Twin paradox in atom interferometers

E. Giese[1], S. Loriani[1], A. Friedrich[1] and the Hannover-Ulm team[1,2]

[1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST),
Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany.

[1]Institut für Quantenoptik, Leibniz Universität Hannover,
Welfengarten 1, D-30167 Hannover, Germany.

Atom interferometry has become an excellent tool for high-precision quantum metrology as well as a testbed for the interface of relativity and quantum mechanics. On the other hand, quantum systems in the form of atomic clocks are routinely employed in tests of special and general relativity. The combination of atom interferometry and atomic clocks in terms of quantum-clock interferometry [1, 2] is a promising candidate for the investigation of special and general relativistic effects with and on quantum objects.

Proper time determines the phase of matter waves, such that atom interferometers are in principle susceptible to special-relativistic and gravitational time dilation. Hence, it is conceivable that light-pulse atom interferometers measure general-relativistic time-dilation effects. However, the kinetic symmetry of the interferometer determines whether proper time differences have an impact on the measured interference pattern. We show which type of light-pulse atom interferometers, performed with a single internal atomic state, are sensitive to time dilation. Only geometries that entail the special-relativistic twin paradox display it, whereas gravitational effects do not contribute in lowest order. In such a configuration, recoil measurements that can be used for the determination of the fine structure constant are sensitive to proper-time differences [3, 4, 5].

When each of the two quantum twins in such a setup carries a superposition of two internal states which constitute a clock, the visibility of the signal is modulated, which can be interpreted as a beating of the interferometers associated with each state. We propose a specific geometry for a quantum clock experiment that displays a genuine implementation of the twin paradox in light-pulse atom interferometry and isolates the effect.

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