Reentrance phenomenon of superfluid pairing in hot rotating nuclei

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When a nucleus rotates (total angular momentum J and/or rotational frequency ω are not zero), the nucleon (proton and neutron) pairs located around the Fermi surface will scatter to the empty levels nearby and lead to the decreasing of pairing correlation. When the J or ω is sufficiently high, i.e., equal to the critical value J_c or ω_c, the scattered nucleons completely block the single-particle levels around the Fermi surface. Consequently, pairing correlation disappears. However, when J is slightly higher than J_c (or $\omega \geq \omega_c$), the increase of temperature T will relax the particles scattered around the Fermi surface and causes some levels become partially unoccupied, making them available for scattered pairs. As a result, the pairing correlation reappears at some critical value T_1. As T goes higher, e.g., at $T_2 > T_1$, the newly created pairs will be eventually broken down again. This phenomenon is called the pairing reentrance. The recently developed FTBCS1 theory that includes the effect due to quasiparticle-number fluctuations in the pairing field and angular momentum z projection at $T \neq 0$ has predicted the pairing reentrance effect in some realistic nuclei[1)]. The shell-model Monte Carlo calculations have suggested that the pairing reentrance effect can be observed in the nuclear level density in a form of a local maximum at low T (or excitation energy E^*) and high J (or ω). Recently, an enhancement of level density of ^{104}Pd at low E^* and high J has been experimentally reported[2)]. In this work we try to see whether the enhancement observed in the extracted level density of ^{104}Pd is an experimental evidence of pairing reentrance phenomenon in atomic nuclei.

The FTBCS1 equations at finite temperature and angular momentum are derived based on the variational method to minimize the expectation value of the pairing Hamiltonian $H = \sum_k \epsilon_k(a^\dagger_{+k}a_{+k} + a^\dagger_{-k}a_{-k}) - G\sum_{kk'} a^\dagger_k a^\dagger_{-k} a_{-k'} a_{k'} - \lambda\hat{N} - \omega\hat{M}$, in the grand-canonical ensemble. This Hamiltonian describes a system rotating about the symmetry axis, which is chosen to coincide with its z component. The particle-number operator $\hat{N}$ and the z projection $\hat{M}$ of the total angular momentum $\hat{J}$ (which coincides with $\hat{M}$ for spherical nuclei) are defined as $\hat{N} = \sum_k(a^\dagger_{+k}a_{+k} + a^\dagger_{-k}a_{-k})$, $\hat{M} = \sum_k m_k(a^\dagger_{+k}a_{+k} - a^\dagger_{-k}a_{-k})$, where $a^\dagger_{\pm k}(a_{\pm k})$ are the creation (annihilation) operators of a particle in the k-th deformed state, whereas ϵ_k, λ, and ω are respectively the single-particle energies, chemical potential, and rotational frequency. The FTBCS1 equation for the pairing gap has the final form as $\Delta_k = \Delta + \delta\Delta_k$, where $\Delta = G\sum_{k'} u_{k'}v_{k'}(1 - n^+_{k'} - n^-_{k'})$, $\delta\Delta_k = G\delta\mathcal{N}^2_k u_k v_k/(1 - n^+_k - n^-_k)$, with u_k, v_k, and n_k being the Bogolyubov' u, v coefficients and quasiparticle occupation numbers, respectively. The total level density $\rho(\mathcal{E}, J)$ is calculated as $\rho(\mathcal{E}, J) = \rho(\mathcal{E}, M = J) - \rho(\mathcal{E}, M = J + 1)$, where $\rho(\mathcal{E}, M)$ is obtained by using the inverse Laplace transformation of the grand partition function.

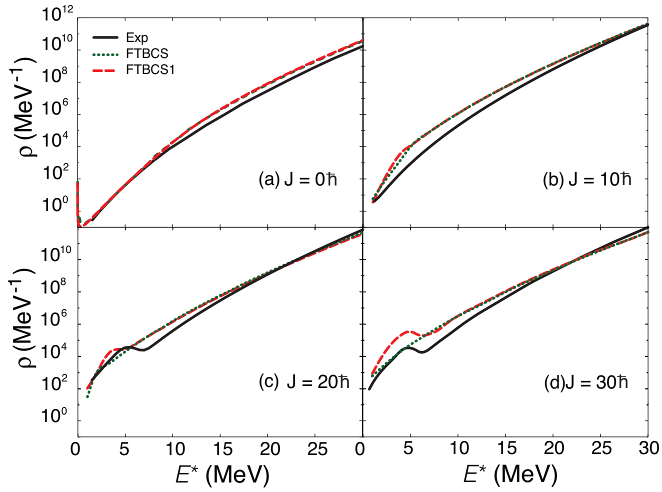

Fig. 1. (Color online) Total level densities for ^{104}Pd as function of E^* obtained within at the quadrupole deformation parameter $\beta_2 = 0.276$ at several J. The dotted and dashed lines stand for the FTBCS and FTBCS1 results, respectively. The solid lines are the experimentally extracted level densities

Because of quasiparticle number fluctuations, the FTBCS1 gaps decrease monotonically with increasing excitation energy E^* and do not collapse at $E^* = E^*_c$ as in the case of the FTBCS. Within the FTBCS1, the pairing reentrance is seen very clearly at $J = 20\hbar$ for neutrons and at $J = 30\hbar$ for protons. Consequently, there appear local enhancements in the FTBCS1 level densities at around $2 < E^* < 5$ MeV at these two values of J(Fig. 1). The FTBCS1 level densities agree fairly well with the experimental data at all J values considered in present work.

References
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