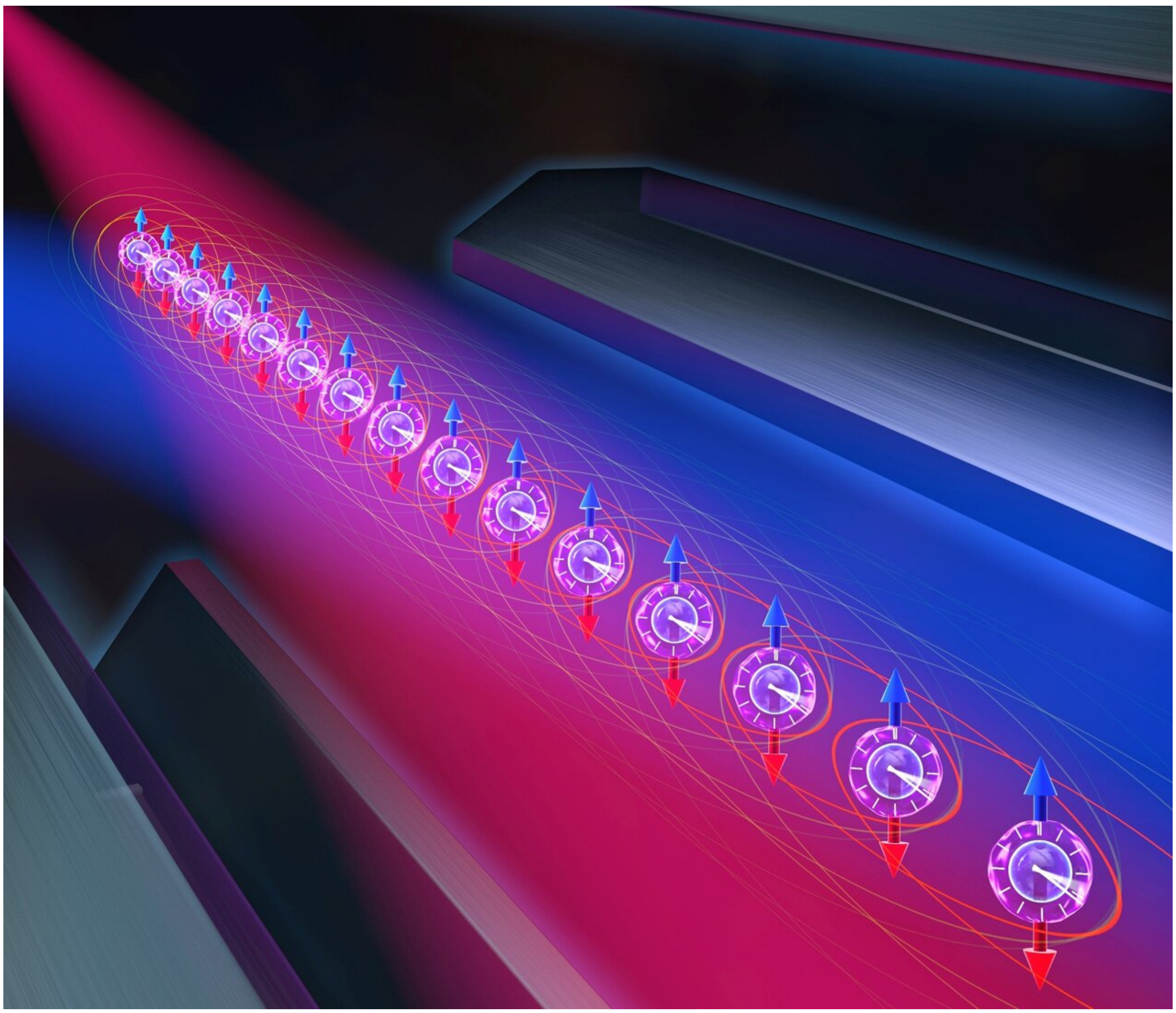
A particular way of creating quantum entanglement may improve accuracy of advanced quantum sensors

August 30 2023



Innsbruck physicists entangled all particles in the chain with each other and produced a so-called squeezed quantum state. Credit: Steven Burrows and the Rey Group/JILA

Metrological institutions around the world administer our time using atomic clocks based on the natural oscillations of atoms. These clocks, pivotal for applications like satellite navigation or data transfer, have recently been improved by using ever higher oscillation frequencies in optical atomic clocks.

Now, scientists at the University of Innsbruck and the Institute of Quantum Optics and Quantum Information (IQOQI) of the Austrian Academy of Sciences led by Christian Roos show how a particular way of creating entanglement can be used to further improve the accuracy of measurements integral to an optical atomic clock's function. Their results have been published in the journal *Nature*.

Measurement error halved in experiment

Observations of quantum systems are always subject to a certain statistical uncertainty. "This is due to the nature of the quantum world," explains Johannes Franke from Christian Roos' team. "Entanglement can help us reduce these errors."

With the support of theorist Ana Maria Rey from JILA in Boulder, U.S., the Innsbruck physicists tested the measurement accuracy on an entangled ensemble of particles in the laboratory. The researchers used lasers to tune the interaction of ions lined up in a vacuum chamber and entangled them.

"The interaction between neighboring particles decreases with the distance between the particles. Therefore, we used spin-exchange interactions to allow the system to behave more collectively," explains Raphael Kaubrügger from the Department of Theoretical Physics at the University of Innsbruck. Thus, all particles in the chain were entangled with each other and produced a so-called squeezed quantum state.

Using this, the physicists were able to show that measurement errors can be roughly halved by entangling 51 ions in relation to individual particles. Previously, entanglement-enhanced sensing mainly relied on infinite interactions, limiting its applicability to only certain quantum platforms.

Even more accurate clocks

With their experiments, the Innsbruck quantum physicists were able to show that quantum entanglement makes sensors even more sensitive. "We used an optical transition in our experiments that is also employed in atomic clocks," says Christian Roos.

This technology could improve areas where atomic clocks are currently used, such as satellite-based navigation or data transfer. Moreover, these advanced clocks could open new possibilities in pursuits like the search for dark matter or the determination of time-variations of fundamental constants.

Christian Roos and his team now want to test the new method in two-dimensional ion ensembles. In the same issue of *Nature*, researchers published very similar results using neutral atoms.

More information: Christian Roos, Quantum-enhanced sensing on optical transitions through finite-range interactions, *Nature* (2023). DOI: 10.1038/s41586-023-06472-z.
www.nature.com/articles/s41586-023-06472-z

Provided by University of Innsbruck