Single magnesium ion brought to standstill by means of novel, simple laser cooling

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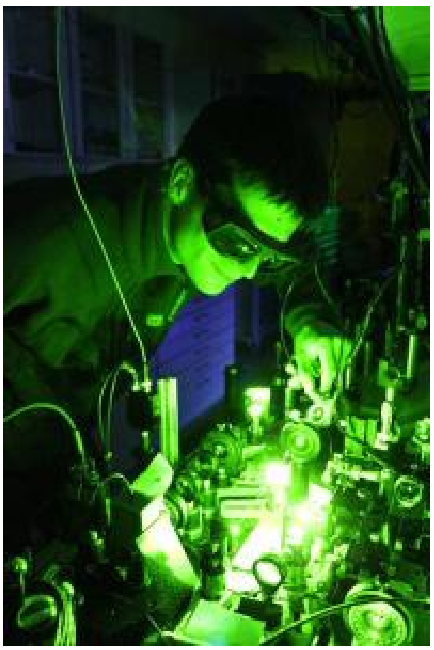

B. Hemmerling is adjusting the magnesium laser system. Credit: PTB

Quantum logic is quite a new and absolutely fascinating field of physics and might – ultimately – lead to the fabrication of a quantum computer. And it could also aid the search for the "theory of everything" – the missing link between traditional physics and quantum physics. One of the fundamental questions hereby is whether fundamental constants possibly vary. To prove this in the case of the fine-structure constant, for instance, we have to measure the spectral lines of atoms (i.e. their inner structure) more accurately than ever before. Quantum logic spectroscopy provides such a method. Physicists from the QUEST Institute at the Physikalisch-Technische Bundesanstalt (PTB) and from the Leibniz University of Hanover have come one decisive step closer to this goal: instead of complex laser arrangements, all they need is one single laser source to bring a single magnesium ion to a complete standstill. Then they use this ion to determine the properties of another ion. The new method has been published in the specialised journal *Applied Physics B*.

The new research results constitute another step towards the conclusion of a scientific dispute, namely the question as to who can provide better measurement results to compare astronomic measured data with laboratory references. In astronomic investigations, light is analysed which is generated by quasars and has traversed all kinds of elements, e.g. in cosmic dusts, on its way down to the Earth. The individual components can be identified via the spectral lines of the quasar light. If these spectra differ from those that researchers have determined in the laboratory for the same elements, this possibly suggests that the fine-structure constant has changed. These reference comparisons have yielded contradictory results. In order to clarify these contradictions, different systematic aspects have to be investigated. One of the fundamental aspects hereby is the accuracy rate of the known laboratory spectra. The complex internal structure of atoms and ions, which leave a characteristic trace in the quasar light, make it difficult for traditional spectroscopic procedures to tackle them.

The scientists from QUEST (Centre for Quantum Engineering and Space-Time Research) have conceived a clever ruse to detect elements such as, e.g., iron or titanium ions which are difficult to measure directly. These ions can be coupled with other ions of the same charge, by mutual repulsion of the charged particles. Together, the two partners form a quantum-mechanical system in which one of the partners can be manipulated and measured and, thus, provides information about the other partner. In this case, the first partner, the so-called "logic ion", is a magnesium ion. It is somehow used as a "sensor" for the "spectroscopy ion" to be investigated, which can be, e.g., ion, titanium or calcium. To this end, the magnesium ion first has to be cooled by means of laser light. Hereby, so much energy is subducted from it that it no longer moves. Then, the researchers can excite specific atomic transitions inside the "spectroscopy ion" – i.e. they can basically cause electrons to move to another energy level. This, in turn, provokes a recoil kick which sets both ions into motion and can be detected very sensitively on the "logic ion".

The first step of the laser cooling procedure has become much easier now. Usually, complicated systems involving several laser sources, which fill large optical tables, are used for the purposes of cooling. This group of scientists has developed a novel and, comparably, compact laser system which only needs a single source. To this end, the frequency of light emitted by a fibre laser is multiplied with the aid of non-linear crystals up to a wavelength of 280 nm. An opto-electronic modulator generates a sideband on the light which is resonant with a transition in the magnesium ion and is used for the state preparation and laser cooling of the ions. "With this arrangement, we have succeeded in cooling a single magnesium ion in a Paul trap down to the ground state of a longitudinal mode", explains Piet Schmidt, Head of the QUEST Institute at PTB. "In a next step, we want to test this cooling scheme for an ionic crystal consisting of a magnesium ion and a calcium ion and then, in yet another step, a frequency comb will be used as a spectroscopic laser."

If this works out, laboratory precision measurements of elements such as titanium or iron (including their isotope shifts) might come within reach. This would contribute to clarifying the question of whether the fine-structure constant possibly varies.

More information: Hemmerling, B.;Gebert, F.; Wan, Y.;Nigg, D.;Sherstov, I.V. ; Schmidt, P.O.: A Single Laser System for Ground

State Cooling of 25Mg+. Applied Physics B 104, 583-590
www.springerlink.com/content/y777025q15412107/

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