Precision spectroscopy of transitions from the metastable 2 $^3S_1$ state of ^{4}He to high-np Rydberg states

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The metastable He ($(1s)^1(2s)^1$) atom in its singlet (^{1}S) or triplet (^{3}S) states is an ideal system to perform tests of ab-initio calculations of two-electron systems that include quantum-electrodynamics and nuclear finite-size effects. The recent determination of the ionization energy of the metastable $2\,^1$S state of ^{4}He [1] confirmed a discrepancy between the latest theoretical values of the Lamb shifts in low-lying electronic states of triplet helium [2] and the measured $3\,^3\mathrm{D} \leftarrow 2\,^3\mathrm{S}$ [3] and $3\,^3\mathrm{D} \leftarrow 2\,^3\mathrm{P}$ [4] transition frequencies and could not be resolved in the latest calculations [5, 6]. Currently, we focus on the development of a new experimental method for the determination of the ionization energy of the $2\,^3$S state of ^{4}He via the measurement of transitions from the $2\,^3\mathrm{S}_1$ state to np Rydberg states with unprecedented accuracy. Extrapolation of the np series yields the ionization energy with sub-MHz accuracy.

We present the progress in the development of our experimental setup, which features a Zeeman decelerator and transverse laser cooling and involves (i) the preparation of a cold, supersonic expansion of helium atoms in the $2\,^3$S state, (ii) the setup and characterization of a laser system for driving the transitions to the np Rydberg states and (iii) the development of a sub-Doppler, background-free detection method. Further, we will provide example spectra of selected $n\mathrm{p}\,^3\mathrm{P}_J \leftarrow 2\,^3\mathrm{S}_1$ measurements with a prediction of uncertainties for our final measurement campaign.

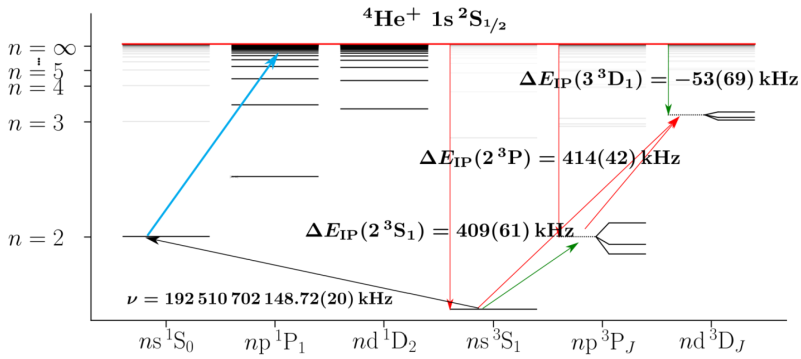

Figure 1: Level diagram of He singlet states (left) and triplet states (right). Comparison of experimentally [1] and theoretically [2] determined ionization energies shown as green and red vertical arrows, where green indicates agreement and red indicates discrepancies.

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[6] V. A. Yerokhin *et al.*, *Phys. Rev. A.* **107**, 012810 (2023).