New 'pendulum' for the ytterbium clock

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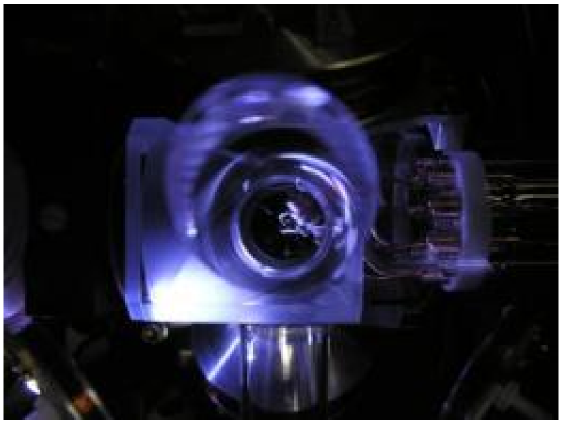

This is the ion trap of the ytterbium clock at PTB. Credit: PTB

The faster a clock ticks, the more precise it can be. Due to the fact that lightwaves vibrate faster than microwaves, optical clocks can be more precise than the caesium atomic clocks which presently determine time. The Physikalisch-Technische Bundesanstalt (PTB) is even working on several of such optical clocks simultaneously. The model with one single ytterbium ion caught in an ion trap is now experiencing another increase in accuracy. At PTB, scientists have succeeded in exciting a quantum-mechanically strongly "forbidden" transition of this ion and – in particular – in measuring it with extreme accuracy. The optical clock based on it is exact to 17 digits after the decimal point. The results are published in the current edition of the scientific journal *Physical Review Letters*.

Optical transitions are the modern counterpart of the pendulum of a mechanical clock. In atomic clocks, the "pendulum" is the radiation which excites the transition between two atomic states of different energy. In the case of caesium atomic clocks, it lies in the microwave range, in the case of optical clocks in the range of laser light so that their "pendulum" oscillates with higher velocity and optical clocks are – consequently – regarded as the atomic clocks of the future.

In the experiment performed at PTB, the scientists devoted themselves to a special forbidden transition. In quantum mechanics, "forbidden" means that the jump between the two energy states of the atoms is almost impossible due to the conservation of symmetry and angular momentum. The excited state can then be very persistent: In the case investigated here, the lifetime of the so-called F-state in the ytterbium ion Yb+ amounts to approx. 6 years. Due to this long lifetime, an extremely narrow resonance – whose linewidth only depends on the quality of the laser used – can be observed during the laser excitation of this state. A narrow resonance line is an important prerequisite for an exact optical clock. At the British National Physical Laboratory (NPL), the sister institute of PTB, the laser excitation of this Yb^+-F state from the ground state was achieved for the first time in 1997. As the transition is, however, strongly forbidden, a relatively high laser intensity is required for its excitation. This disturbs the electron structure of the ion as a whole and leads to a shift of the resonance frequency so that an atomic clock based on it would exhibit a rate depending on the laser intensity.

At PTB it has now been possible to show that alternating excitation of the ion with two different laser intensities allows the unperturbed resonance frequency to be determined with high accuracy. Due to this, it has become possible to investigate other frequency shifts often occurring in atomic clocks – e.g. by electric fields or the thermal radiation of the environment. It has turned out that these are unexpectedly small in the case of the Yb^+-F state, which can be attributed to the special electronic structure of the state. This is a decisive advantage for the further development of this atomic clock. In the experiments at PTB, the relative uncertainty of the Yb^+ frequency was determined with $7 \cdot 10^{-17}$. This corresponds to an uncertainty of the atomic clock of only approx. 30 seconds over the age of the universe.

Both groups at NPL and PTB have measured the frequency of the Yb+ transition with their caesium clocks and the results agree within the scope of the uncertainties ($1 \cdot 10^{-15}$ and $8 \cdot 10^{-16}$) which are mainly determined by the caesium clocks. In a research project recently approved within the scope of the European Metrology Research Programme, the two institutes will in future cooperate with other European partners even more intensively in the development of this optical clock. In the case of the Yb^+ ion, it is of particular interest that it has two transitions which are suitable for optical clocks: Less strongly forbidden, but also very precise, the excitation of the D-level can be used at a wavelength of 436 nm. This opens up the possibility of investigating the accuracy of the optical clock by frequency comparisons of the two transitions in one ion, without having to refer to a caesium clock.

More information:
PTB experiment:
N. Huntemann et al.: High-accuracy optical clock based on the octupole transition in $^{171}Yb^+$. *Phys. Rev. Lett.* 108,090801 (2012)

NPL experiment:
S. A. King et al.: Absolute frequency measurement of the 2S1/2 – 2F7/2 electric octupole transition in a single ion of $^{171}Yb^+$ with 10-15 fractional uncertainty. *New J. Phys.* 14, 013045 (2012)

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