

INTERNSHIP PROPOSAL

Laboratory name: Laboratoire Kastler Brossel	CNRS identification code: UMR 8552
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Internship location: campus Pierre et Marie Curie, 4 place Jussieu, 75005 Paris	
Thesis possibility after internship: NO	Funding: NO

Electron-mediated interactions between nuclear spins in the HD⁺ molecule

The theory of quantum electrodynamics (QED) allows for very accurate predictions. Comparison between experimental and theoretical values of QED-related quantities can be used for stringent tests of the Standard Model and to determine the values of fundamental physical constants. Well-known examples are the electron's anomalous magnetic moment (related to the fine-structure constant α) or the spectrum of the hydrogen atom (related to the Rydberg constant and proton charge radius).

Recently, measurements of ro-vibrational transition frequencies in hydrogen molecular ions (H₂⁺, HD⁺...), the simplest molecules in nature, have reached a record 12-digit accuracy [1]. Owing to the dependence of ro-vibrational energy levels on particle masses, comparison of experimental results with theoretical predictions [2] has led to an improved determination of the proton-electron mass ratio m_p/m_e [3]. It has also contributed to setting constraints on hypothetical new interactions beyond the Standard Model [4], where the added value of molecular systems resides in their sensitivity to interactions between nucleons. The burgeoning experimental activity in this field gives strong motivation to improve further the theory of hydrogen molecular ions by computing higher-order QED corrections.

The internship will be focused on the hyperfine structure, with the goal of computing a new interaction term, which has been neglected so far, but is becoming highly relevant in view of the rapidly increasing experimental accuracy. In HD⁺, the proton and deuteron spins have an effective mutual interaction resulting from their interactions with the electron's spin. This will be studied following the Non Relativistic QED (NRQED) framework, where QED corrections are described by effective Hamiltonians in a nonrelativistic (Schrödinger) formalism. The work is partly analytical (derivation of effective Hamiltonians), and partly numerical (computation of effective operator expectation values, using highly precise variational wavefunctions). In practice, the relative amounts of theoretical and numerical work can be adapted to the applicant's preferences.

[1] S. Patra et al., [Science](#) **369**, 1238 (2020).

[2] V.I. Korobov, L. Hilico, and J.-Ph. Karr, [Phys. Rev. Lett.](#) **118**, 233001 (2017).

[3] Recommended values of fundamental constants can be found at <https://pml.nist.gov/cuu/Constants/>.

[4] M. Germann et al., [Phys. Rev. Research](#) **3**, L022028 (2021).

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics: NO
Quantum Physics: YES

Soft Matter and Biological Physics: NO
Theoretical Physics: YES