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LOCAL QRPA VIBRATIONAL AND ROTATIONAL INERTIAL FUNCTIONS FOR LARGE-AMPLITUDE QUADRUPOLE COLLECTIVE DYNAMICS*

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A new microscopic approach is proposed to derive the five-dimensional quadrupole collective Hamiltonian. It is based on the time-dependent mean-field theory and the adiabatic self-consistent collective coordinate method. We apply the method to studies of oblate–prolate shape coexistence/mixing phenomena and anharmonic vibrations. Experimental data for Se isotopes are well reproduced.

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Nuclei show various shape dynamics associated with the shell structures in low-lying states. For example, the selenium isotopes exhibit rich phenomena including the oblate–prolate shape coexistence on the proton-rich side, and the anharmonic vibrations on the stable and neutron-rich sides. The quadrupole collective degrees of freedom play an essential role in these shape dynamics. Microscopic understanding of these large-amplitude collective motion based on the quadrupole degrees of freedom is an important subject.

In order to describe such large-amplitude quadrupole collective phenomena, we develop a microscopic theory [1] to derive the quadrupole collective Hamiltonian

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$$
\begin{aligned}
H_{\rm coll}(\beta,\gamma) &= V(\beta,\gamma) + T_{\rm vib} + T_{\rm rot}\,, && (1)\\
T_{\rm vib} &= \tfrac{1}{2}D_{\beta\beta}(\beta,\gamma)\dot\beta^2 + D_{\beta\gamma}(\beta,\gamma)\dot\beta\dot\gamma + \tfrac{1}{2}D_{\gamma\gamma}(\beta,\gamma)\dot\gamma^2\,, && (2)\\
T_{\rm rot} &= \sum_{k=1}^{3}\frac{I_k^2}{2\mathcal{J}_k(\beta,\gamma)}\,, && (3)
\end{aligned}
$$

and determine the collective potential V, and the vibrational and rotational inertial functions, D and $\mathcal{J}$. The theory is based on the adiabatic self-consistent collective coordinate method [2]. It consists of the constrained Hartree–Fock–Bogoliubov (CHFB) equation and local quasiparticle random-phase approximation (LQRPA). The central concept of the theory is the local normal modes built on the constrained mean field. The CHFB states are used to obtain the collective potential, and on top of these states, the local normal modes are determined by the LQRPA equation, which is an extension of the QRPA to non-equilibrium states. From the two selected local collective modes, we determine the vibrational inertial functions for β and γ deformations. The rotational moments of inertia are calculated from the three Nambu–Goldstone modes which correspond to the three-dimensional collective rotation. The inertial functions determined with the LQRPA include the contribution from time-odd mean field, which is not taken into account in the widely used Inglis–Belyaev inertial functions.

In this presentation, we choose ^{68}Se and ^{76}Se as typical examples of oblate–prolate shape coexistence phenomena and anharmonic vibrations. Using the pairing-plus-quadrupole force Hamiltonian including the quadrupole-pairing force, the five-dimensional quadrupole collective Hamiltonian for ^{68}Se and ^{76}Se is determined. The CHFB and LQRPA equations are solved numerically in the two-dimensional mesh points in the β and γ directions. The modified-oscillator single-particle energies are used, and the interaction strength parameters which reproduce the mean field properties calculated with the Skyrme SIII (^{68}Se) and SLy4 (^{76}Se) effective interactions are used. See Ref. [1] for more details of the model description.

The collective potential for ^{68}Se presented in Fig. 1 shows an oblate minimum, a prolate local minimum, and a triaxial valley connecting the two local minima. This indicates the oblate–prolate shape coexistence and the γ-soft character in the low-energy dynamics. The vibrational inertial functions show a significant variation as a function of (β,γ). In particular, they increase in the large β region. In comparison with the Inglis–Belyaev inertial functions, the LQRPA rotational and vibrational inertial functions are considerably larger than the Inglis–Belyaev ones, and their ratios change depending on β and γ.

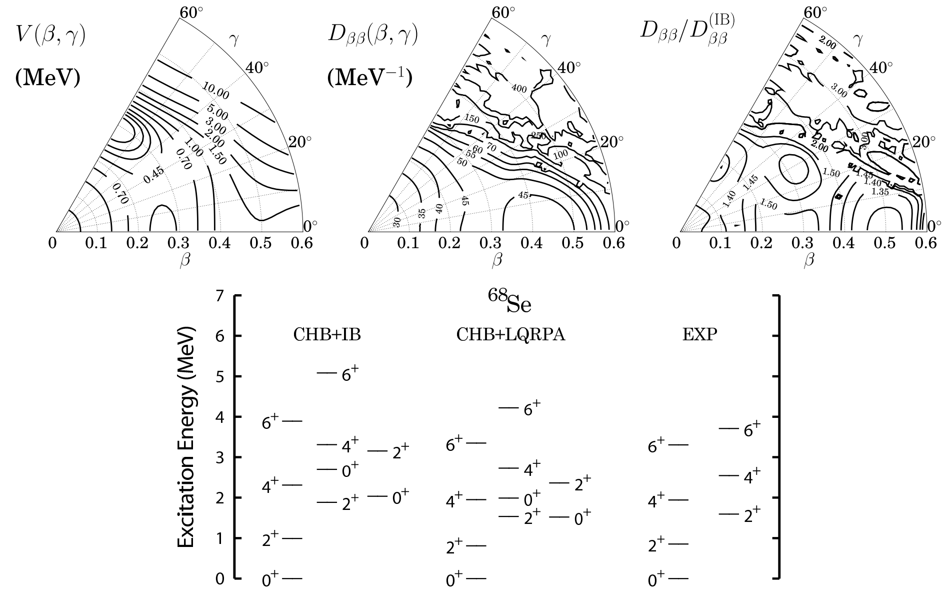

Fig. 1. Collective potential V, vibrational inertial function $D_{\beta\beta}$, ratio to the Inglis–Belyaev inertial function, and the excitation spectra for ^{68}Se. Figures are based on Ref. [1].

The excitation spectra calculated by solving the collective Schrödinger equation are shown together with the experimental data. From the comparison with the calculation using the Inglis–Belyaev inertial functions, it is clearly seen that the excitation energies are lowered by the time-odd mean field contribution included in the LQRPA inertial functions. The agreement with the experimental data is excellent, although no parameters in the effective interactions are fitted to the experimental data. From the analysis of the vibrational part of the collective wave functions, we found the dominance of the large-amplitude vibration in the triaxial shape degrees of freedom along the potential valley. The calculated 0_2^+ state shows the excitation of the β degree of freedom in addition to the γ-soft character, while the 0_3^+ state shows the excitation of the γ degree of freedom.

In Fig. 2, the result of calculation for ^{76}Se is presented. The collective potential has two local minima at oblate and spherical shapes. At the same time, it shows anharmonic structure globally. The collective wave functions do not localize in one of the potential local minima, but spread over the entire anharmonic potential. In comparison with the experimental spectrum, the anharmonicities seen in the energy splitting in the two-phonon triplet ($0_2^+, 2_2^+$ and 4_1^+) are well described in the present framework. Good correspondence with the experimental data is also seen in the higher excited states.

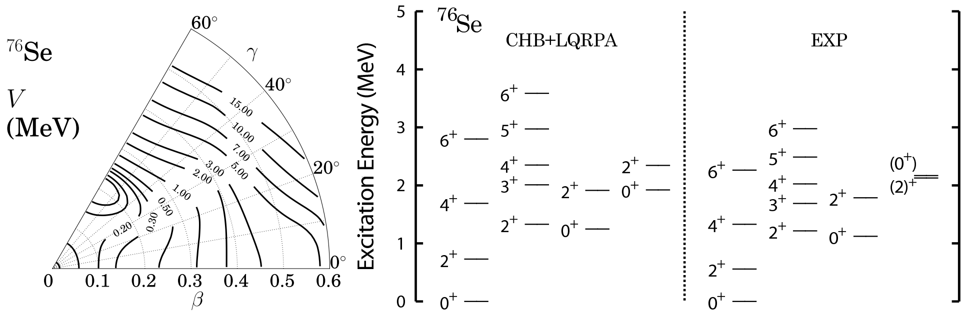

Fig. 2. Collective potential and excitation spectra for ^{76}Se.

In summary, we have presented a new microscopic theory for large-amplitude quadrupole collective dynamics. It requires us to solve the constrained HFB equation and the local QRPA equation at each point in the (β, γ) plane. The results of the numerical calculations for excitation energies of the low-lying states of ^{68}Se and ^{76}Se are in excellent agreement with the experimental data. The magnitudes of the inertial function are significantly increased by the effects of the time-odd components of the moving mean-field. Application of the new theory to a modern energy density functional is an important subject in near future.

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