Quantum mechanical behaviour at the macroscale

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Most quantum physics research to date has used particles such as atoms and electrons to observe quantum mechanical behaviour. Professor Mika Sillanpää of Aalto University is now working in the relatively new field of using supercool temperatures to observe quantum features in larger objects

When considering tiny constituents of matter, such as single atoms or molecules, the laws of physics seem to contradict common sense. Atoms or small elementary particles can properly be understood only by quantum physics, which tells that matter and energy consist of small packets, quanta. On the other hand, according to quantum physics, they both can also behave as waves. Without such detailed knowledge of the fundamental laws of nature, modern electronics, for example, could not have been constructed.

Professor Mika Sillanpää of the Department of Applied Physics and O.V. Lounasmaa laboratory at Aalto University is carrying out basic research on micromechanical resonators measured at ultralow temperatures.

Since everything is built with atoms, macroscopic sized objects should, in principle, follow the counterintuitive quantum laws. Quanta are never directly observed, because the quantum waves in sizable objects usually immediately cancel each other out, leaving behind the everyday world. However, if well protected from noise of the surroundings, tangible objects can retain some quantum features. "We use quite sophisticated

cryogenic equipment to cool our samples close to -273°C, known as absolute zero," Sillanpää explains. "At this temperature, the energies of single vibrational quanta are not excessively disturbed by random motion of atoms due to temperature. This allows us to observe quantum-mechanical behaviour in relatively macroscopic objects such as the micromechanical oscillators that we work with."

In Sillanpää's work, the micromechanical resonators are housed inside a superconducting cavity resonator. When the two quantum resonators are put together, they begin to exchange quanta, and their resonant motion thus becomes amplified. This is very similar to what happens in a guitar, where the string and the guitars' echo chamber resonate at the same frequency, but instead occurring in the realms of quantum physics. Instead of the musician playing with the guitar string, the energy source is provided by a microwave laser.

Quantum computing

Recently, Sillanpää's group successfully connected a superconducting quantum bit, or qubit, with a micrometre-sized drumhead and transferred information from the qubit to the resonator and back again. "This work represents the first step towards creating exotic mechanical quantum states," he states. "For example, the transfer makes it possible to create a state in which the resonator simultaneously vibrates and doesn't vibrate."

A qubit is the quantum-mechanical equivalent of the bits used in computers. A traditional bit can be in a state of 0 or 1, whereas a qubit can be in both states at the same time. In theory, this situation allows for a quantum calculation in which the operations are performed simultaneously for many possible computational pathways. In the case of a single qubit, this means zero and one, but as the number of qubits increases, the amount of possible numbers and simultaneous calculations

grows exponentially. The quantum state of a qubit is very fragile and easily disturbed between and during the operations. The key to successful quantum calculation is being able to protect the qubit state from disturbances in the environment.

Although Sillanpää's ERC project is basic research aimed at understanding the laws of nature, there is a technological motivation in the distance: future quantum information processing. Micromechanical resonators can serve as an intermediator of quantum information from the quantum bits via optical fibers even to the other side of the Earth, which could form the basis of a quantum internet.

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