Study of low-frequency negative-parity vibrational excitations of superdeformed rotational band in ^{40}Ca using cranked Skyrme-RPA calculations

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An atomic nucleus is a unique quantum system. A nucleus exists in various modes with diverse shapes and collective motions by adding only a small percentage of the total binding energy. The diversity also increases with additional isospin and angular momentum.

^{40}Ca is a representative nucleus: the ground state is spherical with a spherical magic number $N = Z = 20$; however a superdeformed (SD) band built on the excited 0^+ state at 5.2 MeV was found.[1)] The large octupole collectivity can be expected in the SD state associated with the SD shell structure that consists of approximately an equal number of positive- and negative-parity levels.

The description of diverse nuclear phenomena through a single theoretical framework is a challenging subject. Toward this direction, we have developed the first computer code of the cranked random phase approximation with Skyrme density functional (cranked Skyrme-RPA). Using this code, once the Skyrme density functional is fixed, we can calculate consistently the ground state as well as the rotational and vibrational excitations in nuclei across the nuclear chart.

We adopt the single-particle Hamiltonian with the triaxially deformed potential that uniformly rotates about the x-axis with a rotational frequency ω_{rot}; $h' = h - \omega_{rot} j_x$. The Skyrme SLy4 interaction is employed for h. Two discrete symmetries, the parity and rotation about the x-axis at the angle π, are imposed on the single-particle wave functions. The wave functions are represented through Fourier-series expansion in order to effectively treat the configurations involving unbound single-particle states.

We solve the RPA equation in the matrix form with a residual interaction derived from the Skyrme force through the Landau-Migdal approximation. The octupole transition operators $O_{3K}^{(\xi,\zeta)}$ can be classified by the z-component K of its angular momentum and the x (z) - signature ξ (ζ) $= \pm 1$ representing the symmetry of rotation about the x (z) - axis. The Coriolis coupling mixes the different K and ζ modes. The excitations can be classified into two types by ξ.

We study the low-frequency negative-parity vibrational excitations of the SD rotational band in ^{40}Ca. The upper part of Fig. 1 shows the six vibrational states with $\xi = -1$ for vibrational energy $E_{vib} < 5$ MeV. The isoscalar octupole transition strength B(IS : O_3) changes as a function of ω_{rot}, and the maximum value for each vibrational state exceeds 50 Weisskopf units (W.u.) within the region from $\omega_{rot} = 0$ to 1.6 MeV/$\hbar$.

The vibrational energy of the first excitation decreases as a function of ω_{rot}. The B(IS : O_3) value is 66.5 W.u. at $\omega_{rot} = 0.4$ MeV/$\hbar$ and then decreases slowly. This ω_{rot} dependence is associated with the rotational alignment of [440]1/2 particle states: This effect reduces the SD shell gap at N (Z) = 20 by 42.4 (40.4) percent while ω_{rot} changes from 0 to 1.5 MeV/$\hbar$. The B(IS : O_3) value is dominated by the $\zeta = +1$ component B(IS : $O_3^{(\zeta=+1)}$) consisting of $O_{31}^{(-1,+1)}$ and $O_{33}^{(-1,+1)}$ operators.

It is quite interesting to investigate what will happen if ω_{rot} is increased further; however we could not obtain reliable RPA solutions. A better method for eliminating the spurious center of mass component may be required. Nevertheless, it seems reasonable to assume that the above discussion will continue: the vibrational energy will decrease further and cross the yrast line. This may indicate an instability of the SD shape, leading to a transition to a non-axial reflection-asymmetric shape.

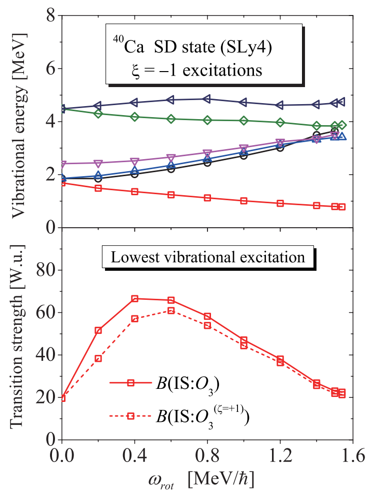

Fig. 1. (Upper) The vibrational energies of negative-parity excitations with $\xi = -1$ of the SD state in ^{40}Ca are shown as a function of ω_{rot}. (Lower) The B(IS : O_3) and B(IS : $O_3^{(\zeta=+1)}$) of the lowest vibrational excitation.

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References
1) E. Ideguchi et al.: Prog. Theor. Phys. Suppl. **196**, 427 (2012).