Single-atom probe uses quantum information for the first time

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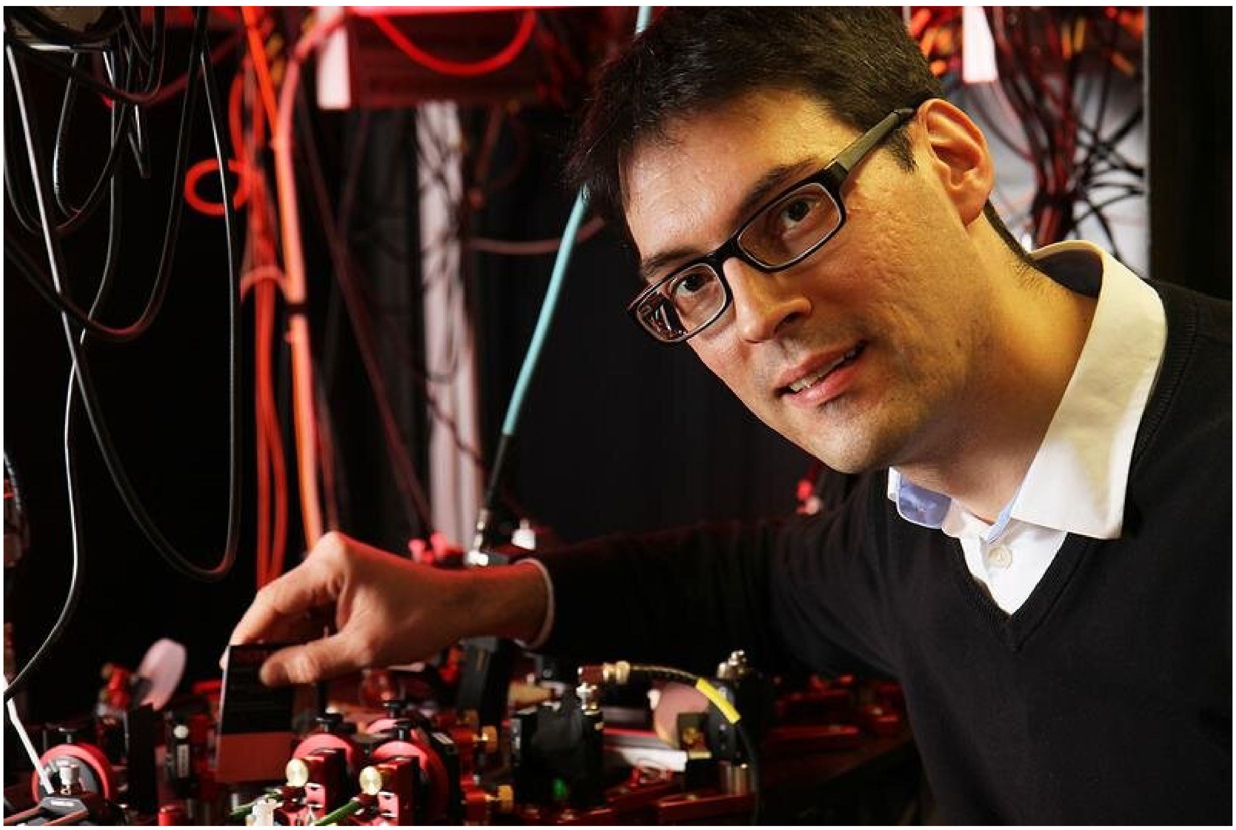

Professor Dr. Artur Widera. Credit: Koziel/TUK

Sensors collect certain parameters such as temperature and air pressure in their proximity. Physicists from Kaiserslautern and a colleague from Hanover have succeeded for the first time in using a single cesium atom as a sensor for ultracold temperatures. To determine the measured data, they used quantum states—the spin or angular momentum of the atom. With these spins, they measured the temperature of an ultra-cold gas and the magnetic field. The system is characterized by a particularly high sensitivity. Such sensors could be used in the future, for example, to investigate quantum systems without interference. The work was published in the journal *Physical Review X*.

In their experiments, scientists led by Professor Dr. Artur Widera, who studies quantum systems, observed individual cesium atoms in a rubidium gas cooled down to near absolute zero. The temperature is only a billionth of a fraction of a degree above this zero point. In their current study, they have investigated whether the spin states of the cesium atom can be used to gain information. "The term spin refers to the intrinsic angular momentum of an atom," explains Professor Widera of Technische Universität Kaiserslautern (TUK). "In cesium, there are seven different orientations for this spin." The research focused on the gas temperature.

Once the single cesium atom is introduced into the rubidium gas, the rubidium atoms collide with it. "This allows angular momentum to be exchanged between the atoms until a balance of spin is achieved," explains Dr. Quentin Bouton, lead scientist and first author of the study. The researchers measure the spin of the individual atom and can thus determine the temperature. Comparing this method with conventional measuring methods, where physicists obtain the same temperature value, confirms its success.

The special feature of the study was the high sensitivity of the measurement. In a typical measurement, it is necessary to bring the sensor into contact with the cold gas and wait until equilibrium is reached. "In fact, for quantum sensors, there is a fundamental limit to their sensitivity in equilibrium. However, we included information about the interactions between cesium and rubidium in advance, so we did not have to wait until the atom was in equilibrium with the rubidium gas," Bouton continues. As a result, the measuring system of the Kaiserslautern researchers has a sensitivity that is about 10 times higher than the fundamental quantum limit requires.

"We only needed three spin exchange processes—in other words, three atomic collisions—to arrive at a result," Bouton continues. Thus, the perturbation of the rubidium gas is also limited to three quanta. This is an important step toward measuring sensitive quantum systems with as little perturbation as possible, which is of interest for future applications in quantum technology.

"This is the first time we have used a single atom as a sensor that uses quantum information and is significantly better than a classic sensor," Widera points out. The physicists also conducted this experiment with magnetic fields and recorded the magnetic states. This novel and highly sensitive sensor is suitable, for example, for examining fragile quantum systems almost without destruction.

In addition to the working group of Professor Widera, Professor Dr. Eberhard Tiemann from Hanover was involved in the work.

More information: Quentin Bouton et al. Single-Atom Quantum Probes for Ultracold Gases Boosted by Nonequilibrium Spin Dynamics, *Physical Review X* (2020). DOI: 10.1103/PhysRevX.10.011018

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