Large-scale shell-model approach to nuclear collective motion

Y. Utsuno[1,2],* N. Shimizu[3], and Y. Tsunoda[3]
[1]*Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, JAPAN*
[2]*Center for Nuclear Study, The University of Tokyo, Hongo, Tokyo 113-0033, JAPAN*
[3]*Center for Computational Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8577, JAPAN*
* *email: utsuno.yutaka@jaea.go.jp*

We will report on recent advances in large-scale shell-model calculations and their applications to nuclear collective motion in the *A*~130 region. The model space consists of the $d_{5/2}$, $g_{7/2}$, $h_{11/2}$, $d_{3/2}$, and $s_{1/2}$ orbitals both for protons and neutrons, and the effective interaction comprises of the combination of semi-empirical interactions for the like-particle interaction and a phenomenological one for the proton-neutron interaction. The shell-model Hamiltonian matrices are diagonalized by the KSHELL code, and some interesting nuclear collective properties such as the magnetic rotation and the chiral doublet bands are investigated in a fully microscopic framework.

1. Introduction

Since the very early stage of nuclear physics, nuclear collective motion has attracted much interest in the community. The simplest example is nuclear deformation, which causes well-known rotational bands in the rare-earth region and also in the actinide region. More recently, with the experimental development of gamma-ray spectroscopy, various novel phenomena about nuclear collectivity have been observed. One of them is rotational bands with strong M1 transition, which are often called the M1 bands or magnetic rotation. Another example is chiral doublet bands that forms two nearly degenerate bands and are interpreted as two different intrinsic states connected by chiral transformation.

Although a lot of experimental data are accumulated with regard to those novel collective phenomena, theoretical interpretation relies mainly on mean-field level analyses. In the present work, we carry out large-scale shell-model calculations for nuclei in the *A*~130 region, which enable fully microscopic description.

2. Theoretical framework

In this study, we focus on nuclei with the neutron number slightly less than 82 and the proton number slightly more than 50. This combination produces proton particles and neutron holes, thus causing exotic collectivity such as M1 bands and chiral doublet bands. Since the nuclei of interest are not strongly deformed, the natural valence shell that consists of the $d_{5/2}$, $g_{7/2}$, $h_{11/2}$, $d_{3/2}$, and $s_{1/2}$ orbitals should work well. Employing this valence shell, we construct an effective interaction as follows. The proton-proton interaction and the neutron-neutron interaction are taken from semi-empirical ones, which are determined to fit the energy levels of the N=82 isotones and the Z=50 isotopes, respectively. The proton-neutron interaction is based on the V_{MU} interaction that is aimed at describing shell evolution in wide ranges of the nuclear chart. The resulting interaction is named the SNV interaction. This interaction has been successfully applied to analyzing experimental level scheme in the *A*~130 region [1].

Since this valence shell includes many orbitals, the dimensions of shell-model Hamiltonian matrices to be diagonalized are quite large, and sometimes reach the order of 10^{11} in the M-scheme. To carry out such very large-scale shell-model calculations, we use a state-of-the-art code, KSHELL [2] run on supercomputers.

3. Results

We have calculated M1 bands that appear in this region. The M1 bands are often interpreted as the shears mechanism, according to which proton angular momentum and neutron angular momentum are directed almost perpendicular at the band head, and the angle is then closed with increasing spin. This scenario is examined with the shell model by decomposing the total angular momentum into proton and neutron ones. For this purpose, we have developed a technique that enables transforming an M-scheme wave function into a J-scheme one.

Some examples of the results, which we call the J_p-J_n plot, are depicted in Fig. 1. Here the band head and the band termination of Band 6 in ^{135}La are shown in the upper and the lower panels, respectively. This band is considered to be dominated by $J_p=11/2^-$ and $J_n=10^+$ states. The shell-model calculation basically follows this interpretation, while $\Delta J=2$ fluctuation is clearly seen. This fluctuation is very important to extend this band to $35/2^-$, because the naïve $J_p=11/2^-$ and $J_n=10^+$ configuration is able to make angular momentum $J \leqq 31/2$.

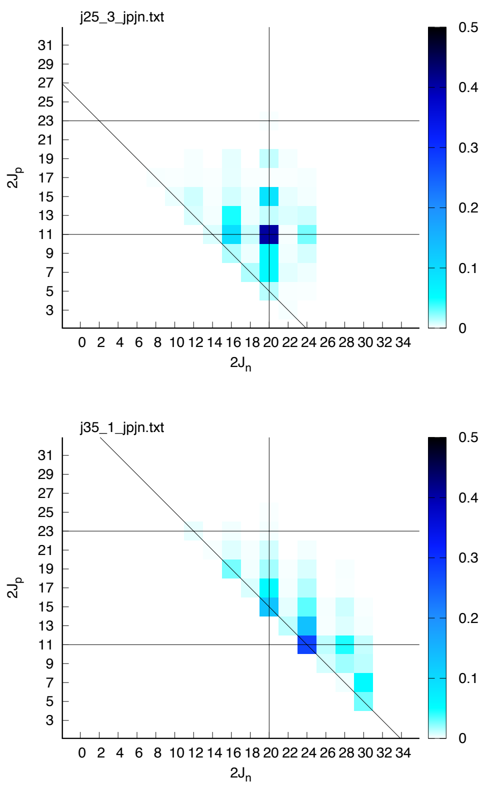

Fig. 1 Example of the J_p-J_n plot for the $25/2^-$ state (upper) and the $35/2^-$ state (lower) of Band 6 in ^{135}La [1]. The probabilities of a given J_p-J_n are drawn.

In this talk, we will present rather detailed analyses of M1 bands in this region, and if time allows, we will show shell-model results for chiral doublet bands in Cs isotopes.

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References

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