INTERNSHIP PROPOSAL

Laboratory name: Laboratoire Kastler Brossel CNRS identification code: UMR 8552

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Thesis possibility after internship: YES
Funding: NO

QED calculations for Standard Model tests

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, spectroscopy experiments on hydrogen molecular ions (H_2^+ or its isotope HD^+), the simplest molecules in nature, have reached a record 12-digit accuracy [1], creating a strong motivation to improve the theory [2]. Owing to the dependence of ro-vibrational spacings on particle masses, comparison between theory and experiment has led to an improved determination of the proton-electron mass ratio m_p/m_e [1]. It also contributes to setting constraints on hypothetic new interactions beyond the Standard Model [3], where the added value of molecular systems resides in their sensitivity to interactions between nucleons.

Another three-body system of interest is the negative hydrogen ion H^-. An improved determination of its photodetachment threshold (also called electron affinity) is planned, the best measurement so far dating back to more than 30 years. It is therefore desirable to revise and improve theoretical predictions. Precise knowledge of the photodetachment threshold is also useful for the GBAR project [4], which aims at measuring the gravitational behavior of antimatter. In this experiment an antihydrogen atom with very small initial velocity will be prepared by photodetachment from an ultracold antimatter ion $\overline{H}^+$, the antimatter counterpart if H^-, with a well-controlled energy difference with respect to the threshold.

The internship will be devoted to improving the theoretical value of the H^- electron affinity. In this case, sufficient precision can be achieved by considering the leading orders of the QED expansion. The aim of the PhD is to advance further the theoretical accuracy in the hydrogen molecular ions (in particular the hyperfine structure) through the evaluation of higher-order QED diagrams. Calculations are performed using the nonrelativistic QED (NRQED) approach. This involves both analytical and numerical work: one first needs to express the energy correction in a suitable form, then the numerical calculation is performed using very precise wavefunctions obtained by numerical resolution of the Schrödinger equation.

[1] S. Patra, M. Germann, J.-Ph. Karr, M. Haidar, L. Hilico, V.I. Korobov, F.M.J. Cozijn, K.S.E. Eikema, W. Ubachs, J.C.J. Koelemeij, *Proton-electron mass ratio from laser spectroscopy of HD^+ at the part-per-trillion level*, Science **369**, 1238 (2020).
[2] V.I. Korobov, L. Hilico, and J.-Ph. Karr, *Fundamental Transitions and Ionization Energies of the Hydrogen Molecular Ions with Few ppt Uncertainty*, Phys. Rev. Lett. **118**, 233001 (2017).
[3] M. Germann, S. Patra, J.-Ph. Karr, L. Hilico, V.I. Korobov, E.J. Salumbides, K.S.E. Eikema, W. Ubachs, J.C.J. Koelemeij,*Three-body QED test and fifth-force constraint from vibrations and rotations of HD^+*, Phys.Rev. Research **3**, L022028 (2021).
[4] https://home.cern/fr/science/experiments/gbar

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

Condensed Matter Physics: NO Soft Matter and Biological Physics: NO
Quantum Physics: YES Theoretical Physics: YES