Towards high-precision spectroscopy of the 1S–2S transition in He^+

Fabian Schmid[a], Akira Ozawa[a], Johannes Weitenberg[a,b], Theodor W. Hänsch[a,c], and Thomas Udem[a,c]

[a] *Max Planck Institute of Quantum Optics, Garching, Germany*
[b] *Fraunhofer Institute for Laser Technology ILT, Aachen, Germany*
[c] *Ludwig Maximilian University, Munich, Germany*

The simplicity of hydrogen and hydrogen-like systems allows for extremely accurate predictions of their energy levels using bound-state quantum electrodynamics (QED). These theory values contain fundamental constants, most importantly the Rydberg constant and the nuclear size. By comparing theory and experiment, these constants can be determined and the validity of the theory itself can be tested.

The frequency of the extremely narrow 1S–2S two-photon transition was measured in atomic hydrogen with a relative uncertainty below 10^{-14} [1, 2]. This value can be combined with measurements of other transitions in order to extract values for the Rydberg constant and the proton size [3].

We are currently setting up an experiment to do spectroscopy of the 1S–2S transition in the simplest hydrogen-like ion, He^+. This could give new insights into a so-far unresolved discrepancy between different determinations of the proton charge radius which is known as the *proton radius puzzle* [4]. Furthermore, interesting higher-order QED corrections scale with large exponents of the nuclear charge which makes this measurement much more sensitive to these corrections compared to the hydrogen case [5]. Finally, He^+ ions are charged particles that can be trapped and cooled in an ion trap. This greatly reduces systematic effects due to particle motion that dominate the uncertainty in the hydrogen measurements.

However, driving this transition requires narrow-band radiation at 61 nm. This lies in the extreme ultraviolet (XUV) range where no refractive optics and no laser sources exist. We will therefore perform direct frequency comb spectroscopy by converting an infrared high power frequency comb to the XUV using high harmonic generation in a gas target. The He^+ ions will be trapped in a Paul trap and sympathetically cooled by co-trapped Be^+ ions.

This talk will give an overview of the planned experimental setup and report on its current status.

---

[1] C. G. Parthey *et al.*, Phys. Rev. Lett. **107**, 203001 (2011)
[2] A. Matveev *et al.*, Phys. Rev. Lett. **110**, 230801 (2013)
[3] A. Beyer *et al.*, Science **358**, 79 (2017)
[4] A. Antognini *et al.*, Science **339**, 417 (2013)
[5] M. Herrmann *et al.*, Phys. Rev. A **79**, 052505 (2009)