Requantization of time-dependent mean field for pairing collective motion in superfluid nuclei

(超流動核における対励起集団運動に対する時間依存平均場再量子化)

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The low-lying excited 0^+ states in most of nuclei had been traditionally considered as either β vibration or two-phonon excitation associated with quadrupole vibrations. However, plenty of recent experimental data indicate that not only quadrupole correlations but also pairing correlations play important roles in such excited 0^+ states. The competition between quadrupole correlations and pairing correlations causes complex and mysterious structure for the low-lying excited 0^+ states. We aim to understand such excited 0^+ states based on the time-dependent mean-field (TDMF) theory. Because quantum fluctuation is large in low-lying excitation region, we need to treat the collective motion in large-amplitude regime. However, the theoretical framework to describe pairing collective motions in the large-amplitude regime is not yet established. The nature of low-lying pairing collective motions is still unclear.

We aim at developing a new theoretical framework to describe large-amplitude collective motions associated with nuclear pairing. In our approach, the low-lying excited states are obtained in two steps: (1) solve TDMF equation to obtain the classical trajectories; (2) quantize such classical trajectories to obtain the excited states. The step 2 is called “requantization". First, we consider the pairing collective motions in multi-level pairing model. The pairing models can be classified into two classes, integrable and non-integrable systems. The former one corresponds to the two-level system and the later one corresponds to the system with three levels or more.

In the integrable system, the requantization of TDMF is particularly feasible because we can easily find the periodic orbits. We apply three different requantization methods, canonical quantization, Fourier decomposition of the time-dependent observables, and stationary phase approximation (SPA) to the path integral. Comparing each requantization method with the exact solution, respectively, SPA turns out to be the most accurate among the three and can describe the excited states quantitatively, including two-particle transition strength. Because the requantized wave functions from SPA are given in terms of the microscopic degrees of freedom, the transition matrix elements can be calculated directly.

Unfortunately, the application of the SPA to the non-integrable system is not straightforward because finding the periodic orbits is an extremely difficult task. We propose a new theoretical approach which makes the SPA to be applicable to non-integrable systems, that is, combining the SPA with the adiabatic self-consistent collective coordinate (ASCC) method (ASCC+SPA). The concept is that we employ the ASCC to extract an integrable subspace from original TDMF phase space, and apply the SPA to the integrable subspace. We apply the ASCC+SPA to the low-lying excited 0^+ states in three-level system and Pb isotopes system. We find that the ASCC+SPA can properly describe the pairing collective motions.

We also examine the validity of the pairing collective model which assumes the pairing gap parameter and gauge angle as the phenomenological collective coordinates. We check the one-to-one correspondence between the collective coordinates self-consistently determined with the ASCC and those assumed in the collective model. We find the collective coordinate describing pairing vibration has no one-to-one correspondence between the two, in both integrable and non-integrable systems. The applicability of the collective model is limited for the nuclear pairing.

With the development of computational power and numerical techniques, the ASCC+SPA is a promising tool to elucidate the structure of mysterious low-lying excited 0^+ states in nuclei, in near future.