Shell-model description of beta-decays for pfg-shell nuclei

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The effective interaction is a key ingredient for successful shell-model calculations. Owing to recent developments in computers as well as novel numerical techniques, the applicability of the shell model is rapidly expanding. On the other hand, our knowledge of the effective interaction is still insufficient especially for cases where more than one major shell should be taken as an active valence space. Such a treatment is essentially important for describing neutron-rich nuclei.

We have developed an effective interaction[1)] for shell-model calculations in the model space consisting of valence orbits $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$ and $0g_{9/2}$ assuming an inert ^{56}Ni core (f5pg9-shell). It can be regarded as a first step for future extensions to the pf+sdg model space. Starting from a microscopic interaction (renormalized G-matrix)[2)] based on a realistic NN-potential, we have varied 45 linear combinations of Hamiltonian parameters (133 two-body matrix elements and four single-particle energies) by a least-squares fit to the 400 experimental binding and excitation energy data out of 87 nuclei with masses A=63-96. In the latest iteration, we have attained the rms error of 185 keV.

As an application of this interaction, we have evaluated the β-decay properties for N=50 and 49 nuclei, aiming at the analysis of the r-process nucleosynthesis. For understanding the r-process, we need precise information of nuclear properties over a wide mass range under extreme conditions which is not accessible by current experiments. For this purpose, nuclear structure calculations based on the mean-field approximation have been widely used. Such methods are applicable to any nuclei in the nuclear chart, but are not necessarily accurate because only limited correlations can be treated. On the other hand, the shell model can treat any two-body correlations and can give accurate description of nuclear structure, if we can use suitably chosen model spaces and effective interactions.

Because of the strong energy dependence of the phase space factor, low-lying states mainly contribute to the β-decay half-life. The spin-flip decays $\nu g_{9/2}\rightarrow\pi g_{7/2}$ and $\nu f_{5/2}\rightarrow\pi f_{7/2}$ are both out of the present f5pg9-shell model space. Since we consider N=50 and 49 neutron-rich nuclei, the former mode should appear at high excitation energy in the daughter nucleus and may not be important. On the other hand, the latter mode may be important because it is predicted that, due to the strong repulsive interaction between the $\pi f_{7/2}$ and the $\nu g_{9/2}$ orbit through the tensor force[3)], as neutrons occupy the $g_{9/2}$ orbit, the effective single-particle energy gap above the proton $f_{7/2}$ orbit decreases and the excitation from the Z=28 core may be enhanced.

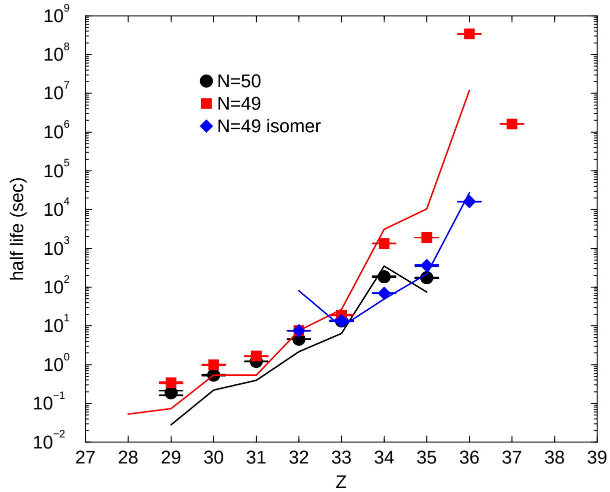

Fig. 1. Comparison of the β-decay half-life between the shell-model results (lines) and experimental data (symbols) for N=50 and 49 nuclei. For N=49 cases, the results for the low-lying isomer are also shown.

We have calculated the β-decay half-life for the allowed transitions by using the experimental Q-values and the same quenching factor q=0.6 for the evaluation of the Gamow-Teller strength as in Ref.[1)]. Shell-model calculations have been carried out in a conventional way by using the code MSHELL.[4)] The results are shown in Fig.1. It can be seen that the shell-model results are in reasonable agreement with the experimental data for less neutron-rich nuclei (Z>30) except for ^{84}Br, ^{85}Kr and the isomer state in ^{81}Ge, while for neutron-rich nculei (Z<30), the shell-model predictions systematically underestimate the experimental values. This result may indicate the importance of an explicit treatment of the Z=28 core excitation.

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