1. OPIS PROJEKTU DOKTOSKIEGO (4000 znaków max., łącznie z celami i planem pracy)

Tytuł projektu:

Experimental studies on ultra-cold Hg-Rb mixture.

1.1. Cele projektu:

- Performing photoassociation Rb*-Hg spectroscopy
- Measurements of Rb-Hg collisional properties.
- Determination of the optical STIRAP conditions.

1.1. Zarys pracy

In recent years, significant progress in ultracold molecular physics has been achieved when the field of ultracold diatomic molecules expanded to heteronuclear classes. Combining alkali and alkaline-earth-like atomic species results in new exciting properties. The main difference between bi-alkali and open-shell molecules is that the latter possess both electric and magnetic permanent dipole moments in the absolute ground state. Therefore, they can be trapped and manipulated with magnetic fields. This leads to a broad range of possible applications covering quantum information [1], quantum simulations [2], precise measurements in the field of fundamental physics (parity violation [3], evolution of fine structure constant [4]), and even creation of exotic quantum states [5]. Considering all the above opportunities, it is no surprise that there is a kind of competition toward creating the ultracold molecular system composed of closed-shell alkaline-earth-like and open-shell alkali atoms. A number of systems have been actively explored, including RbSr [6], RbYb [7-9], LiYb [10], and CsYb [11]. The proposed project will extended this list by RbHg molecules, which, sharing all the exciting properties of the open-shell molecules, provide additional opportunities since the van der Waals interaction of Hg with other atoms is significantly weaker than in Sr or Yb. Together with other aforementioned advantages, it makes molecules containing Hg especially suitable for searching for new kinds of barionic interactions (hypothetical fifth force [12] or corrections to gravitational interactions at the nanometer scale [13]).

Within the project, ultracold Rb*Hg molecules will be created in their electronic excited state by a single-photon photoassociation (PA), and thus an appropriate intermediate state for STIRAP will be determined. These goals will be realized with a tunable cw TiSa laser as a source of photoassociation light at the frequency near the D1 transition in rubidium (795 nm). The laser is already installed and operating in KL FAMO. The first approach will be based on already existing dual-species Rb+Hg magneto-optical trap (MOT) [14]. Given the relatively low density in such a system, the atoms must be transferred into a dipole trap before the photoassociation process. Such a trap will be formed from the high power (up to 20 W of cw operation) laser beam at 1560 nm produced by a single-mode fibre laser already installed in KL FAMO. To detect the trap loss signal due to PA, a set of photodetectors consisting of two CCD cameras, a photomultiplier and photodiodes will be used.The numerical simulations by Borkowski et al. [15] will be used as the basis for determining the possible routes for STIRAP transfer to the ground-state molecular state. The predictions were calculated for the experimental conditions reachable for the experimental system existing in KL FAMO.

The other experimental objective is to measure the collisional properties of a heteronuclear mixture containing ultracold ^{87}Rb and different Hg isotopes. The experimental method is based on a comparative analysis of the dynamics MOT loading. A similar technique was used in our studies on photoionization processes in dual-species MOT [16].

1.2. Plan pracy

1. Rearrangement of the experimental system in KL FAMO for transferring Rb and Hg atoms into an optical dipole trap.

2. Performing photoassociation spectroscopy in the ultra-cold Rb-Hg mixture.

3. Determination of the collisional parameters in Hg-Rb system.

4. Preparation of the experimental arrangement for STIRAP.

5. Verification experimental results against theory.

1.3. Literatura

[1] D. DeMille, *Quantum Computation with Trapped Polar Molecules*, Phys. Rev. Lett. **88**, 067901 (2002).

[2] A. Micheli, G. K. Brennen, and P. Zoller, *A toolbox for lattice-spin models with polar molecules*, Nat. Phys. **2**, 341 (2006).

[3] D. DeMille, et al., *Using Molecules to Measure Nuclear Spin-Dependent Parity*

Violation, Phys. Rev. Lett. **100**, 023003 (2008).

[4] E. R. Hudson, et al., *Cold Molecule Spectroscopy for Constraining the Evolution of the Fine Structure Constant*, Phys. Rev. Lett. **96**, 143004 (2006).

[5] M. Lewenstein, *Polar molecules in topological order*, Nat. Phys. **2**, 309–310 (2006).

[6] V. Barbé, et al., *Observation of Feshbach resonances between alkali and closed-shell atoms*. Nat. Phys. **14**, 881–884 (2018).

[7] N. Nemitz, et al., *Production of heteronuclear molecules in an electronically excited state by photoassociation in a mixture of ultracold Yb and Rb,* Phys. Rev. A 79, 061403(R) (2009).

[8] M. Borkowski, et al., *Scattering lengths in isotopologues of the RbYb system,* Phys. Rev. A **88**, 052708 (2013).

[9] V. D. Vaidya, *et al., Degenerate Bose–Fermi mixtures of rubidium and ytterbium, Phys. Rev. A* ***92****, 043604 (2015).*

[10] H. Hara, et al., *Quantum degenerate mixtures of alkali and alkaline-earth-like atoms,* Phys. Rev. Lett. **106**, 205304 (2011).

[11] A. Guttridge, et al., *Interspecies thermalization in an ultracold mixture of Cs and Yb in an optical trap,* Phys. Rev. A **96**, 012704 (2017).

[12] E. J. Salumbides, et al., *Bounds on fifth forces from precision measurements on molecules*, Phys. Rev. D **87**, 112008 (2013).

[13] M. Borkowski, *et al., Weakly bound molecules as sensors of new gravitylike forces, Sci. Rep.* ***9*** *14807 (2019).*

[14] M. Witkowski et al., *Dual Hg-Rb magneto-optical trap*, Opt. Express **25**, 3165 (2017).

[15] M. Borkowski et al., *Optical Feshbach resonances and ground-state-molecule production in the RbHg system*, Phys. Rev. A **96**, 063411 (2017).

[16] M. Witkowski, et al., *Photoionization cross sections of the $5S_{1/2}$ and $5P_{3/2}$ states of Rb in simultaneous magneto-optical trapping of Rb and Hg,* Phys. Rev. A **98**, 053444 (2018).

1.5. Wymagana wstępna wiedza i umiejętności kandydata na doktora

1. An excellent academic record.
1. Good knowledge of quantum mechanics, atomic, molecular and optical physics.
1. Computer and experimental skills.
1. It is highly beneficial if the master thesis has been done in experimental atomic, molecular or optical physics.

1.6. Oczekiwany rozwój wiedzy i umiejętności kandydata na doktora

PhD student will get experiences in the following areas:
- cold atom physics
- working with ultra-cold atoms
- high resolution spectroscopy
- experimental vacuum and laser systems
- data analysis and confrontations of experimental data with ab initio calculations