New Research Promises Better Atomic Clocks

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(PhysOrg.com) -- The most accurate timekeepers in the world are atomic clocks, which tell time based on the absorption of a very specific and unchanging microwave frequency, which induces electrons in an atom to “jump” from one particular energy level to another. But to improve atomic clocks further, a new basis is needed.

Research in recent years points to a better candidate: the optical transition. Here, the frequency of absorbed visible light is used instead of microwave radiation. Although the frequency of this absorbed light is never exact - there is always a bit of “fuzziness” - optical transitions have narrower linewidths than microwaves ones. This means a clock based on an optical transition would be, in theory, a more accurate clock.

Scientists from the UK's National Physical Laboratory, Oxford University, and Imperial College London have been studying optical transitions that take place in very cold atoms. Recently, they published work showing how they greatly improved a measurement of a very fine, very weak optical transition in a single ytterbium ion. Their research could help lead to atomic clocks that are the most accurate yet.

The researchers loaded one ytterbium ion into a trap that holds the ion in place using a radio-frequency electric field. They chilled the ion with a laser, a process in which the laser “pumps” heat away from the ion. They then used probe laser light with a specific wavelength, 467 nanometers, to drive the specific electronic transition they were interested in. This was successful as a result of a tricky laser alignment process.

"Whilst there are also other optical clock possibilities in other atoms and ions, this absorption at 467 nanometers in the ytterbium ion is particularly interesting because it is the narrowest optical transition available from a theoretical viewpoint," said the paper's corresponding researcher, Patrick Gill, to *PhysOrg.com*. "However, it should be recognized that the eventual experimental limitation on the linewidth of the transition and also the uncertainty of the clock will depend on how narrow and stable the probe laser can be made."

Because the transition of interest is so weak and spectrally narrow, it is difficult to spatially overlap the probing laser beam so that it is tightly focused on the ion and simultaneously know that the frequency is exactly right. This was achieved by overlapping the probe with a tracer beam at the so-called ion cooling wavelength (369 nanometers), which, even from a single ion, generates a relatively strong fluorescence signal. They watched the effect on this fluorescence when the probe beam hit the ion at the right frequency. This "quantum jump" detection process, as it is known, is a well-used method to detect weak clock absorptions from a single ion.

Their alignment approach, along with techniques that increased the experiment's mechanical stability, led Gill and his colleagues to achieve an uncertainty in the frequency measurement of $2x10^{-14}$, or two parts in 100 trillion, which is a 50-fold improvement over previous reported measurements for this particular transition.

"But we still need to develop a narrower probe laser to drive the octupole clock transition more efficiently and without perturbing the ion's spectrum too much. This will lead to further improved measurements," said Gill.

More information: Frequency measurement of the $^2S_{1/2}$-$^2F_{7/2}$ electric octupole transition in a single $^{171}Yb^+$ ion, *Phys. Rev. A*, 79, 033403

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