Enhanced collectivity of γ vibration in the neutron-rich Dy isotopes around $N = 108$ †

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The γ vibrational mode of excitation is an acknowledged collective mode in deformed nuclei. Quite recently, a sudden decrease in the excitation energy of the γ vibration was observed at RIKEN for the neutron-rich Dy ($Z = 66$) isotopes at $N = 106$[1]. In the present report, by systematically studying the microscopic structure of the γ vibration in the neutron-rich Dy isotopes with $N = 98 - 114$, we try to understand the mechanism of the observed softening. The low-frequency modes of excitation in the neutron-rich rare-earth nuclei are described on the basis of nuclear density-functional theory.

Atomic nuclei reveal spontaneous breaking of rotational symmetry in both real space and gauge space in stepping away from magic numbers. Most of the deformed nuclei still retain the axial symmetry. In axially deformed nuclei, a low-frequency quadrupole mode of excitation, known as the γ vibration, emerges. The γ vibrational mode of excitation is regarded as a precursory soft mode of the permanent non-axial deformation. It would be interesting to investigate the possibility of occurrence of the γ vibration in exotic nuclei, and to achieve a deep understanding of the microscopic mechanism for the generation of collective vibrations in atomic nuclei.

Figure 1 shows the excitation energy of the γ vibration in the neutron-rich Dy isotopes. Here, we employ the Skyrme energy-density functionals (EDF's) in the Hartree-Fock-Bogoliubov calculation for the ground states and in the Quasiparticle Random-Phase Approximation (QRPA) for the excitations. The results of the calculation are compared with experimental data[1–3]. Both the SkM* and SLy4 functionals reproduce the isotopic trend in energy well; lowering when N increases from 104 to 106.

Based on the analysis of the wave functions, we found that the coherent contribution of the $\nu[512]3/2 \otimes \nu[510]1/2, \nu[510]1/2 \otimes \nu[512]5/2$, and $\nu[512]3/2 \otimes \nu[514]7/2$ excitations satisfying the selection rule of the non-axial quadrupole matrix element,

$$\Delta N = 0 \text{ or } 2, \Delta n_3 = 0, \Delta\Lambda = \Delta\Omega = \pm 2, \quad (1)$$

plays a major role in generating the collectivity, *i.e.* lowering of the frequency and enhancement in the transition strength.

One can see in Fig. 1 that the excitation energy of the γ vibration decreases toward $N = 110(108)$ in the case of the calculation employing the SkM* (SLy4) functional. This is because the Fermi level of neutrons lies among the orbitals that play an important role in generating the collectivity around $N = 106$.

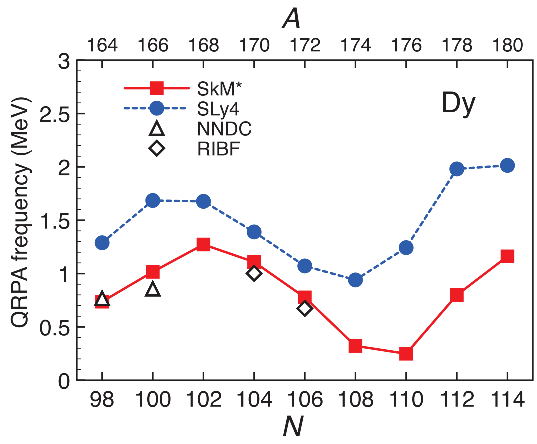

Fig. 1. QRPA frequency of γ vibration obtained by using SkM* and SLy4 EDF's. Also shown are the experimental data[1–3].

We found a similar isotopic dependence of the excitation energy in the neutron-rich Er ($Z = 68$) and Yb ($Z = 70$) isotopes. We can thus conclude that the microscopic mechanism governing the enhanced collectivity around $N = 108$ in the Dy isotopes is robust in the neighboring nuclei. Note that we obtained the strongest collectivity for $Z = 66$ because the 2qp excitations of $\pi[411]1/2 \otimes \pi[411]3/2$ and $\pi[411]1/2 \otimes \pi[413]5/2$, located around the Fermi level of protons and satisfying the selection rule (1), make a coherent contribution to generation of the γ vibration together with the excitation of neutrons.

The numerical calculations were performed on SR16000 and CRAY XC40 at the Yukawa Institute for Theoretical Physics, Kyoto University, and on COMA (PACS-IX) at the Center for Computational Sciences, University of Tsukuba.

References
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