НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ЦЕНТР
«КУРЧАТОВСКИЙ ИНСТИТУТ»
ИНСТИТУТ ТЕОРЕТИЧЕСКОЙ
И ЭКСПЕРИМЕНТАЛЬНОЙ ФИЗИКИ

To whom it may concern

Report on the Ph.D. dissertation of Mgr. Andrej Babič entitled

**NEUTRINO INTERACTIONS WITH ATOMS
AND DOUBLE-BETA DECAY**

The Dissertation of Mr. Andrej Babič is devoted to modem problems of neutrino physics, namely to the study of neutrino interactions and fundamental properties of neutrinos. The observation of neutrino oscillations has opened a new exciting era in neutrino physics. The observed small neutrino masses have profound implications for our understanding of the Universe and are now a major focus in astrophysics, particle and nuclear physics, and cosmology. At present, the search for the neutrinoless double-beta decay represents one of the most important problems of neutrino physics. Its observation would mean that neutrino is a Majorana particle and would allow concluding about the absolute scale of neutrino masses and possible CP violation in the lepton sector.

The Dissertation of Mr. Andrej Babič is devoted to the study of the particular mode of neutrino scattering on the matter and different modes of the two-neutrino and neutrinoless double-beta decay ($2\nu\beta\beta$ decay and $0\nu\beta\beta$ decay). The brief Introduction highlights the importance of neutrino physics for understanding the universe and presents the main processes of particles and nuclei with the participation of neutrinos. In each of the next four Chapters, a separate physical problem related to neutrinos is discussed in the context of modern theory and phenomenology. The method of solving the problem is presented, and the main results and conclusions are listed.

Chapter 1 is devoted to the problem of inelastic scattering of low-energy solar neutrinos and reactor antineutrinos on bound electrons, leading to the transition of the electron to an excited state in the atom. It was concluded that these processes have practically no impact on the observation of solar neutrino oscillations in the Borexino experiment and measurement of the magnetic moment of neutrinos in the GEMMA experiment.

Chapter 2 presents new channels of double-beta decay, namely double-beta decays into a bound state, in which one β-electron is emitted from the atom, and the second one occupies a vacant bound level of the daughter ion. It was found that both the two-neutrino and non-neutrino modes of the bound-state double-beta decay are strongly suppressed compared to the processes of $2\nu\beta\beta$ decay and $0\nu\beta\beta$ decay, respectively. However, it was found that the SuperNEMO experiment, which is currently under development, has the potential to observe the two-neutrino bound-state double-beta decay.

In Chapter 3, the light and heavy mass mechanisms of the $0\nu\beta\beta$ decay are studied within the seesaw mechanism of the neutrino mass generation within the left-right symmetric models. In this context, an interpolating formula is proposed for the inverse half-life of the $0\nu\beta\beta$ decay, which allows calculating the decay rate for arbitrary neutrino masses. By considering a simplified seesaw type 6×6 neutrino-mixing matrix, the mixing matrix of heavy neutrinos appears to be the Hermitian conjugate of the 3×3 PMNS matrix of light neutrinos. Several simplified benchmark scenarios are considered within the framework of left-sided symmetric models and the conditions for the dominance of the light or heavy neutrino mass mechanisms in $0\nu\beta\beta$ decay are analyzed.

Chapter IV presents the quark condensate seesaw (QCSS) mechanism for the generation of Majorana neutrino masses. The smallness of neutrino masses is due to the large ratio between the lepton number violating scale and the scale of spontaneous breaking of chiral symmetry accompanied by the formation of a quark condensate. The obtained QCSS predictions for the $0\nu\beta\beta$ decay lead to a normal hierarchy of neutrino masses with narrow admissible ranges of neutrino masses.

The main results are briefly covered at the end of the Thesis. The Appendix describes the GRASP2K code for calculation of energies and wave functions of different atomic structures of bound electrons. The Dissertation is well written, with significant care for precision and clarity. The work is sound and based on established and proven theoretical techniques.

The physical problems of the thesis and related publications were formulated by the coauthors of Mr. Andrej Babič. There is no doubt that Mr. Andrej Babič has performed a substantial deal of work in solving the physical tasks and in the preparation of publications. The results are convincing and have already attracted wide interest in the physical community. Mr. Andrej Babič presented them at different conferences, e.g., MEDEX'13, '15, and '17, CNNP2017, and others. The original results presented in the Thesis are worth pursuing further both theoretically and experimentally.

The Dissertation of Mr. Andrej Babič entitled "Neutrino Interactions with Atoms and Double-Beta Decay" makes a valuable contribution to the theoretical understanding of neutrino scattering on atomic electrons, the description of two-neutrino and neutrinoless double-beta decays and uncovers new theoretical schemes for generating Majorana neutrino masses. The Dissertation contains original results and fully meets the requirements for Dissertations for the degree of Doctor of Philosophy. I recommend that Mr. Andrej Babič be awarded the scientific and academic degree of Doctor of Philosophy.

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