Precision spectroscopy in electronic and muonic H and He^+

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Ultraprecise spectroscopy in simple systems like atomic hydrogen has been improved in recent years by several orders of magnitude in precision, according to the formidable progress of laser techniques. The H(1S-2S) transition frequency was measured at *MPQ-Garching* to a precison of 10^{-14} using a cold hydrogen beam and the *frequency comb laser* invented at *MPQ*. Further improvements are in sight. This level of precision is appealing to test fundamental physics laws. Comparison with theory is presently limited by the poor knowledge of the proton rms radius r_p. We therefore perform presently an experiment at PSI to measure the 2S-2P energy difference in muonic hydrogen (μp) to 30 ppm in order to deduce r_p to 10^{-3}, twenty times better than from electron scattering data. This will improve the ultimate precision of this bound-state QED test from 6×10^{-6} to 5×10^{-7}. The uncertainty of the Rydberg constant will also be reduced by an order of magnitude.

Bound-state QED has three expansion parameters: α (similar to free QED), $Z\alpha$ (binding), and m/M (relativistic two-body). Particular problems arise in the expansion in $Z\alpha$ which contains also logarithmic terms, $\ln[(Z\alpha)^{-2}]$. Big progress has been achieved in recent years to calculate higher order QED terms of the H(1S) Lamb shift. The expansion of the two-loop self energy in powers of $Z\alpha$ and $\ln[(Z\alpha)^{-2}]$ lead to surprisingly large terms and is therefore considered as prototype for badly converging series. Progress in this field, both from the theoretical and experimental side, is highly desirable.

The group of T. Hänsch at *MPQ* has therefore started a challenging project to improve the precision spectroscopy in hydrogen-like atoms: the measurement of the 1S-2S transition frequency in He^+ by trapping a single He ion and directly exciting the two-photon transition with a XUV frequency comb laser operated at $\lambda = 60$ nm. Since bound-state QED corrections to the energy levels scale like $Z^{4 \ldots 6 \cdots}$, spectroscopy on He^+ offers the possibility to test the interesting QED corrections $\sim$16 times better than in H.

As in the case of H, the uncertainty resulting from the nuclear size term has to be reduced by an order of magnitude. Measuring the 2S-2P energy difference in μ^4He^+ ions to 50 ppm will result in a determination of the ^{4}He nuclear radius to 3×10^{-4}, good enough to exploit the potential of the He^+(1S-2S) experiment. The μHe(2S-2P) experiment can be performed at PSI, with small changes of the setup presently used for μp. The μHe experiment is significantly easier because the gas pressure can be raised from 1 to 30 mbar where the 2S-lifetime is still above 1 μs. Laser pulses at 812 nm can be produced with the existing TiSa laser, optically pumped by our *thin disk laser* developed at *IFSW Stuttgart*. Detectors for the laser-induced 2P-1S transitions at 8 keV will be provided by the *Coimbra group.*