Muonic atoms: from atomic to nuclear and particle physics

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Muonic atoms are atomic bound states of a negative muon and a nucleus. The muon, which is the 200 times heavier cousin of the electron, orbits the nucleus with a 200 times smaller Bohr radius. This enhances the sensitivity of the atomic energy levels to the nucleus finite size tremendously.

By performing laser spectroscopy of the $2S-2P$ transitions in muonic hydrogen we have determined the proton root mean square charge radius $r_p = 0.84087(39)$ fm [1,2], 20 times more precisely than previously obtained. However, this value disagrees by 4 standard deviations from the value extracted from "regular " hydrogen spectroscopy and also by 6 standard deviations from electron-proton scattering data. The variance of the various proton radius values has led to a very lively discussion [3] in various fields of physics: particle and nuclear physics (proton structure, new physics, scattering analysis), in atomic physics (hydrogen energy level theory, fundamental constants) and fundamental theories (bound-state problems, QED, effective field theories). The origin of this discrepancy is not yet known and the various (im)possibilities will be presented here.

An important piece of information regarding the "proton radius puzzle" is provided by spectroscopy of muonic deuterium and muonic helium [4]. In December 2013 we have succeeded for the first time to measure the $2S_{1/2}-2P_{3/2}$ transition in the $\mu^4\mathrm{He}^+$ ion at the Paul Scherrer Institute (Switzerland). As next we will measure transitions also in $\mu^3\mathrm{He}^+$. Here we present preliminary results of muonic deuterium and helium spectroscopy, which beside helping to disentangle the origin of the observed "proton radius puzzle" also provide values of the corresponding nuclear charge radii with relative accuracies of few 10^{-4}. These radii are interesting benchmarks for few-nucleon theories and can be combined with already measured isotope shifts in He and H.

References

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