PHD PROJECT DESCRIPTION

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

Project title:

1.1. Project goals

- Experimental study of the transport of ultracold atoms in optical potentials (optical lattices, dipole traps, and others) for experiments such as superradiance, investigations of cavity QED, and coherent manipulation of atoms (e.g., toward quantum computing)

- Fundamental physics searches with ultracold atoms and optical atomic clocks.

1.2. Outline

Ultracold atoms enable some of the most precise measurements achievable in modern physics. They are widely used in optical atomic clocks [Lud15], state-of-the-art gravimeters, quantum computing platforms, and a broad range of experiments in fundamental physics [Wci18]. At such low temperatures, atomic motion is strongly suppressed (quantized), allowing for exquisite control over quantum states and interactions.

Cold atoms confined in optical potentials (such as optical lattices and dipole traps [Gri99]) can maintain quantum coherence over timescales of several seconds. In well-isolated environments, these systems can serve as extremely sensitive probes for external fields, making them ideal for precision sensing and metrology, including tests of fundamental physics. However, a key experimental challenge arises from the fact that the optimal conditions for producing ultracold atoms often differ from those required for performing high-precision measurements. Atom preparation typically good access, whereas precision measurements demand exceptional isolation.

The proposed research aims to address this challenge by developing a system based on moving optical potentials, which will allow for the spatial separation of the atom preparation stage from the precision measurement region. In this approach, ultracold atoms are first prepared under optimal cooling and trapping conditions and then transported into a well-isolated environment optimized for high-precision measurements. Such a system would significantly enhance experimental flexibility and performance, enabling new levels of sensitivity in precision metrology and fundamental physics search.

The doctoral research will involve work toward a continuous [Che22] active optical atomic clock [Bob22a, Bob22b] and its use in fundamental physics. The created setup will also be well suited for research in cavity QED, quantum systems, quantum metrology, many-body interactions, and quantum computing.

The project will be realised in the National Laboratory for Atomic, Molecular and Optical Physics (KL FAMO), which is a national consortium established at the Nicolaus Copernicus University (UMK) in Toruń, Poland, for inter-university research. The main areas of research cover ultracold and degenerate matter, optical lattice atomic clocks, Bose–Einstein condensation, quantum state engineering, ion traps, ultracold molecules, cavity ring-down spectroscopy, and optical frequency combs. Hz-level laser frequency control is also implemented for spectroscopic and metrological applications, as well as for new concepts of optical atomic clocks. Other key activities in KL FAMO include both experimental and theoretical studies of new physics beyond the Standard Model, in particular the search for transient signatures of hypothetical dark matter in the form of scalar fields or stable topological defects.

1.3. Work plan

- Creation of a moving optical lattice potential for cold strontium atoms (M1–M12)
- Creation of a 2D crossed optical lattice with different wavelengths (M6–M24)
- Creation of a continuous source of ultracold atoms (M12–M40)
- Experiments with ultracold atoms (M12–M40)
- Writing, submission, and defence of the thesis (M36–M48)

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

[Bob22a] Bober M. and Bennetts S., Design of continuous mHz-line clock apparatus (2022), https://cordis.europa.eu/project/id/820404/results
[Bob22b] Bober M. and Bennetts S., Continuous mHez-line clock apparatus (2022), https://cordis.europa.eu/project/id/820404/results
[Che22] Chun-Chia Chen et al., Nature 606, 683-687 (2022)
[Gri99] Rudolf Grimm et al., Optical dipole traps for neutral atoms, https://arxiv.org/abs/physics/9902072
[Lud15] Ludlow A.D. et al., Rev. Mod. Phys. 87, 637 (2015),
[Wci18] Wcisło P. et al., Science. Advance 4(12) aau4869 (2018)

1.5. Required initial knowledge and skills of the PhD candidate

- The applicant has to have finished a master degree within the last 7 years prior to recruitment in physics or a closely related field
- An excellent academic record.
- Experience through coursework and/or a research project in atomic and molecular physics
- Experience through coursework and/or a research project in quantum mechanics up to the second quantization.
- It is highly beneficial if the master thesis has been done in experimental atomic, molecular or optical physic

1.6. Expected development of the PhD candidate's knowledge and skills

experience, knowledge and skills that are important in the high-tech industry and academia: experimental cold atoms, atom-light interaction, collective effects in quantum gases, high resolution spectroscopy, laser physics and optics, ultra-high vacuum systems, e¬lectronics, programming and other