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Theory of Lamb Shift in Muonic Hydrogen

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There has been for a while a large discrepancy between the values of the proton charge radius measured by the Lamb shift in muonic hydrogen and by other methods. It has already been clear that theory of muonic hydrogen is reliable at the level of this discrepancy and an error there cannot be a reason for the contradiction. Still the status of theory at the level of the uncertainty of the muonic-hydrogen experiment (which is two orders of magnitude below the discrepancy level) requires an additional clarification. We revisit theory of the $2p - 2s$ Lamb shift in muonic hydrogen. We summarize all the theoretical contributions in order $\alpha^5 m$, including pure quantum electrodynamics (QED) ones as well as those which involve the proton-structure effects. Certain enhanced higher-order effects are also discussed. We basically confirm former QED calculations of other authors, present a review of recent calculations of the proton-structure effects, and treat self-consistently higher-order proton-finite-size corrections. Eventually, we derive a value of the root-mean-square proton charge radius. It is found to be $0.84029(55)$ fm, which is slightly different from that previously published in the literature ($0.84087(39)$ fm [Antognini et al., Science 339, 417 (2013)]).

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