Hadronic vacuum polarization: contributions to spectra of hydrogen-like atoms and ions revisited

Franziska Hagelstein[1,2], Vadim Lensky[2,†], Bogdan Malaescu[3], Vladimir Pascalutsa[1]

[1]Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, D-55128 Mainz, Germany
[2]Paul Scherrer Insitut, CH-5232 Viligen PSI, Switzerland
[3]LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, 75252 Paris, France
†corresponding author's email: vlenskiy@uni-mainz.de

The unprecedented precision reached by experimental measurements of energy spectra of the simplest atomic systems, hydrogen-like atoms and ions (see, e.g., the most recent CODATA report [1] and references therein), demands high-precision theoretical predictions of the corresponding energy levels to test the underlying physics. While QED provides the overwhelmingly dominant (and, as a rule, calculable to a very high precision) part of the theory results [2], the contributions of hadronic and nuclear degrees of freedom often limit the theoretical accuracy. Their importance has recently been made even more prominent thanks to the experimental progress with muonic atoms (see [3] and references therein), where the short distance between the muon and the nucleus increases the sensitivity to dynamics at nuclear and hadronic scales [4, 5].

Here, we reexamine the leading effect of hadronic vacuum polarization on the hyperfine splitting of normal and muonic hydrogen, as well as muonic $^3\mathrm{He}^+$ ion. In particular, we investigate the effects of the recoil corrections and of the nuclear electromagnetic form factors on the hadronic vacuum polarization contribution. We find that both of these are very important numerically. We compare our results with previous work [6, 7, 8]. The updated values obtained by us are important, in particular, in view of the experiments envisaged by the CREMA and FAMU collaborations that aim to measure the hyperfine splitting of the $1S$ level in muonic hydrogen and muonic $^3\mathrm{He}^+$ [9, 10, 11].

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