Immunizing quantum computers against errors

February 28 2019

Credit: fauxels from Pexels

Building a quantum computer requires reckoning with errors—in more than one sense. Quantum bits, or "qubits," which can take on the logical values zero and one simultaneously, and thus carry out calculations faster, are extremely susceptible to perturbations. A possible remedy for this is quantum error correction, which means that each qubit is represented redundantly in several copies, such that errors can be detected and eventually corrected without disturbing the fragile quantum state of the qubit itself. Technically, this is very demanding. However, several years ago, an alternative proposal suggested storing information not in several redundant qubits, but rather in the many oscillatory states of a single quantum harmonic oscillator. The research group of Jonathan Home, professor at the Institute for Quantum Electronics at ETH Zurich, has now realised such a qubit encoded in an oscillator. Their results have been published in the scientific journal *Nature*.

Periodic oscillatory states

In Home's laboratory, Ph.D. student Christa Flühmann and her colleagues work with electrically charged calcium atoms that are trapped by electric fields. Using appropriately chosen laser beams, these ions are cooled down to very low temperatures at which their oscillations in the electric fields, inside which the ions slosh back and forth like marbles in a bowl, are described by quantum mechanics as so-called wave functions. "At that point, things get exciting," says Flühmann, who is first author of the *Nature* paper. "We can now manipulate the oscillatory states of the ions in such a way that their position and momentum uncertainties are distributed among many periodically arranged states."

Here, "uncertainty" refers to Werner Heisenberg's famous formula, which states that in quantum physics, the product of the measurement uncertainties of the position and velocity (more precisely: the momentum) of a particle can never go below a well-defined minimum. For instance, manipulating the particle in order to know its position very well—physicists call this "squeezing"—requires making its momentum less certain.

Reduced uncertainty

Squeezing a quantum state in this way is, on its own, only of limited value if the aim is to make precise measurements. However, there is a clever way out: if, on top of the squeezing, one prepares an oscillatory state in which the particle's wave function is distributed over many periodically spaced positions, the measurement uncertainty of each position and of the respective momentum can be smaller than Heisenberg would allow. Such a spatial distribution of the wave function—the particle can be in several places at once, and only a measurement decides where one actually finds it—is reminiscent of Erwin Schrödinger's famous cat, which is simultaneously dead and alive.

This strongly reduced measurement uncertainty also means that the tiniest change in the wave function, for instance by some external disturbance, can be determined very precisely and—at least in principle—corrected. "Our realisation of those periodic or comb-like oscillatory states of the ion are an important step towards such an error detection," Flühmann explains. "Moreover, we can prepare arbitrary states of the ion and perform all possible logical operations on it. All this is necessary for building a quantum computer. In a next step we want to combine that with error detection and error correction."

Applications in quantum sensors

A few experimental obstacles have to be overcome on the way, Flühmann admits. The calcium ion first needs to be coupled to another ion by electric forces, so that the oscillatory state can be read out without destroying it. Still, even in its present form the method of the ETH researchers is of great interest for applications, Flühmann explains: "Owing to their extreme sensitivity to disturbances, those oscillatory states are a great tool for measuring tiny electric fields or other physical quantities very precisely."

More information: Flühmann C, Nyuyen TL, Marinelli M, Negnevitsky V, Mehta K, Home J: Encoding a qubit in a trapped-ion mechanical oscillator. *Nature*, 27 February 2019, DOI: 10.1038/s41586-019-0960-6

Provided by ETH Zurich