New record for measurement of atomic lifetime

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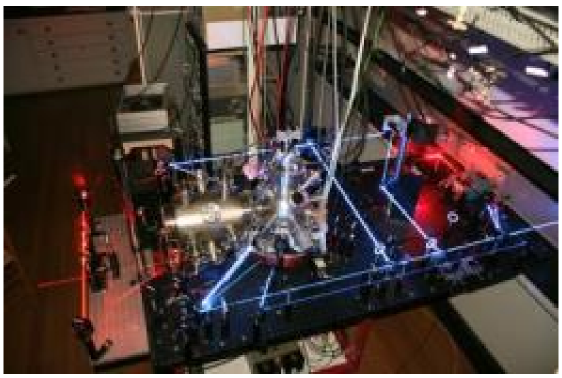

The experimental setup in the laboratory. The atoms are captured in the magneto-optical trap in a vacuum chamber in the middle of the image using ultraviolet laser light (blue rays). The magnetic coils sit inside the chamber. The red laser light is used to transfer the atoms to the metastable state. Credit: Niels Bohr Institute

Researchers at the Niels Bohr Institute have measured the lifetime of an extremely stable energy level of magnesium atoms with great precision. Magnesium atoms are used in research with ultra-precise atomic clocks. The new measurements show a lifetime of 2050 seconds, which corresponds to approximately ½ hour. This is the longest lifetime ever measured in a laboratory. The results have been published in the scientific journal *Physical Review Letters*.

The experiment consists of magnesium atoms which are captured using laser light in a so-called magneto-optical trap and cooled to near absolute zero, minus 273 degrees Celsius. Then the atoms are energized with laser light, which causes the electrons to jump from their ground state into a higher energy level. This higher energy level is called an excited state, but this state is usually very unstable and normally decays within a few nanoseconds. However, some special states may live much longer, up to several seconds or more before they decay, and are therefore called metastable states.

Extremely long lifetime

"Some atoms are easy to manipulate, while others are more difficult to get to jump into an excited state and the harder it is to get them to jump, the longer they last. We have been working with the magnesium-24 isotope, which is the most common form of magnesium. This atom has a metastable state, which is very difficult to excite, but using a special technique we have been able to transfer the magnesium atoms to the metastable state and measure a lifetime for this state of 2050 seconds. This is an extremely long lifetime", explains atomic physicist Philip G. Westergaard, who as part of the research group under the leadership of Jan W. Thomsen at the Niels Bohr Institute is working towards developing an atomic clock based on ultra-cold magnesium atoms.

To be more precise, the measurement revolves around the lifetime of the quantum mechanical state of two electrons in the third electronic shell for magnesium-24. In order to perform the lifetime measurement, up to 108 (hundred million) magnesium atoms are captured and cooled using laser light in a magneto-optical trap. Then the atoms are excited to the metastable state and transferred to a magnetic trap, where the lifetime can be measured.

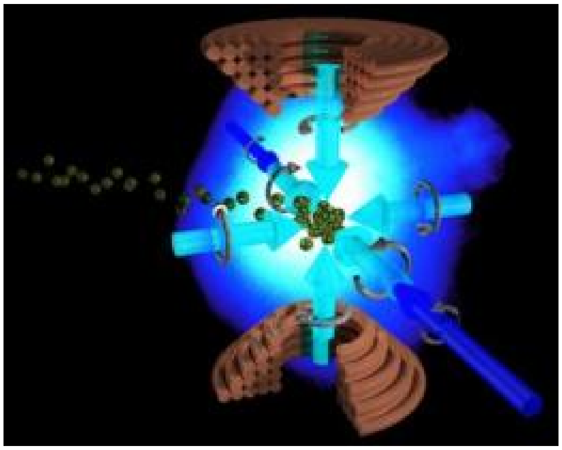

Illustration of the magneto-optical trap (MOT). The atoms (green spheres) are captured and cooled using three pairs of opposing laser beams (blue arrows) and a magnetic field generated by coils placed above and below the atoms. Credit: Niels Bohr Institute

In order to rule out systematic effects on the measured value, several sources of errors were measured. This included cooling the entire experiment down to below 0 degrees Celsius using dry ice, though without it affecting the result. The final uncertainty of the result was 5.5 %, which is a rather small uncertainty for this type of measurement. This means that the measurement can be used to verify theoretical predictions in quantum physics and help to make more accurate theoretical models of multi-electron systems.

Extremely accurate atomic clock

The long lifetime of the excited state of the magnesium atoms will have an impact on the advancement of ultra-precise atomic clocks, which the research group at the Niels Bohr Institute is working to develop.

The atomic clock consists of a gas of magnesium atoms, which is held in a trap using laser light and magnetic fields and cooled down to minus

273 degrees C. In this state the researchers can exploit the quantum properties of the atoms and get them to function like a clock with a pendulum. The electrons of the atoms move in fixed orbits around the nucleus and using ultra-stable laser light you can get the electrons to jump back and forth between these orbits, and this is what constitutes the pendulum in the atomic clock.

"Our new results with keeping the atoms in the excited state for a very long time give us better control of the electrons jumping between orbits and this means that the quantum uncertainty is reduced. This can be used to develop an atomic clock that is so accurate that it only loses one second per 900 million years", explains Jan W. Thomsen.

Ultra-precise atomic clocks can be used to verify Einstein's general theory of relativity as well as test whether constants of nature change over time, for example, the fine structure constant, which describes the size of the electron energies of the atomic structure. In addition, atomic clocks can be used for navigation, for example for GPS, and high-speed telecommunications.

More information: *Physical Review Letters*: Reference is volume 107, page number 113001 prl.aps.org/toc/PRL/v107/i11

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