1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title: *Positron annihilation lifetime spectroscopy in organic liquids*

1.1 Project goals

- Modifications of positron annihilation lifetime spectrometer (PALS) available at Center of Quantum Optics, Nicolaus Copernicus University in Torun, in order to carry out the characterization of liquid samples. Careful calibration of experimental system in a new configuration.
- Characterization of positron lifetimes in chosen organic liquids. Analysis of acquired data using available theories for positron interaction with condensed matter. The investigation of the ortho - positronium to para – positronium formation ratio. Study of the influence of dissolved gasses (oxygen, argon, nitrogen) on the positron lifetimes.

1.2 Outline

Positron annihilation lifetime spectroscopy (PALS) is a powerful and nondestructive characterization technique used to study microstructural properties of the matter. Positron annihilation in solid bodies is used to investigate defects composition and their influence on mechanical, thermal, electrical and optical properties of the material [1]. PALS is also used to study positron annihilation with single atoms and molecules in a gas phase [2] in order to investigate a basic nature of matter-antimatter interaction. Positron behavior in liquid environment was also intensively studied by this experimental technique, however majority of data come from the early times of the method (1960s). Recent re-new interest in liquids is triggered by new medical applications of positrons, particularly the rapid all-body Positron Emission Tomography (PET) [3, 4]. The new applications require a deeper knowledge of positron annihilation in condense (and disordered) matter such as liquids. Formerly performed measurements [5, 6] of organic liquids were focused mainly on the longest lifetime component, in the range of few ns, that is attributed to the annihilation of ortho-Ps (o-Ps), i.e. a positron – electron bound system in triplet spin state. An accurate characterization of shorter lifetime components was difficult in the past due to poor time resolutions of available experimental systems. A new generation of positron lifetime spectrometers allow for much clearer separation of individual lifetimes from measured spectra. In particular it is possible now to characterize such processes as para-Ps (p-Ps) formation and annihilation of unbound positrons in the bulk of material, both effects characterized by much shorter lifetimes than o-Ps. There are many open issues to be investigated in the positron interaction with liquid environments. For instance, it has long been thought that the formation of the ortho- (o-Ps) and para- (p-Ps) states of positronium should strictly result in the intensity ratio $I_{p\text{-}Ps}/I_{o\text{-}Ps} = 1/3$ in the annihilation spectrum as predicted by quantum electrodynamics. This prediction is usually met when Ps is formed in free gases or solid crystals. However, experiments in liquids shows sometimes anomalously high ratios $I_{p\text{-}Ps}/I_{o\text{-}Ps}$ through conventional analysis of the LT spectra into 3 decaying exponential components. This effect requires detailed investigation. Moreover, it is also a well-known phenomenon that the presence of different dissolved gases (such as oxygen [7,8]) may lead to the quenching and /or inhibition of the o-Ps formation. However, the influence of dissolved gases on the shorter lifetime components is still essentially unknown.

In summary, the main goal of this project is a systematic study of positron interaction with organic liquids using PALS technique. The main experimental work will be done with the fast–fast coincidence ORTEC PALS system equipped with plastic scintillators (St. Gobain BC418) and RCA 8850 photomultipliers [9]. One of the main elements of the work will be an adaptation of this setup for the characterization of liquid samples and a careful calibration of new configuration.

1.3 Work plan

- Introduction into basics of the positron annihilation lifetime spectroscopy,
- Introduction into the methodology of PALS data analysis
- Taking part in the design and alignment of new configuration of experimental setup for characterization of liquid samples, calibration of the system
- Characterization of positron lifetimes in chosen organic liquids with dissolved gases, analysis of data

1.4 Literature

1. F. Tuomisto, I. Makkonen, Rev. Mod. Phys. 85, 1583 (2013)
2. M. Charlton, T. Giles, H. Lewis and D. P. van der Werf, J. Phys. B: At. Mol. Opt. Phys. 46, 195001 (2013)
3. P. Moskal et al., Phys. Med. Biol. 64, 055017 (2019).
4. P. Moskal, B. Jasińska, E. Ł. Stępień, S. D. Bass, Nature Rev. Phys. 1, 527 (2019).
5. P.R. Gray , C.F. Cook, G. P. Sturm Jr., J. Chem. Phys. 48, 1145 (1968).
6. O.E. Mogensen, *Positron Annihilation in Chemistry*, Springer, Berlin 1995.
7. G. Consolati, I. Genco, M. Pegoraro, L. Zanderighi, *J. Polym. Sci. B Polym. Phys.* 34, 357 (1996).
8. A. Karbowski, K. Fedus, K. Służewski, J. Bruzdowska, G. Karwasz, *Acta Phys. Pol. A* 132, 1466 (2017).
9. A. Karbowski, J. D. Fidelus, G.P. Karwasz, Mater. Sci. Forum 666, 155 (2011)

1.4 Required initial knowledge and skills of the PhD candidate

The candidate will develop all necessary knowledge and skills during the project realization. However, basic knowledge in at least one of the following areas is expected:

- basics in computer programming (preferably C++, Matlab, LabView),
- basic knowledge in electronics, circuits and mechanical design
- basic knowledge in atomic and condensed matter physics

1.5 Expected development of the PhD candidate's knowledge and skills:

The PhD candidate will gain the knowledge about:
- Positron annihilation spectroscopy
- Principles of matter - antimatter interaction
- Methods for analysing complex experimental data