

Application Note QUANTUM TECHNOLOGY

**National Institute of Standards and Technology (NIST), Gaithersburg
Menlo Systems, Martinsried**

High-Flying Electrons May Provide New Test of Quantum Theory

Authors: Joseph N. Tan (NIST, Atomic Spectroscopy Group), Benjamin Stein (NIST, Public Affairs Office), and Benjamin Sprenger (Menlo Systems)

Contact email address: b.sprenger@menlosystems.com

Researchers at the National Institute of Standards and Technology (NIST) and Max Planck Institute for Physics in Germany believe they can achieve a significant increase in the accuracy of one of the fundamental constants of nature by boosting an electron to an orbit as far as possible from the atomic nucleus that binds it. The experiment, outlined in a recent paper, would not only mean more accurate identifications of elements in everything from stars to environmental pollutants but also could put the modern theory of the atom to the most stringent tests yet.

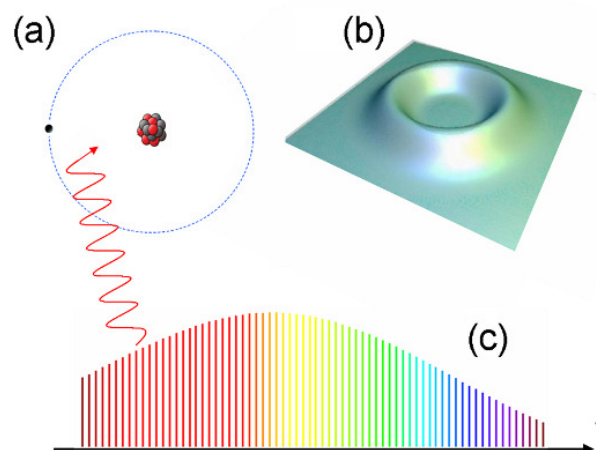


Figure: (a) In a Rydberg atom, an electron (black dot) is far away from the atomic nucleus (red and grey core). (b) Probability map for an electron in a Rydberg atom shows that it has virtually no probability of being near the nucleus in the center. (c) An optical frequency comb for producing ultraprecise colors of light can trigger quantum energy jumps useful for accurately measuring the Rydberg constant. Image credit: NIST

The physicists' quarry is the Rydberg constant, the quantity that specifies the precise color of light that is emitted when an electron jumps from one energy level to another in an atom. The current value of the Rydberg constant comes from comparing theory and experiment for 23 different kinds of energy jumps in hydrogen and deuterium atoms. Researchers have experimentally measured the frequencies of light emitted by these atomic transitions (energy jumps) to an accuracy of as high as 14 parts per quadrillion (one followed by 15 zeros), but the value of the Rydberg constant is known only to about 6.6 parts in a trillion—500 times less accurate. The main hurdle to a more accurate value comes from uncertainties in the size of the atom's nucleus, which can alter the electron's energy levels and therefore modify the frequency of light it emits. Another source of uncertainty comes from the fact that electrons sometimes emit and reabsorb short-lived "virtual photons," a process that also can slightly change the electron's energy level.

To beat these problems, NIST physicist Peter Mohr and his colleagues propose engineering so-called hydrogen-like Rydberg atoms—atomic nuclei stripped of all but a single electron orbiting in a high-flying energy level far away from the nucleus. In such atoms, the electron is so far away from the nucleus that the latter's size is negligible. As another advantage, the electron would accelerate less in its high-flung orbit, reducing the effects of "virtual photons" it emits. These simplifications allow theoretical uncertainties to be as small as tens of parts in a quintillion (one followed by 18 zeros).

NIST researchers Joseph Tan and colleagues hope to implement this approach experimentally using an Electron Beam Ion Trap (EBIT). The idea would be to strip an atom of all its electrons, cool it and let it capture a single electron in a high-flying orbit. Then the researchers can use a sensitive instrument known as a frequency comb to measure the light absorbed by this Rydberg atom. When compared with the elegant theory, the ultraprecise frequency measurements in such highly-ionized Rydberg atoms would yield an improved value for the Rydberg constant with enough sensitivity to reveal possible anomalies in quantum electrodynamics, the modern theory of the atom.

Recently, a frequency comb was used effectively in an experiment at NIST to investigate a long-standing puzzle in the observed fine-structure splitting among various isotopes of lithium. The high-resolution measurements revealed the importance of quantum interference in exquisite detail with results that validate sophisticated atomic structure calculations and corroborate the potential of high-precision spectroscopy for probing exotic nuclei.

Publications:

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S.F. Hoogerheide, A.S. Aung, J.M. Dreiling, S.M. Brewer, N.D. Guise, and J.N. Tan: Experiments with highly-ionized atoms in unitary Penning traps; *Atoms* 2015, **3**, 367-391 (2015); [open access](#).

Weblinks:

The Atomic Spectroscopy Group at NIST:

<https://www.nist.gov/pml/quantum-measurement-division/atomic-spectroscopy>

Contact information:

Menlo Systems GmbH
Am Klopferspitz 19a
82152 Martinsried
Germany

Tel.: +49 89 189 166 0
Fax: +49 89 189 166 111

Contact person: Dr. Benjamin Sprenger
Email: b.sprenger@menlosystems.com

www.menlosystems.com