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Construction of 1S0 pair collective Hamiltonian using the constrained BCS + local QRPA method

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One of the important correlations in atomic nuclei is pairing, where two nucleons form a pair. The pairing correlation can lead to a phase transition into a superfluid state, analogous to the superconducting state observed in electronic systems. In the superfluid phase, the global U(1) gauge symmetry is spontaneously broken. As a result, a new type of the collective mode emerges: the pair rotational mode (Nambu-Goldstone mode) which corresponds to the motion along the bottom of a wine-bottle-shaped effective potential, in addition to the pair vibrational mode which involves fluctuations in the magnitude of the order parameter.
In finite systems such as nuclei, phase transitions do not occur sharply due to significant quantum fluctuations. Instead, a critical state exists between the normal and the superfluid phase. Nuclei near closed-shell configurations are typically considered to exhibit pair vibrational modes. However, previous studies (Clark et al. 2006) have shown that some magic-number nuclei may actually be in a critical state.
To describe shape coexistence phenomena (Kris and John 2011) with quantum fluctuations, such as those observed in 98Kr, five-dimensional quadrupole collective Hamiltonian has been extensively used (Próchniak and Rohoziński 2009). In a similar spirit, describing nuclei in a pairing critical state requires the construction of a pair collective Hamiltonian that can simultaneously include both pair rotational and vibrational dynamics and their couplings. Despite its importance, research on pair collective Hamiltonians remains limited, with most models relying on simple monopole pairing interactions (Bes et al. 1970). Consequently, current approaches are restricted to narrow model spaces and can only be applied to a limited number of nuclei.

To extend the applicability of the pair collective models to a wider range of nuclides, we aim to construct the pair collective Hamiltonian based on nuclear density functional theory. The potential energy surface is expressed as a function of the pairing gap (the collective variable), while the inertial functions, namely the pair rotational moment of inertia and the pair vibrational mass, are obtained using local QRPA calculations that account for the pairing gap dependence. We then construct a pair collective Hamiltonian that can describe the pair dynamics in the critical regime and allows us to reassess the stability of the magic nuclei from the perspective of the pairing correlations.
As a first step toward this goal, we have obtained the potential energy surface using BCS calculations with constraints on the pairing gap, employing monopole pairing interactions. In this presentation, we will also discuss the pairing gap dependence of the pair rotational moment of inertia and the pair vibrational mass using the local QRPA method.

Research field of your presentation

Theoretical Low-energy nuclear physics

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