Atomic fountain clocks are becoming still more stable

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They are at present the most accurate clocks in the world: Caesium fountain clocks furnish the second accurate to 15 places after the decimal point. Until they reach this accuracy, caesium fountain clocks, however, need a certain measurement time.

This time has now been considerably reduced with the aid of a new method developed at the Physikalisch-Technische Bundesanstalt (PTB, Germany) which makes the output frequency of the caesium fountains more stable. For excitation of the caesium atoms, the PTB physicists make use of a novel microwave source: they replace the oscillating quartz by a microwave oscillator which has been stabilized with the aid of a laser to such an extent that its noise becomes insignificant for fountain operation. For this purpose, techniques were applied which have originally been developed for optical atomic clocks which are regarded as the atomic clocks of the future. Now these previous competitors can complement one another, and the technology of the optical clock leads to a considerable improvement of the established caesium clocks. The results are currently published in the journal *Physical Review A*.

Caesium fountains are more accurate than "normal" atomic caesium clocks, because in fountains the caesium atoms are cooled down with the aid of laser beams and come ever slower - from a rapid velocity at room temperature to a slow "creep pace" of a few centimetres per second at a temperature close to the absolute zero point. Thus, the atoms remain together for a longer time so that the physicists have considerably more time to measure the decisive property of the caesium atoms which is required for the "generation of time": their resonance frequency. When a maximum of atoms has changed into an excited state, the frequency of the exciting signal is measured - those approximately nine billions of microwave oscillations which must elapse until exactly one second has past.

In this way, the second has been defined in the International System of Units, SI. Realization of the second is achieved the more accurate, the finer the frequency of the microwave signal is tuned to the resonance frequency of the atoms and the lesser the microwave signal varies around the optimal value. This noise is considerably reduced with the aid of the new technique.

The new technique no longer employs an oscillating quartz for microwave generation, but a microwave oscillator which can be excellently stabilized with the aid of extremely stable lasers. For this purpose, a so-called optical comb is used - a technique which has been developed for the establishment of optical atomic clocks. In the case of these atomic clocks, no microwave transitions, but optical transitions with frequencies five orders of magnitude above the microwave frequencies are used. For their well-aimed excitation, these transitions require extremely low-noise laser light which is generated with the aid of lasers which have been stabilized to special high-quality resonators. For measurement, the frequency of this laser light can be converted with the aid of the optical comb into microwave or low-frequency oscillations which finally allow the second pulses to be generated.

For use with a fountain, the microwave oscillator - which has been pre-stabilized by the highly stable laser and the optical comb - is slowly readjusted by the fountain output signal (like formerly the quartz oscillator). The results so far achieved show an improvement of the relative frequency instability by approximately 50% which leads to a reduction in the measurement times by a factor of 3.2. Instead of in three days, a measurement can then, for example, be performed in one day. The experiments show without a doubt that the microwave oscillator stabilized by the laser does no longer furnish any noise contribution so that the quantum projection noise limit has been reached. This noise is given by the quantum nature of the caesium atoms. This is caused by the fact that in clock operation, the atoms can never definitely change into the excited state, but that this always happens with a certain probability which leads to a noise contribution: the quantum projection noise.

The results clear the way for further improvements of the instability by increasing the atomic numbers used in the fountain clock. Improved instabilities are not only favourable as regards the required measurement times, but also allow systematic frequency-shifting effects to be investigated in closer detail. They are, therefore, also indispensable for future reductions in the overall uncertainty of the clock. This allows a fruitful interaction: while the fountains benefit from the technology of the optical clocks, the development of the latter benefits from the more exact fountain clock as an improved reference.

More information: Reaching the quantum limit in a fountain clock using a microwave oscillator phase locked to an ultrastable laser, S. Weyers, B. Lipphardt, and H. Schnatz, Phys. Rev. A 79, 031803(R) (2009) link.aps.org/doi/10.1103/PhysRevA.79.031803

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