Oponentský posudek
dizertační práce

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Název**: Neutrino Interactions with Atoms and Double-Beta Decay**
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The present Work is a collection of 4 selected topics, which belong to the neutrino physics, in particular, it is focused on theory of neutrino scattering, neutrinoless double beta decay and origin of neutrino masses. They have in common the goal to explore new ways towards determination of neutrino properties – interactions and masses – and towards probing the lepton number violation. This is highly topical goal which helps to interpret data from the experimental chase for physics beyond the Standard Model. The objectives of the Ph.D. thesis are 1) Inelastic Scattering of Low-Energy Neutrinos by Atomic Electrons, 2) Neutrinoless and Two-Neutrino Bound-State Double-Beta Decay, 3) Light- and Heavy-Neutrino Exchange in Left-Right Symmetric Model, 4) Quark-Condensate Seesaw Mechanism for Majorana Neutrino Mass.

By the present Work the Author clearly demonstrates his expertise in the field which is proven by the list of top-class publications (PRD, PRC) of which the Author is co-author (together with the leading experts, e.g., M.I. Krivoruchenko, S. Kovalenko, F. Šimkovic). The achieved results are sound, and they advance the understanding of the neutrino weak-interaction phenomena. The Author has significantly contributed to elaboration of the original ideas and to necessary analytical and numerical analyses of the investigated phenomena. From the scientific point of view the Work is of high quality.

From the presentation point of view, the text is understandable, written in high-level English language, with almost no typos, and with strong dedication towards pleasant typographical appearance. The achieved results and the mathematical paths towards them are described at appropriate level. The Work is written with the emphasis to *descriptive* completeness and self-containtness at the expense of, to my taste, lack of enough emphasis to *motivate* various steps, approximations and Ansätze.

In the following I comment the section one-by-one:

0) **Introduction:** It provides nice descriptive introduction to the broadness of neutrino physics. However, to my taste, it lacks the motivation and brief context of the topic selection of the Thesis.
1) **Section 1 - Inelastic Scattering of Low-Energy Neutrinos by Atomic Electrons:** The Author spends first 13 pages for historical/ textbook review of neutrino physics before going into the actual topic. However nice and detailed the text is, it could have been skipped or included into the Introduction section. Instead of the review text, the thorough context of the actual topic should have been presented at first place – What has been achieved in the previous literature by other authors? At which point the Author continues and what new he brings

and improves?

Questions:

- **A.** To my understanding, the sentence "*Note that at zero momentum transfer (|q|= 0), orthogonality of the electron wave functions from Eq. (1.83) implies that no transition can occur: F_{ab}(0) = \delta_{ab}.*" seems to contradict the Fig. 1.9 for 6C and 8O, whose formfactors do not vanish at (|q|= 0). Am I missing something?
- **B.** How relevant is the calculation for realistic experiments with often *molecular* targets, where the spherical symmetry may not be present?

2) **Section 2 - Neutrinoless and Two-Neutrino Bound-State Double-Beta Decay:** This is very clear section and I have no questions here. I just want to emphasise the message from the Conclusion: "*In the future, it would be desirable to generalize the proposed formalism to a more realistic description including the collective effects of electron shells which belong to atoms embedded in a periodic crystal-lattice structure, since under the standard conditions for temperature and pressure most of the double-beta-decay isotopes are solids.*" This is a program of high importance, worth of continuation!

3) **Section 3 - Light- and Heavy-Neutrino Exchange in Left-Right Symmetric Model:**

Questions:

- **C.** Eq. (3.22): What is the motivation for the choice of this particular form of the interpolating function? I guess one can invent many. Can the Author motivate and comment?
- **D.** Eq. (3.23): One expects <p^2> ~ (270 MeV)^2. The product of masses is me.mp ~ (22 MeV)^2. One then needs ratio of the NME's to be MN/Mn ~ 1/100. Where one can understand this ratio from? Is there some obvious reason for such value of the ratio?

4) **Section 4 - Quark-Condensate Seesaw Mechanism for Majorana Neutrino Mass:** The original motivation for this topic is very interesting and worth to be elaborated. The question of the nuclear matter effect to the neutrinoless double beta decay (and other weak processes) is relevant. However, the actual realization via the dim=7 operator, is shown to be a bit cumbersome, the model of the QCSM dominance appears to be quite artificial. Yet, the thorough elaboration brings lot of interesting theoretical physical aspects, which certainly deserves further attention.

Questions:

- **E.** To manipulate the model to exhibit QCSM dominance, the operator H\bar{q}_L u_R is set to be forbidden, to forbid the Yukawa induced current mass term, m_u \bar{u}_L u_R, in this Work. However, in order to achieve massless u-quark, that might not be sufficient. One should also care about the mixing terms of the type \bar{c}_L u_R, \bar{t}_L u_R, \bar{u}_L c_R, \bar{u}_L t_R. Would that somehow interfere with the CKM experimental data? Can the Author comment on that?
- **F.** For the QCSM dominance, the explicit breaking of the u-quark chiral symmetry is crucial. In the Work it is suggested that the origin of the explicit symmetry breaking is the QCD next-to-leading effect and the non-perturbative instanton effect. It is so important piece of the QCSM construction, that I would like to ask the Author to explain it, at least, briefly? Please provide the corresponding Feynman diagram(s) for the mass term and comment the estimate of the resulting value of the mass, m_u ~ 2.33 MeV.

To summarize the report: It is undisputable that the Work contains valuable scientific information which advances the field of neutrino physics. The contribution of the Author is significant in elaborating the original ideas. The presentation has high-quality form, however, to my taste, it is poorer in explaining the motivation and the context of the subjects. In this report, I am posing 6 questions, which, I understand, is quite a lot, but it should be understood as coming from my curiosity and interest to the subjects, and not as a sign of critique. I would be happy to see at least brief answers in the defense presentation, while some details can be postponed to the private communication.

Based on this report I recommend the Work to be accepted as the Ph.D. thesis.

12.07.2022 in Prague
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