Joint project for large-scale nuclear structure calculations in 2016

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A joint project for large-scale nuclear structure calculations has been promoted since 2002 based on a collaboration agreement between the RIKEN Accelerator Research Facility (currently RIKEN Nishina Center) and the Center for Nuclear Study, the University of Tokyo. Currently, we maintain 16 PC servers with Intel CPUs for large-scale nuclear shell-model 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 ^{38,40}P ^{48}Ca, ^{55}Ca, ^{128}Cd, ^{130}Sn, and ^{132}Sn, under various collaborations with many experimentalists.[1)] In parallel, we have performed several theoretical studies for understanding nuclear structure. Among them, we briefly show three theoretical achievements: the sophisticated perturbation theory for constructing shell-model interaction[2,3)] shell-model study of the beta decay of neutron-rich $13 \leq Z \leq 18$ nuclei,[4)] and the development of the unitary-model-operator approach (UMOA).[5)]

We have developed a novel many-body perturbation method to derive the effective interaction for shell model calculations. Our new theory (extended Kuo-Krenciglowa method) can handle an arbitrary model space, such as two major shells,[2)] unlike conventional standard theory (KK method). Then, we derived a new effective interaction for the $sd + pf$ shell, starting from the nuclear force based on chiral effective field theory and Fujita-Miyazawa three-body force. With this interaction, we succeeded in describing the nuclear shell structure around the region so-called "island of inversion," where the breaking of the $N = 20$ shell gap is important. In this year, we further investigated the physics around the "island of inversion" and clarified the long-standing problem of how the sd-to-pf excitations occur in Mg isotopes with distinct differences from conventional approaches. As an example, Fig. 1 shows the low-lying states of ^{31}Mg, where energy levels of positive and negative parity states are quite near and configuration mixing related to the $N = 20$ gap is important. We can see that experimental values are reproduced better than in other shell model studies.[3)] Using the EKK method, we have also started investigating nuclei in other regions.

In order to discuss the systematic properties of beta decay of neutron-rich nuclei, we performed large-scale shell-model calculations and obtained the Gamow-Teller transition for the 78 nuclei with $13 \leq Z \leq 18$ and $22 \leq N \leq 34$.[1,4)] In this calculation, the SDPF-MU interaction was adopted.[6)] Shell-model results of the 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.

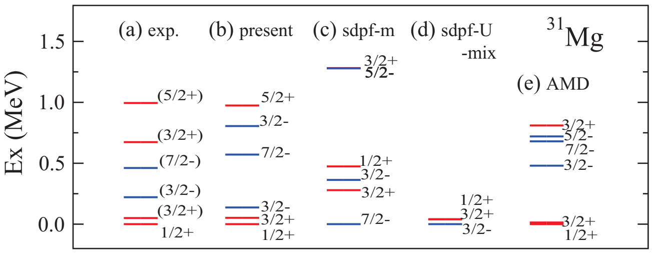

Fig. 1. Energy levels of ^{31}Mg, (a) experimental values, (b) present work, (c) sdpf-m, (d) sdpf-U-mix and (e) AMD+GCM calculation.

The UMOA was developed and extended in order to investigate the medium- and heavy-mass nuclei based on the underlying nuclear interactions.[5)] In the UMOA, we construct the effective Hamiltonian which does not induce the 1-particle-1-hole and 2-particle-2-hole excitations. We have calculated the ground-state energies and radii with the similarity-renormalization-group transformed nucleon-nucleon (NN) interactions[7)] for the closed-shell nuclei across the nuclear chart up to lead region. The converged results can be obtained when we take 15 major shells as a model space. Our resulting energies and radii are unrealistically overbound and smaller than the experimental data, respectively. We have found that the neutron-skin thicknesses are insensitive to the choice of resolution scale for the NN interaction and can be determined uniquely. For a quantitative understanding, it is necessary to include the three-nucleon-force effect which cannot be treated in the current UMOA framework. In such a situation, we are extending the UMOA framework and are carrying out benchmark calculations for light nuclei.

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