QRPA calculations with Skyrme energy density functional for rotating unstable nuclei

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The energy density functional (EDF) theory is the only tractable microscopic theory that can be applied across the entire table of nuclides. The EDF has been optimized using the basic nuclear properties, and the extension to various collective dynamics in unstable nuclei is a current hot issue.

We have developed a new computer code for the quasiparticle random phase approximation (QRPA) calculations. As an input, we adopt the Skyrme EDF.

At first, we solve the Hartree-Fock-Bogoliubov (HFB) equation in the matrix form

$$\begin{pmatrix} h'-\lambda & \Delta \\ -\Delta^* & -h'+\lambda \end{pmatrix} \begin{pmatrix} U_k \\ V_k \end{pmatrix} = E_k \begin{pmatrix} U_k \\ V_k \end{pmatrix}. \quad (1)$$

The single-particle Hamiltonian $h' = h - \omega_{rot} j_x$ describes the independent-particle motion in the triaxially deformed potential that is uniformly rotating with the rotational frequency ω_{rot} about the x-axis. The Skyrme SkM* parametrization and the mixed-type density-dependent zero-range pairing force are employed. The Fourier-series expansion method is used to efficiently represent wave functions (WFs) of unbound and weakly bound states[1)].

We solve the QRPA equation in the matrix form with WFs obtained by the HFB calculation. The particle–hole residual interaction is derived from the Skyrme force through the Landau–Migdal approximation, while the pairing residual interaction is selfconsistently treated.

As a first application, we studied the rotational effect on the $K^\pi = 0^+$ isoscalar quadrupole excitations in neutron-rich nuclei, ^{34}Mg and ^{36}Mg. Figure 1 shows the strength function at $\omega_{rot} = 0$ in ^{34}Mg. Here, the ground state has a prolate deformation $\beta_2 = 0.22$. We obtained a collective state at the vibrational energy $E_{vib} = 3.31$ MeV with the transition strength $B(IS2) = 11.4$ w.u.

In Fig. 1, the result without the residual pairing interaction ($\delta\Delta = 0$) is also shown. Without the fluctuation of the pairing field, this excited state can not emerge. As a main configuration, the fluctuation of the neutron-pair occupation between the oblate-type [202]3/2 orbit and the prolate-type [321]3/2 one across the $N = 22$ shell gap induces vibration of the particle-number density.

In Fig. 2, the $B(IS2)$ value of the lowest collective states in ^{34}Mg is shown as a function of ω_{rot}. We found that the $B(IS2)$ value decreases with small ω_{rot}. This is because the $K^\pi = 0^+$ excitation strongly depends on the pairing properties, while pairing is sensitive to breaking of time-reversal symmetry. Here, the neutron pairing gap is $\Delta_n = 2.2$ MeV at $\omega_{rot} = 0$, and 1.4 MeV at $\omega_{rot} = 0.6$ MeV/$\hbar$ corresponding to the total angular momentum $J_z = 2.6\hbar$. We also found the same results for ^{36}Mg, as shown in Fig. 2.

In conclusion, we developed a new computer code for the QRPA calculations with Skyrme EDF. By using this code, we emphasized the role of pairing and collective rotation for $K^\pi = 0^+$ quadrupole excitations in ^{34}Mg and ^{36}Mg. This is a unique phenomenon that can emerge only in atomic nuclei as finite quantum systems.

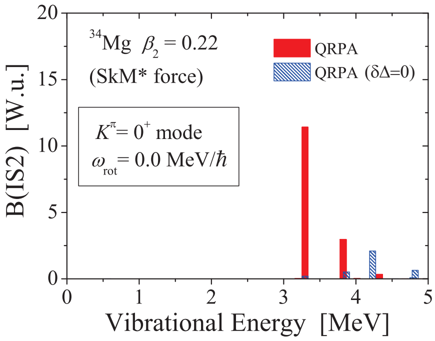

Fig. 1. Strength function of $K^\pi = 0^+$ isoscalar quadrupole excitation at $\omega_{rot} = 0$ in ^{34}Mg. The resut of QRPA calculation without the residual pairing interaction ($\delta\Delta = 0$) is also shown.

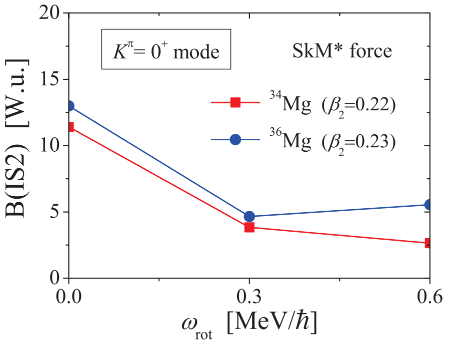

Fig. 2. $B(IS2)$ values of the lowest $K^\pi = 0^+$ excitations in ^{34}Mg and ^{36}Mg as a function of ω_{rot}.

References
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