

Exploring Fundamental Constants with High-Precision Spectroscopy of Molecular Hydrogen Ions

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Molecular hydrogen ions (MHIs) are the simplest molecules; they have significant potential for refining our understanding of fundamental physics, e.g. novel tests of CPT invariance, search for new physics, and determination of fundamental constants (FCs). So far, the heteronuclear HD^+ has been the most intensively studied, providing precise data on rovibrational transitions. These have been found to be in good agreement with ab initio predictions, with a few exceptions [1]. Extending the investigations to other isotopologues brings new challenges, particularly with homonuclear MHIs, that present difficulties for laser spectroscopy due to the absence of electric-dipole transitions. We have succeeded in measuring an electric-quadrupole (E2) rovibrational transition in H_2^+ , demonstrating the first vibrational laser spectroscopy of H_2^+ [2]. We have also performed a Doppler-free spectroscopy campaign of H_2^+ and measured two spin components of a first-overtone rovibrational transition. We determined the spin-averaged transition frequency and, in combination with precise theoretical predictions, derived an independent value for the proton-electron mass ratio. The value is consistent with the recent CODATA 2022 value [3] and the uncertainty is comparable, see Fig. 1. This work marks a step towards testing CPT invariance through a comparison of a vibrational transition in H_2^+ with that of its antimatter counterpart, anti- H_2^+ [4, 5]. A long-term perspective for MHI spectroscopy involves measuring a moderately large set of transitions for all or nearly all MHI isotopologues (H_2^+ , D_2^+ , T_2^+ , HD^+ , HT^+ , DT^+) with 1-Hz experimental uncertainties. The combination of such precise measurements with future improved theoretical predictions and H/D data could significantly reduce the uncertainties of m_p/m_e , m_d/m_e , m_t/m_e , and of the triton charge radius, compared to those of CODATA 2022. From this data of purely electronic systems, additionally, proton and deuteron radii could be determined with uncertainties comparable to those of CODATA 2022, thereby enabling a test of lepton universality.

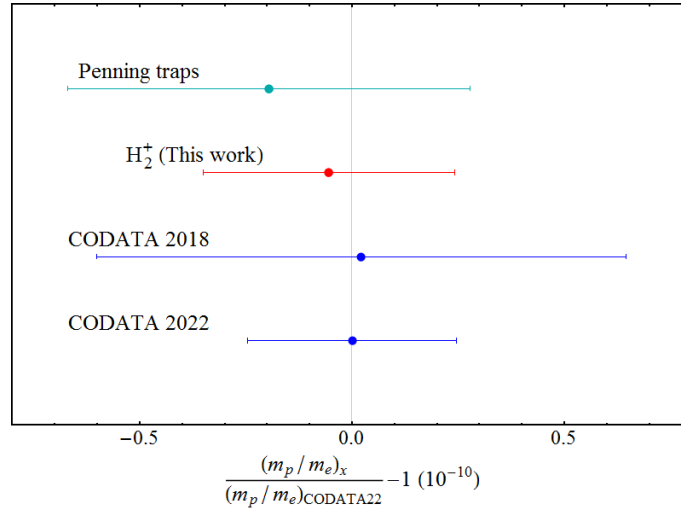


Figure 1: The proton-to-electron mass ratio relative to the CODATA 2022 value. The CODATA 2018 value did not include the results from MHI spectroscopy, whereas these results are incorporated into the CODATA 2022 value.

References

- [1] For an introduction and references, see e.g. S. Schiller, *Contemp. Phys.* **63**, 247 (2022).
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