First Observation of the He^+ 1S-2S Transition in an Atomic Beam

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Precision spectroscopy of simple, calculable atomic and molecular systems has been an important tool for tests of bound-state quantum electrodynamics, the determination of fundamental constants, and searches for physics beyond the standard model. Singly-ionized helium is a promising alternative system to hydrogen, as high-order QED corrections scale with high powers of the nuclear charge Z [1]. As He^+ is charged, it can be confined in a Paul trap and sympathetically cooled close to the ground state of the trap. To excite the 1S-2S transition, light at extreme ultraviolet (XUV) wavelengths is required, and a method to do precision spectroscopy in this spectral range. We aim to measure this transition with 1 kHz or better accuracy using Ramsey-comb spectroscopy (RCS)[2], combined with high-harmonic generation (HHG)[3].

In RCS, two pulses (near 790 nm) from a frequency comb (FC) pulse train are selectively amplified to the mJ-level, upconverted to the XUV via HHG, and then used to do a Ramsey-type measurement by slightly scanning the repetition frequency of the FC. This is repeated for different pairs of (amplified) pulses of the FC, at different macro-delays that are equal to an integer times the repetition time of the FC. From the relative phase between the Ramsey fringes, the transition frequency is determined, and common-mode phase shifts drop out. For a trapped He^+ ion, this will enable us to cancel the first-order Doppler shift by synchronizing the repetition frequency of the comb to the secular frequency of the helium ion. As a result, Doppler-free excitation will become possible with unequal photons, one at 790 nm, and one at its 25^{th} harmonic (32 nm).

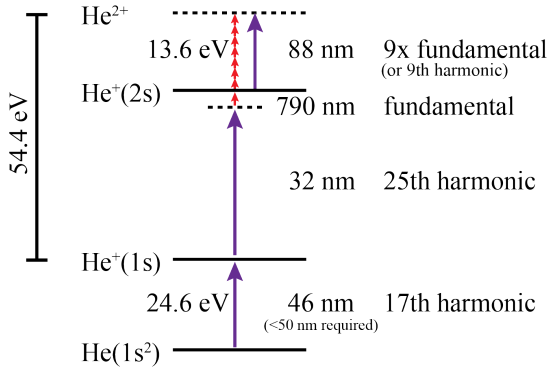

Figure 1: Excitation scheme in the He beam experiment.

We now demonstrate an important step towards this goal with the first laser excitation of the 1S-2S transition in He^+, based on an atomic beam of helium. Within a single 150 fs laser pulse, helium atoms are first ionized to He^+, then excited from the 1S to the 2S state (in He^+) with 32 nm+790 nm, and finally the He^+ ions in the 2S state are ionized again to He^{2+}. By scanning the central wavelength of our frequency comb laser, we can observe the 1S-2S resonance with the He^{2+} signal. We can independently vary the XUV and 790 nm intensity, and show that the observed ac-Stark shifts are consistent with the expected values and are compatible with RCS. This paves the way to high-precision 1S-2S laser spectroscopy of He^+ in an ion trap.

[1] Krauth *et al.*, PoS (FFK2019) 49, (2019)
[2] Morgenweg *et al.*, Nat. Phys. 10, 30–33 (2014)
[3] Dreissen *et al.*, Phys. Rev. Lett. 123, 143001 (2019)