A new twist for quantum systems

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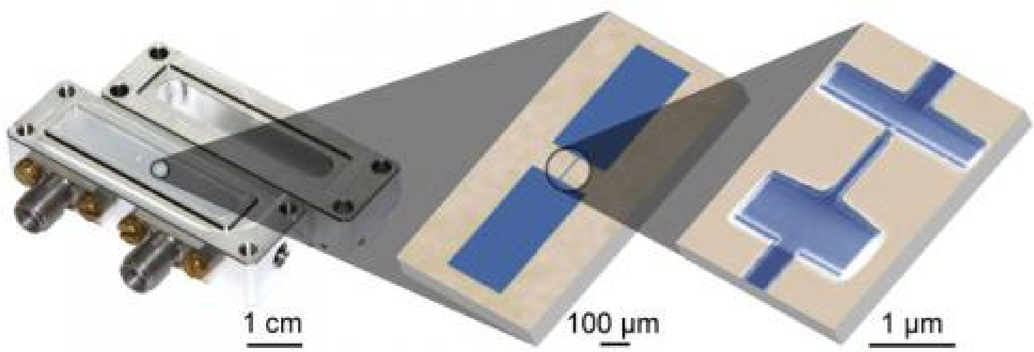

Macroscopic quantum objects: A microwave resonator measuring 32 mm x 15 mm x 5 mm (left) contains superconducting circuits (center and right) that display similar quantum behavior as atoms. Credit: Abdufarrukh Abdumalikov / ETH Zurich

Physicists at ETH Zurich have developed a method for precisely controlling quantum systems by exploiting a trick that helps cats to land on their feet and motorists to fit their cars into parking spots. In the longer run, the method could lead to the development of more reliable quantum computers.

To maneuver a car into a parking spot parallel to the road can be quite a challenge. It would be an easy task, of course, if only the vehicle could move sideways. As this is not possible, the sideways motion must be pieced together – sometimes elegantly, sometimes less so – in a series of forward and backward movements and turns on the steering wheel. Such a finely tuned sequence of movements also enables cats to almost always land on their feet after a free fall. Researchers at ETH Zurich have now used a similar principle for steering a quantum system into a desired state. This new type of control should be useful in situations in which quantum systems must be precisely controlled, not least in the context of quantum computers.

Big quantum world

For their research, scientists in the group of Andreas Wallraff, a professor at the Department of Physics, use "artificial atoms" made of electronic circuits, which they control with microwave pulses. These circuits comprise superconducting components – that is, components in which electric currents can flow without resistance—and typically measure fractions of a millimeter. "For a quantum physicist, these circuits are enormously large objects, but they display behavior that is very similar to that of atoms," explains Wallraff.

Unlike in natural quantum systems, such as atoms, electrons or photons, the design and properties of the quantum circuits can be changed and adapted to different applications. Moreover, the fragile quantum states can survive for several microseconds in these superconducting circuits – a relatively long time for quantum objects. During this time the state can be manipulated with microwave pulses, in order to study the quantum state itself or to make use of it in a quantum computation.

Finding the right twist

These favorable properties notwithstanding, the quantum circuits are highly sensitive to external disturbances (caused, for example, by imperfect shielding), just as natural quantum systems. Under the direction of Stefan Filipp, a scientist in the Wallraff group, the ETH Zurich researchers have now found a possible way to render the quantum states more robust against disturbances. They make use of the geometry of so-called Hilbert spaces; these abstract spaces are the 'natural habitat' of any quantum system. Similarly as a car is driven through a two-dimensional space, a quantum system is steered through its Hilbert space.

Both for parallel parking and for controlling quantum systems, the specific sequence of operations is important. For example, when a motorist first performs all steering-wheel movements and then all forward and backward movements, then she or he will hardly end up in the parking spot. The situation is comparable for the physicists' artificial atoms, which they control with microwave pulses. "We obtain different results depending on the order in which we apply the individual pulses, even if the pulses have an identical shape, the same energy and the same length. This can only be explained by the different routes the system takes through its Hilbert space," says Stefan Filipp.

Path towards a quantum computer

"This is the first time that somebody obtained this specific type of control over an isolated quantum object and was able to study the process in detail," adds Abdufarrukh Abdumalikov, scientist in the Wallraff group. An important factor for the ETH physicists' success was that they could work with relatively short microwave pulses. "This allowed us to perform operations quickly, before the quantum state was irrevocably destroyed," says Abdumalikov.

The researchers expect that their method may provide a viable path towards a practical quantum computer. The development of such devices, which use the laws of quantum mechanics to tackle computational tasks, is a very active field of current study. Quantum physics opens up a whole range of new possibilities for information processing, and one day quantum computers may help solve problems that are computationally too complex for any conventional computer to solve within reasonable time.

More information: Abdumalikov AA, Fink JM, Juliusson K, Pechal M, Berger S, Wallraff A, Filipp S: Experimental Realization of non-Abelian non-adiabatic geometric gates. Nature, 2013, doi: 10.1038/nature12010

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