Joint project for large-scale nuclear structure calculations in 2017

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We have been promoting a joint project for large-scale nuclear structure calculations since the year 2002 based on a collaboration agreement between the RIKEN Accelerator Research Facility (currently RIKEN Nishina Center) and Center for Nuclear Study, the University of Tokyo. Currently, we maintain 16 PC servers for large-scale nuclear structure calculations. Based on this project, we performed shell-model calculations of the various nuclides that have been measured or are proposed to be measured at the RIKEN RI Beam Factory and other facilities, such as ^{35}Mg,[1)] ^{136}Ba, ^{138}Ce, and ^{135}La under various collaborations with many experimentalists. In parallel, we performed several theoretical studies for understanding the nuclear structure. Among them, we briefly show three theoretical achievements: shell-model study of the beta-decay properties of neutron-rich nuclei,[2)] the development of an *ab initio* nuclear structure calculation,[3)] and the theoretical estimation of nuclear matrix elements that are essential for surveying physics beyond the standard model.[4–6)]

In order to discuss the systematic properties of the beta decay of neutron-rich nuclei, we performed large-scale shell-model calculations with $sd + pf + sdg$ model space and evaluated the contributions from both Gamow-Teller and first-forbidden transitions for the 78 nuclei with $13 \leq Z \leq 18$ and $22 \leq N \leq 34$.[2)] The obtained beta-decay half-lives and delayed neutron emission rates remarkably agree with experimental data. This indicates the validity of large-scale shell-model calculations for nuclei in the neutron rich region. The shell-model results predict that the first-forbidden transition has a non-negligible contribution to the half-lives in $N > 30$ nuclei. We also discuss the emergence of the Gamow-Teller giant resonance and its origin.

In order to investigate the medium-heavy nuclei based on the underlying nuclear interactions in an *ab initio* way, the unitary-model-operator approach[3)] (UMOA) has been developed. In the UMOA, the many-body Hamiltonian is transformed by a unitary transformation such that the one-particle-one-hole and two-particle-two-hole excitations do not occur. We calculated the binding energies and radii of ^{4}He and several oxygen isotopes using the similarity-renormalization-group evolved chiral effective-field-theory interaction consisting of two-nucleon and three-nucleon forces. The resulting binding energies successfully reproduce the experimental data. On the other hand, the calculated radii are underestimated compared to the experimental values. This situation is consistent with the recent studies by the other *ab initio* methods. For a unified description of binding energies and radii, further improvements about the nuclear force are expected.

We performed calculations for determining of the nature of dark matter and neutrinos in experiments using atomic nuclei. On the one hand, we obtained the nuclear matrix element for the interaction of dark matter particles with nuclei via the coupling of nucleons to the Higgs boson.[4)] Our results included for the first time the coupling of the Higgs boson to two nucleons via pion-exchange currents. The uncertainty on the matrix element was reduced by roughly an order of magnitude. On the other hand we studied the nuclear matrix elements of neutrinoless double-beta decay, when it is mediated by heavy sterile neutrinos.[5)] Contrary to the light-neutrino-exchange channel, different many-body methods agree well when heavy neutrinos are exchanged. This result suggests that long-range nuclear correlations are responsible for the disagreement between matrix elements in the standard light-neutrino-exchange channel. In addition, we investigated the double Gamow-Teller strength distribution of double-beta decay emitters, such as ^{48}Ca. We theoretically predict a linear relation between the nuclear matrix elements of the double Gamow-Teller transition and the $0\nu\beta\beta$ decay.[6)]

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