JAGIELLONIAN UNIVERSITY
IN KRAKOW

Szymon Pustelny
Department of Photonics Institute of Physics Jagiellonian University

Kraków, 10 September 2021

Job offer for a PhD student within the project entitled Nondemolution tomography of a quantum state and detection of spin interaction

We are seeking for PhD candidates interested in joining the project entitled **Nondemolution tomography of a quantum state and detection of spin interaction** realized within SONATA BIS programme by the National Science Centre of Poland. Detailed of the project, along with the important information are given below.

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Details of the offer

Project title: Nieniszcząca tomografia stanów kwantowych i detekcja oddziaływań spinowych (Nondemolution tomography of a quantum state and detection of spin interaction)

Project leader: Szymon Pustelny

Institution: Marian Smoluchowski Institute of Physics

Advertised position: PhD student

Requirements:

Basic requirements:
1. MSc diploma in physics or closely related field.
2. Detailed knowledge of quantum mechanics, optics, and atomic physics.
3. Experience in experimental atomic physics.
4. Good English language abilities.

Required documents:
1. Cover letter.
2. Professional curriculum vitae.
3. Brief description of the research activity to date.
4. Copy of higher education diploma.

Job description:

Experimental research in quantum and nonlinear optics with room-temperature alkali-metal atomic vapor. The main scientific responsibilities are:
1. Development of experimental schemes enabling quantum-state engineering
2. Development and construction of an experimental setup.
3. Measurements of signals in strongly coupled spin system.
4. Development of experimental models explaining observed signals

The selected candidate will be also expected to:
1. Present the results of the project at international conferences and collaboration meetings.
2. Prepare material for publication and contribute to the manuscript preparation
3. Collaborate with the scientific partner of the project.

Project funding: SONATA BIS – ST NCN

Application deadline: 27 September 2021,

00:00 **Application form**: email

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Offer conditions:

We offer:
1. Possibility to participate in an exciting research project at the edge of several interesting disciplines.
2. Collaboration with the renown international team.
3. Access to world-class experimental apparatus.
4. Monthly stipend (2000 PLN).

Additional information
If you are interested in the offer, please send the required documents to **pustelny@uj.edu.pl**.

Based on the received documents, the selection committee will shortlist the best candidates, which may be invited for an interview (in person of online). As a result process, the ranking of applicants will be prepared and position will be offer to the candidates with best ranking (starting from the top of the list).

Project description:
Understanding laws of physics, governing the world at a microscopic level, is one of the main drives of modern science and stimuli for develpment of quantum cryptography, computation, and engineering. Two crucial ingredients of most of quantum-information systems are the information carrier and the processor. Due to its robustness to environmental perturbation, photon is often considered as the carrier, but an optimal system for the processor is yet to be identified. One of the potential platform for that are atoms, so that light-“atom” interaction is a promising framework for quantum-information applications.

Most of the systems hitherto developed for quantum-computation purposes has been complicated and bulky. This originates from the necessity of detecting and manipulating single quantum objects. Application of volumetric systems with a large number of parties has been also considered. A particular example of such a system are hot and cold atomic vapors. While ultra-cold atoms have been explored for the application, this medium does not solve the above-mentioned problem. The alternative are room-temperature atomic vapors, which are easy to handle and deal with. The problem of limited lifetime of quantum states in such media can be also overcome. Despite those advantages, however, an open question regarding the system is:

Are hot atomic vapors "quantum enough" to be useful in quantum-computation applications?

The main concern is to what extent the systems containing 10^9 atoms can be treated as a single quantum-mechanical object. Fundamentally, it cannot, as, for example, absorption of a single photon, rather than causing change of a single-atom internal state, generates entangled state of all the particles in the medium. Still, can mimic such systems in a limitted way? There are other pressing questions regarding the vapor, for example:

What is the role of inhomogeneous broadening and how far it compromises the “quantumness” of the medium? We will first tackle the question theoretically. By comparison between Landau’s single-particle density matrix and von Neumann’s collective density matrix, we will investigate the

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deviations of the two approaches, starting from low-number systems and successively enlarging them. With Monte-Carlo simulations, we will also investigate the role of the inhomogeneous broadening in the quantum-dynamics of the system.

Simultaneously, with the theoretical investigations, we will construct the experimental setup for quantum-state tomography of a hot atomic vapor. The system will be based on light-atom interaction, where light will be used to prepare and monitor the quantum state of the system. The tomography will be done using weak continuous measurements (negligible back action). The polarization state of off-resonance probe light will provide information about optical properties of the medium and hence specific elements of the collective density matrix. To provide access to other elements, magnetic field, mixing the elements together, will be applied at the detection stage. In such a way, the full density matrix will be reconstructed. Completion of the task will require development of a theoretical treatment relating all density-matrix element of multilevel-structure with physical observables.

Development of the reliable tomography technique will allow us to perform research on quantum manipulation. The system will be manipulated using static and oscillating magnetic fields. The fields will be appropriately tuned, timed, and oriented to controllably change the state of the system. In particular, we will demonstrate the ability to negate the system or perform Hadamard-gate operation. Next, we will explore more complicated operations, by selectively coupling ground-state magnetic sublevels, to fully demonstrate the capabilities of the system. Finally, we will demonstrate transfer of a quantum state between two hyperfine states.

The envisioned studies will also allow us to study the spin dynamics of the system. By implementing pulsed optical pumping, special multipass cells, and dedicated data-processing algorithms, we will construct a magnetometer free from systematic errors, offering good temporal resolution. Realization of the project will provide theoretical and experimental tools enabling manipulation and tomography of a collective quantum state of hot atomic vapor and show to which extent the systems can be used in quantum-information purposes.