PHD PROJECT DESCRIPTION
(4000 characters max., including the aims and work plan to de published online)

Project title: Investigation of Atomic Collisions and Interaction Potentials in Cold Atom Systems

1.1. Project goals

- Implementation of an optical lattice operating at the Hg magic wavelength of 363 nm

- Construction of a system for controlled gas introduction into the vacuum setup

- Studies of collisional shift and broadening of narrow optical lines in ultracold Hg atoms

1.2. Outline

The aim of the project is to utilize the existing research infrastructure at National Laboratory for Atomic, Molecular and Optical Physics (KL FAMO), in particular the dual-species Rb-Hg magneto-optical trap system [Wit17], and to adapt/extend its experimental capabilities by implementing an optical lattice operating at the magic wavelength for Hg atoms (363 nm) [Kat09, Kat11] as well as integrating a system for controlled gas introduction into the vacuum chamber. The modified setup will then be used to conduct precise measurements of collision parameters between ultracold Hg atoms and other atomic species. The studies will focus on measuring the effects of collisional shifts and broadening of ultranarrow optical Hg lines (so-called clock transitions) resulting from interactions with different velocity groups of other atoms.

High-precision clock spectroscopy will be made possible by utilizing the already existing KLFAMO infrastructure, based on the stabilization of laser systems using an ultrastable optical cavity [Lin23] designed to operate at two different wavelengths (1062 nm and 908 nm). After frequency doubling, these wavelengths correspond to the optical transitions from the Hg ground state to the $^3P_0$ state (266 nm) and to the $^3P_2$ state (227 nm).

The results of the collision parameter measurements will then be analyzed based on the theory developed in our group, which concerns the influence of the presence of thermal Rb atoms on the shift and broadening of the Hg $^1S_0 – ^3P_0$ line [Bal26]. These results are extremely important not only for atomic physics, as they allow a better understanding of the atomic energy structure and the potentials of atomic interactions, but also for the development of precision metrology based on Hg clock transitions. Knowledge of the perturbation of clock line positions is crucial in the context of improving the accuracy of atomic clocks [Lud15].

1.3. Work plan

- Construct, and characterize an optical lattice that traps ultracold Hg atoms while minimizing light-induced shifts on the clock transition (M1-M12)
- Develop and integrate a system to introduce controlled amounts of gases into the ultrahigh vacuum chamber (M12-M24)
- Quantify collisional shifts and broadening as a function of atomic density, temperature, and trap parameters (M24-M48)
- Analysis of the experimental results; comparison of the experimental results with theoretical models of interatomic interactions (M24-M48)

1.4. Literature (max. 7 listed as a suggestion for a PhD candidate preliminary study)

[Wit17] M. Witkowski et al., Dual Hg-Rb magneto-optical trap, Opt. Express 25, 3165 (2017),
[Kat11] H. Katori, Optical lattice clocks and quantum metrology, Nat. Photonics 5, 203–210 (2011),
[Kat 09] H. Katori, K. Hashiguchi, E. Yu. Il'inova, V. Ovsiannikov, Magic Wavelength to Make Optical Lattice Clocks Insensitive to Atomic Motion, Phys. Rev. Lett., 103, 153004 (2009),
[Lin23] A. Linek, R. Muñoz-Rodriguez, M. Zawada and M. Witkowski, Dual-Wavelength Ultra-Stable Optical Cavity, Joint Conference of the European Frequency and Time Forum and IEEE International Frequency Control Symposium (EFTF/IFCS) (2023),
[Bal26] R. Bala, A. Linek, M. Witkowski, P. S. Żuchowski, M. Zawada, P. S. Julienne, R. Ciuryło, Isotopic effect on collisional widths and shifts of Hg clock transition induced by cold Rb atoms, arXiv:2605.01908,
[Lud15] Ludlow A. D. et al., Optical atomic clocks, Rev. Mod. Phys. 87, 637 (2015).

1.5. Required initial knowledge and skills of the PhD candidate

- An excellent academic record,
- Good knowledge of quantum mechanics, atomic, molecular and optical physics,