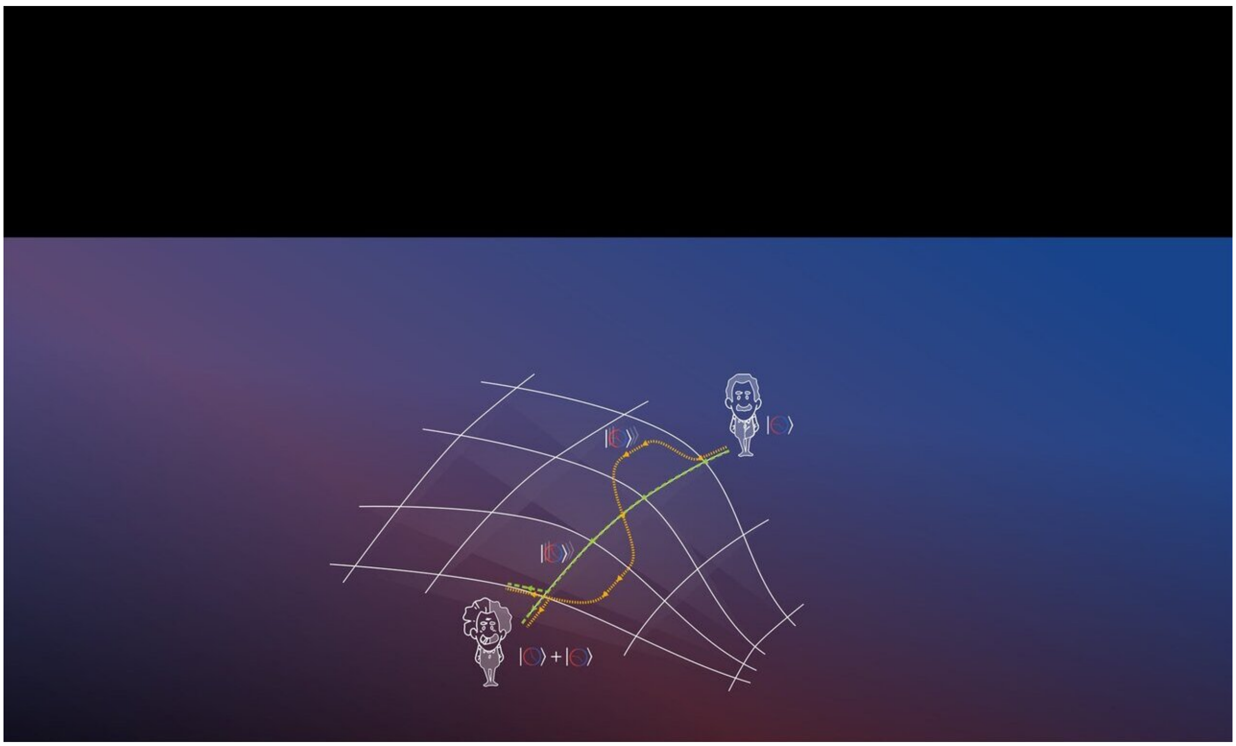
Researchers develop quantum-mechanical variant of the twin paradox

October 7 2019



Graphic illustration of the quantum-mechanical variant of the twin paradox. Credit: Ulm University

One of the fundamental challenges of physics is the reconciliation of Einstein's theory of relativity and quantum mechanics. The necessity to critically question these two pillars of modern physics arises, for example, from extremely high-energy events in the cosmos, which so far can only ever be explained by one theory at a time, but not both theories in harmony. Researchers around the world are therefore searching for deviations from the laws of quantum mechanics and relativity that could open up insights into a new field of physics.

For a recent publication, scientists from Leibniz University Hannover and Ulm University have taken on the twin paradox known from Einstein's special theory of relativity. This thought experiment revolves around a pair of twins: While one brother travels into space, the other remains on Earth. Consequently, for a certain period of time, the twins are moving in different orbits in space. The result when the pair meets again is quite astounding: The twin who has been travelling through space has aged much less than his brother who stayed at home. This phenomenon is explained by Einstein's description of time dilation: Depending on the speed and where in the gravitational field two clocks move relative to each other, they tick at different speeds.

For the publication in *Science Advances*, the authors assumed a quantum-mechanical variant of the twin paradox with only one twin. Thanks to the superposition principle of quantum mechanics, this twin can move along two paths at the same time. In the researchers' thought experiment, the twin is represented by an atomic clock. "Such clocks use the quantum properties of atoms to measure time with high precision. The atomic clock itself is therefore a quantum-mechanical object and can move through space-time on two paths simultaneously due to the superposition principle. Together with colleagues from Hannover, we have investigated how this situation can be realised in an experiment," explains Dr. Enno Giese, research assistant at the Institute of Quantum Physics in Ulm. To this end, the researchers have developed an experimental setup for this scenario on the basis of a quantum-physical model.

The vacuum chamber for the atomic fountain with magnetic shield. Credit: Leibniz University Hannover

A 10-metre-high atomic fountain, which is currently being built at Leibniz University Hannover, plays an essential role in this endeavour. In this atomic interferometer and with the use of quantum objects such as the atomic clock, researchers can test relativistic effects—including the time dilation described in the twin paradox. "In an experiment, we would send an atomic clock into the interferometer. The crucial question is then: Under what conditions can a time difference be measured after the experiment, during which the clock is simultaneously on two orbits after all," explains Sina Loriani from the Institute of Quantum Optics at Leibniz University Hannover.

The theoretical preliminary work of the physicists from Ulm and Hannover is very promising: As described, they have developed a quantum-physical model for the atomic interferometer, which factors in the interaction between lasers and atoms as well as the movement of the atoms—while also taking into account relativistic corrections. "With the help of this model, we can describe a "ticking" atomic clock that moves simultaneously along two paths in a spatial superposition. Moreover, we demonstrate that an atomic interferometer, such as the one being built in Hannover, can measure the effect of the special relativistic time dilation on an atomic clock," recaps Alexander Friedrich, a doctoral researcher at the Institute of Quantum Physics in Ulm. Based on their theoretical considerations, the researchers can already make the assumption that a single atomic clock behaves as predicted in the twin paradox: Relativity theory and quantum mechanics are therefore indeed reconcilable in this scenario. The influence of gravity as assumed by other groups, however, does not seem verifiable in an experimental proposal of this kind.

The theoretically described experiment is anticipated to be put to the test in the new atomic interferometer in Hannover in a few years' time. In practice, the scientists' findings could help to improve applications based on atomic interferometers such as navigation, or acceleration and rotation measurements.

More information: Sina Loriani et al. Interference of clocks: A quantum twin paradox, *Science Advances* (2019). DOI: 10.1126/sciadv.aax8966

Provided by Leibniz Universität Hannover