



# Editorial: Neutrino Nuclear Responses for Astro-Particle Physics by Nuclear Reactions and Nuclear Decays

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## Editorial on the Research Topic

### Neutrino Nuclear Responses for Astro-Particle Physics by Nuclear Reactions and Nuclear Decays

## 1 AIM OF THE RESEARCH TOPICS

The special issue of the research topics "Neutrino Nuclear Responses for Astro-Particle Physics by Nuclear Reactions and Nuclear Decays" includes 10 contributions by 88 authors. Here we briefly report about the aim of the special issue and summarize the contributions.

Fundamental properties of neutrinos, such as the Majorana nature and the neutrino masses, which are beyond the standard model, are searched for by measuring neutrinoless double beta decays (DBDs) in nuclei. Astro-neutrino nucleosyntheses and astro-neutrino productions are studied by investigating neutrino nuclear interactions. The neutrino nuclear response, given by the square of the nuclear matrix element (NME), is crucial for neutrino studies in nuclei.

The neutrino nuclear responses have been studied experimentally by means of charge-exchange nuclear reactions, nuclear scatterings, and ordinary muon capture reactions and theoretically by various nuclear models. The present special issue reports recent experimental and theoretical studies of the neutrino nuclear responses and discusses perspectives of these studies.

## 2 EXPERIMENTAL STUDIES OF NEUTRINO NUCLEAR RESPONSES

Current experimental approaches to neutrino nuclear responses for DBDs and astro-neutrinos and field perspectives are briefly reviewed by H. Ejiri. Recent experimental studies discuss nuclear weak decays, charge-exchange reactions, double charge-exchange reactions, muon-capture reactions, photon capture reactions, and neutrino reactions. It is emphasized that experimental studies of the neutrino responses and the quenching of the axial-vector coupling are useful for neutrino studies in nuclei.

Ordinary muon captures (OMCs), which are lepton charge-exchange reactions, are used for studying anti-neutrino nuclear responses for astro-neutrinos and the  $\tau^+$  (isospin raising operator) responses for DBDs. Recent experimental studies of OMCs at RCNP Osaka are briefly reviewed by

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I. H. Hashim and H. Ejiri. OMCs give access to neutrino nuclear responses in wide excitation-energy and momentum-transfer regions, which are relevant to neutrinoless DBDs and supernova neutrinos.

Heavy ion charge-exchange reactions are useful tools to probe neutrino nuclear responses. A constrained analysis of the  $^{40}\text{Ca}$  ( $^{18}\text{O}, ^{18}\text{F}$ )  $^{40}\text{K}$  reaction mechanism at 275 MeV is reported by M. Cavallaro et al. The elastic and inelastic scattering data at the same energy are used for the analyses. The direct single charge-exchange reaction mechanism describes the cross-section and the shape of the angular distribution.

Double charge-exchange (DCE) reactions with light heavy ions provide valuable information on neutrino nuclear responses for neutrinoless DBDs. F. Cappuzzello et al. reported the NUMEN project, which aims to access experimentally driven information of NMEs for neutrinoless DBDs by measuring DCE. Recent R&D activities for upgrading the superconducting cyclotron accelerator and the magnetic spectrometer for the DCE reactions are discussed.

In order to study the axial-vector weak coupling in nuclei, H. Matsubara and A. Tamii discussed the quenching of the isovector and isoscalar spin-M1 excitation strengths in  $N = Z$  nuclei. They were studied by measuring the inelastic scattering of 295 MeV protons from the RCNP ring cyclotron. The isoscalar M1 strengths are consistent with the shell-model predictions, while the isovector ones are quenched in comparison with the predictions.

### 3 THEORETICAL STUDIES OF NEUTRINO NUCLEAR RESPONSES AND DOUBLE BETA DECAY MECHANISMS

DBD NMEs have been studied theoretically using proton-neutron quasiparticle random phase approximation (pnQRPA), interacting boson model (IBM), interacting shell model (ISM), and other models. A comparative analysis of the DBD NMEs and the OMC NMEs for  $^{106}\text{Cd}$  is reported by L. Jokiniemi, J. Suhonen, and J. Kotila. The NMEs are derived using the pnQRPA with the large no-core single-particle basis. Good correspondence between the DBD NMEs and the OMC NMEs is found.

A comparison of the microscopic IBM (IBM-2) NMEs and the pnQRPA NMEs for DBD nuclei is made by J. Kotila. The IBM NMEs agree with the pnQRPA ones for most DBD nuclei, except for the nuclei with  $A=110$  and  $124$ , in the case of the light-neutrino exchange. However, the IBM NMEs disagree with the pnQRPA NMEs in the case of the heavy-neutrino exchange. Detailed discussions are made for the two models.

ISM calculations for the  $^{82}\text{Se}$  DBD with the left-right weak-boson exchange are reported by Y. Iwata and S. Sarkar. The DBD NMEs for the  $\lambda$ -mechanism (the left-right weak-boson exchange) and the neutrino-mass mechanism (light neutrino exchange) are evaluated, and bounds on the neutrino mass and the lepton-number violation parameters are derived.

DBD phase space factors are required to extract the neutrino mass and other physics parameters beyond the standard model (BSM). Recent theoretical results of DBD NMEs and DBD phase space factors are briefly reviewed by A. Neacsu, V. A. Sevestreen, and S. Stoica. Constraints on the BSM parameters are derived using the DBD NMEs, the phase space factors, and the most stringent limit on the experimental DBD rate.

Weak interactions of leptons with nucleons and nuclei in stars are interesting subjects of neutrino nuclear responses. The role of the lepton interactions in the late stage of the stellar evolution and the astro-neutrino nuclear interactions relevant to terrestrial detection of astro-neutrinos are briefly reviewed by T. S. Kosmas, I. Tsoulos, O. T. Kosmas, and P. G. Giannaka.

In summary, the scientific benefits of the present special issue are evident from the wide range of the research subjects covered by the included papers. The selected topics fall at the forefront of multidisciplinary investigations within experimental, phenomenological, and theoretical nuclear physics, in major overlap with atomic physics, particle physics, astrophysics, and cosmology.

### AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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