography," says Fedorov.

More information: E.O. Kiktenko, A.K. Fedorov, O.V. Man'ko, and V.I. Man'ko. Multilevel superconducting circuits as two-qubit systems: Operations, state preparation, and entropic inequalities // *Physical Review A* arxiv.org/abs/1411.0157

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