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Towards testing Fundamental Physics using Ramsey-Comb Spectroscopy on He^{+}+

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Simple atomic systems are the ideal probe to test fundamental physics. For example, for hydrogen the 1S-2S transition frequency can nowadays be calculated with an impressive relative accuracy of 10^{-12} [1], and measurements reach an even higher relative accuracy of 10^{-15}[2]. Combining different measurements in hydrogen has been used to determine fundamental constants such as the Rydberg constant and the proton charge radius. These constants are also required to compare theory with experiment, e.g. to test bound state Quantum Electrodynamics (QED). However, it can lead to conflicting results. Measurements in muonic hydrogen resulted in a surprisingly small proton charge radius [3], known as the "proton radius puzzle". Since then, an increasing number of high-precision atomic physics experiments are performed in order to solve this puzzle.

An alternative system to study QED and finite nuclear size effects is singly-ionized helium. We aim to measure the 1S-2S transition in He^{+} at 30 nm with 1 kHz accuracy. Such a measurement poses a QED test by probing difficult to calculate 2-loop contributions which scale with large powers of the nuclear charge. Those contributions currently limit the theory of the 1S-2S transition in hydrogen-like atoms.

The measurement is performed using Ramsey-comb spectroscopy (RCS) [4], where two pulses from the pulse train of a frequency comb laser (FC) create a Ramsey-like excitation in the optical domain. By selecting different pairs of pulses from the FC we can record a series of Ramsey fringes from which we can accurately determine the transition frequency. Systematics which are constant between different pulse pairs, such as the AC Stark shift, cancel. The pulse pairs are amplified to the mJ-level which enables upconversion of the fundamental at 790 nm to its 25th harmonic (32 nm) using high-harmonic generation (HHG). We drive the transition in He^{+} with two copropagating unequal photons, 790 and 32 nm, in order to enhance the transition probability. The helium ion is trapped in a linear Paul trap and sympathetically cooled with a beryllium ion. Any frequency shift due to the motion of the helium ion is significantly reduced by synchronizing the repetition rate of the laser with the secular frequency of the trap.

In order to characterize possible delay-dependent phase shifts in the HHG process, we performed a measurement of the $5p^6 - 5p^5 8s^2[3/2]_1$ one-photon transition in xenon at 110 nm. We reached the highest accuracy to date with a HHG source [5]. Moreover, the results show that delay-dependent phase shifts are only present at very short pulse delays (< 16 ns), not relevant for the future measurement of the 1S-2S transition in He+.

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