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Precision spectroscopy of Rydberg states in ^{4}He and ^{3}He

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The metastable He ($(1s)^1(2s)^1$) atom in its singlet ($^1S_0$) or triplet ($^3S_1$) 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 $2\,^1S_0$ 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 $3\,^3D \leftarrow 2\,^3S$ [3] and $3\,^3D \leftarrow 2\,^3P$ [4] transition frequencies. This discrepancy could not be resolved in the latest calculations [5,6].
Recently, we developed a new experimental method for the determination of the ionization energy of the $2\,^3S_1$ state of ^{4}He via the measurement of transitions from the $2\,^3S_1$ state to np Rydberg states.
In this talk, we present the the first results on the ionization energy of metastable helium obtained with improved experimental setup and methods, which include (i) the preparation of a cold, supersonic expansion of helium atoms in the $2\,^3S_1$ state, (ii) the development and characterization of a laser system for driving the transitions to np Rydberg states, (iii) the implementation of a new sub-Doppler, background-free detection method, and (iv) the integration of an interferometer-based retro-reflector canceling the 1^{st}-order Doppler shift to enable Doppler-free spectroscopy. We illustrate its power with a new determination of the ionization energy of $2\,^3S_1$ metastable He with a fractional uncertainty in the 10^{-12} range using extrapolation of the np series.
The first results of similar experiments carried out on the ^{3}He isotope are also presented as part of an effort to determine the difference between the charge radii of the $^3He^{+2}$ and $^4He^{+2}$ nuclei.

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